The Center for Secure and Resilient Maritime Commerce (CSR)

Stevens Institute of Technology
Hoboken, NJ

Year 6 Annual Report:
July 1, 2013 to September 31, 2014
May 19, 2015
U.S. Department of Homeland Security National Center of Excellence
Center for Secure and Resilient Maritime Commerce (CSR)

DHS Leadership

Dr. Matthew Clark, Director, University Programs, Science and Technology Directorate
Mr. Theophilos C. Gemelas, Program Manager, University Programs

Team Participants

University Partners

Massachusetts Institute of Technology
Monmouth University

Rutgers University

Stevens Institute of Technology (lead institution)
University of Miami
University of Puerto Rico at Mayaguez

Non-University Partners

Mattingley Group

Nansen Environmental Remote Sensing Center
Pacific Basin Development Council

Port Authority of New York and New Jersey

Cooperative Agreement 2008-ST-061-ML0001
Department of Homeland Security
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1. Educational Programs and Activities
Since the center’s inception in 2008, CSR in collaboration with its academic partners, Stevens Institute of Technology, Rutgers University, University of Miami, University of Puerto Rico-Mayaguez, Massachusetts Institute of Technology, and Monmouth University, have worked to develop a portfolio of maritime security-centric programs designed to enhance the knowledge, technical capabilities, emergency response and leadership skills of our nation’s current and prospective homeland security workforce. Over the past six years, CSR has developed and delivered the following programs:

- Professional development programs tailored to maritime security practitioners;
- The Maritime Systems Graduate Certificate Program;
- The Maritime Systems and Security Doctoral and Master’s Degree Fellowship Program;
- The Summer Research Institute (SRI); and
- The Stevens-based USCG Auxiliary Detachment Program.

In Year 6, CSR continued to collaborate with its public and private homeland security stakeholders to provide enhanced professional development and multi-disciplinary learning opportunities for its students. Representatives from Customs and Border Protection (CBP), New York Police Department-Counterterrorism Division (NYPD-CT), New Jersey Office of Homeland Security and Preparedness (OHSP), the U.S. Coast Guard Auxiliary, and the U.S. Coast Guard (USCG), played key roles in the experiential learning and career development of CSR’s students.

This section of the CSR Year 6 annual report highlights the center’s educational activities and achievements for 2013/2014.

1.1 Professional Development Programs

During Year 6, CSR continued to co-host the Maritime Systems Seminar Series in collaboration with Stevens Institute of Technology. The seminar series includes lectures by CSR researchers and leading experts and practitioners in homeland security. The seminar series is designed to engage a broad audience of faculty, students, industry and government stakeholders, and the general public in relevant and timely topics in the maritime and homeland security domain. The seminar series is delivered on-campus at Stevens Institute. The seminars delivered during Year 6 are outlined below in Table 1.

1.2. Maritime Security Graduate Certificate program

Over the 2013/2014 academic year, five students were officially enrolled in the Maritime Security Graduate Certificate program. While enrollment in the program appears small, students from other degree programs routinely register for the maritime security courses to fulfill elective course requirements or for personal or professional reasons. In Year 6, two out of the five Certificate students successfully completed the Graduate Certificate program.

The Maritime Security Graduate Certificate program at Stevens Institute of Technology is a four-course, 12 credit graduate-level program that can be used as a stepping stone towards a Master’s degree in Maritime Systems. The homeland-security focused certificate program is designed to provide students with the operational and technological skills needed to address safety and security issues in the Marine Transportation System. The course curriculum provides students with an in depth understanding of current and emerging threats in the maritime domain, the use of risk-based analysis to manage maritime safety and security concerns, and the principles of sensor technologies that can be used to enhance maritime domain awareness.

In Year 6, Stevens Maritime Security faculty members leveraged CSR’s industry and government homeland security partnerships to build-upon the program curricula. CSR meetings with stakeholders continue to provide a platform for Stevens faculty to discuss the program’s course work with representatives from the U.S. Coast Guard (USCG), Port Authority of New York and New Jersey (PANYNJ), NJ Office of Homeland Security and

<table>
<thead>
<tr>
<th>Seminar</th>
<th>Faculty/Guest Lecturer</th>
<th>Date of Seminar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovations for Robust Infrastructure Services in a Time of Extremes.</td>
<td>Rae Zimmerman, Wagner Rudin Center for Transportation Policy and Management. NYU</td>
<td>July 2, 2014</td>
</tr>
<tr>
<td>LNG Safety and Security – What are the issues?</td>
<td>Gerhardt Muller, SanSail Inc.</td>
<td>June 25, 2014</td>
</tr>
<tr>
<td>Science and Technology in Disasters, Preparedness Opportunities Revealed by Sandy</td>
<td>Mitchell Erickson, DHS S&amp;T Directorate</td>
<td>December 17, 2013</td>
</tr>
</tbody>
</table>
Preparedness (NJOHSP), and Customs and Border Protection (CBP) among others. Conversations with CSR industry and government partners has provided invaluable insight into the current and emerging trends in homeland security and have facilitated the sharing of agency reports and case studies, as well as created opportunities for stakeholder to provide guest lectures and seminars.

An example of this exchange includes the sharing of a PANYNJ case study that was used in Dr. Barry Bunin’s Maritime Safety and Security course. The case study illustrated how the multi-state organization uses risk assessment methodologies to prioritize security projects and allocations. Students in Dr. Bunin’s course were also given the opportunity to meet with a representative from the PANYNJ to learn first-hand about the agency’s processes for conducting risk assessments. Other examples include shared reports by the U.S. Coast Guard on the use of game theory to optimize asset allocations and deployment, and conversations with representatives from Sandia National Laboratories on system resilience, that later resulted in the use of a Sandia publication to build out lesson plans on critical infrastructure and system resilience in Dr. Bunin’s and Dr. Thomas Wakeman’s Advanced Maritime Security course.

1.3. Maritime Security Doctoral Fellowship - DHS Career Development Supplement Award – Year 6

New to the CSR in Year 6, was the creation and implementation of the Maritime Security Doctoral Fellowship program. The program was developed through the support of a DHS OUP Career Development Supplement.

The doctoral fellowship complements the university’s Maritime Systems Master’s Degree Fellowship program and is designed to provide opportunities beyond the Master’s degree for students of superior academic caliber to pursue maritime and homeland security focused research on the doctoral level. The objective of the fellowship program is to enhance the nation’s technical leadership through research and the development of new maritime security applications, strategies for maritime resilience and improved methods for emergency planning, preparedness and response. The research focused fellowship was organized to provide full funding support and a monthly stipend for up to three years, for a student of notable achievement for whom the university assessed would make original contributions to theory and practice in the field of Maritime Security.

Efforts to recruit students for the doctoral fellowship included outreach and distribution of electronic announcements to CSR’s broad network of academic partner institutions, including MSI and HBCU schools, stakeholders and Summer Research Institute program alumni. Recruitment also included a featured webpage on the Stevens website. The webpage can be found via the following weblink: http://www.stevens.edu/ses/ceoe/graduate/masters/maritime/doctoral-fellowship
A doctoral fellowship committee, comprised of CSR researchers and Stevens Maritime Systems faculty was convened to assess prospective candidates. The application process included completion of an online application form, official graduate-level and undergraduate-level transcripts, a statement of purpose and three letters of recommendation. Candidates were also required to have received formal admission into the Ocean Engineering doctoral program through Stevens Institute of Technology’s Office of Graduate Admissions.

Following review by the fellowship committee and an interview with the Dean of the School of Engineering and Science at Stevens, Alex Pollara was selected in June 2014 to receive the Maritime Security Doctoral Fellowship award. Alex is a graduate of Steven’s Maritime Systems Master’s Degree program and a former DHS 2011 CDG Maritime Systems Fellow.

The doctoral fellowship is based within the Charles V. Schaefer, Jr. School of Engineering and Science at Stevens Institute of Technology and is administered by CSR’s director of education.

1.3.1. Doctoral Program Requirements and Activities

As part of his doctoral requirements, Alex Pollara is working with his dissertation advisors Dr. Alexander Sutin, Research Professor, Davidson Laboratory, and Dr. Michael Bruno, Dean, School of Engineering and Science, to develop a three-year study plan to include requisite courses and research hours for the tenure of his academic program. It is Stevens’ policy that study plans be completed no later than the end of the student’s second academic semester.

Table 2 below provides a general overview of the program format for the doctoral fellowship and the anticipated activities and milestones. The section highlighted in yellow shows activities undertaken during Year 6 of the CSR.

Table 2. Maritime Security Doctoral Fellowship: Three-year program sequence.

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Activities/Milestones</th>
<th>Coursework</th>
<th>Research</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Awarded Fellowship. Assigned dissertation advisor(s).</td>
<td>Complete core course requirements and begin research hours.</td>
<td>Confirm dissertation topic.</td>
</tr>
</tbody>
</table>
Since starting the doctoral fellowship in June 2014, Alex has enrolled in the following courses and research activities:

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course</th>
<th>Credit</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 2014</td>
<td>Summer Research Institute – Research Mentor – Sensor Technologies Team</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall 2014</td>
<td>EE 548: Digital Signal Processing</td>
<td>3</td>
<td>B</td>
</tr>
<tr>
<td>Fall 2014</td>
<td>OE 560: Fundamentals of Remote Sensing</td>
<td>3</td>
<td>A</td>
</tr>
<tr>
<td>Fall 2014</td>
<td>BIA 652: Multivariate Data Analysis</td>
<td>3</td>
<td>*</td>
</tr>
</tbody>
</table>

*Grades for this course will be available at the end of the Fall 2014 semester.

During the months of June – August 2014, Alex served as a research mentor for the CSR Summer Research Institute, providing guidance and leadership to the Sensor Technologies student research team. The student team was composed of a diverse group of undergraduate engineering students (e.g., Mechanical Engineering, Electrical Engineering, Computer Science, and Mathematics) who attended the program from the University of Puerto Rico-Mayaguez, Rutgers University and Stevens Institute of Technology.

The research project included the classification of vessels by their acoustic signature. The team’s work involved the processing of previously recorded vessel signatures and using signal-processing techniques (Spectrogram, Demon, other) to display key spectral components. The students were then asked to manually classify the collected signals into classes and then run an automated classifier to assess how it performs compared to manual inspection.

Alex coordinated daily meetings with the student research team, facilitated experiments and provided tutorials on the science behind underwater sound propagation and the application of machine learning algorithms to support vessel signature classification.

Outcomes from the team’s research included a final research report and a presentation to CSR stakeholders from Customs and Border Protection (CBP), U.S. Coast Guard.
(USCG), Port Authority of New York and New Jersey (PANYNJ), National Urban Security Technology Laboratory (NUSTL) and New Jersey Office of Homeland Security and Preparedness (NJ OHSP).

A copy of the team’s final presentation slides entitled *Acoustic Vessel Signature Analysis for Automated Vessel Classification* can be found on the CSR Summer Research Institute website at [http://www.stevens.edu/ses/summer-research-institute-2014](http://www.stevens.edu/ses/summer-research-institute-2014).

Following the summer research program, two students from Alex’s team have requested to continue their work with him and are now completing independent research projects under his mentorship.

### 1.3.2. Conferences

In late August 2014, Alex attended the Transportation Research Board’s (TRB) 15th Annual Biennial Harbor Safety Committee and Area Maritime Security Committee Conference in Philadelphia, PA. The theme of the conference was Partnering for Safe, Secure and Resilient Port Operations. Conference presenters and attendees included representatives from the USCG, regional port authorities, terminal operators, and DHS affiliate organizations.

### 1.3.3. Research and Experiments

![Figure 1. Maritime Security Doctoral Fellow Alex Pollara prepares for the deployment of a Passive Acoustic Signal Recorder (PASR) with support by the U.S. Coast Guard Auxiliary.](image)

Early in his academic career, Alex engaged in a summer internship with the USCG Command Center at Sector New York. During his internship, Alex took the lead on a project that included the deployment of passive acoustic signal recorder (PASR) devices in security zones in the Hudson River. The objective of his research was to analyze incursions into designated areas of concern for the Coast Guard. The results of his
experiment included vessel detections, however, the experiment did not properly track vessels as they entered and left the security zone.

This initial experiment inspired Alex’s quest to continue his work on the doctoral-level and to develop a low-cost, mobile PASR device that can be easily deployed to reliably detect, track and record vessel signatures.

In late October 2014, Alex conducted a second PASR device experiment in conjunction with CSR researchers and members from the U.S. Coast Guard Auxiliary, near the Verrazano Bridge in Staten Island. Results of the experiment are currently being analyzed and will be detailed in a research report for the CSR.

In preparing for the experiment, Alex obtained the written permission of the USCG Sector New York to deploy the recorder devices and utilized USCG Auxiliary vessels to conduct the deployment of the devices in the river.

1.3.4. Program Impacts

Having worked with the CSR during his Master’s degree and now on the doctoral-level, Alex has developed professional relationships with several of the Center’s key stakeholders. These relationships have helped to facilitate opportunities, including the one described above, where he was able to deploy research equipment with the written approval of the USCG Sector New York, which may not have been provided otherwise.

Alex’s professionalism and research knowledge have also made him an integral part of the Center’s outreach activities when hosting visiting guests and stakeholders. CSR leadership often requests his support in providing hands-on demonstrations of the Center’s passive acoustic technologies, when meeting with senior-level homeland security officials and other visiting guests in the Maritime Security Laboratory.

1.4. Maritime Systems Master’s Degree Fellowships – Student Inclusion in CSR Research Activities

Stevens Institute of Technology with the support of CSR’s director of education has been awarded three DHS S&T Career Development Grants. These awards provide for full-tuition support and stipends for high achieving, homeland security career-motivated students pursuing a Master’s degree in Maritime Systems with a Graduate Certificate in Maritime Security.

The research activities in the Master’s degree fellowship program are directly linked to the ongoing and evolving research conducted through the CSR. As part of the DHS CDG-funded program, the fellowship recipients are required to engage in multidisciplinary research-based projects in conjunction with CSR researchers in the
Summer Research Institute and in field-based internships with CSR stakeholders. The DHS CDG-funded students must also complete an in-depth research project in the form of a Master’s thesis at the culmination of their degree programs.

Since 2010, eight students have been awarded Maritime Systems Master’s Degree Fellowships from Stevens Institute of Technology. Five out of the eight students have successfully completed the fellowship program and are currently employed in homeland security related positions or are pursuing homeland security-centric doctoral study. A ninth fellowship award will be conferred during the Stevens 2014/2015 academic year.

As of Year 6, Grace Python and Alex Pollara both completed the Master’s Degree Fellowship requirements and Chris Polacco, Nicholas Haliscak, and Hasan Shahid remain in varying stages of the program. Section 1.4.1. below provides an overview of the respective DHS CDG Fellows activities and engagement with the CSR over the past year.

1.4.1. DHS CDG Fellows – Year 6

Grace Python joined the Maritime Systems fellowship program in the summer of 2012 and completed her degree requirements to receive a Master of Science degree in Maritime Systems with a Graduate Certificate in Maritime Security, in December 2013. During Year 6, Grace completed a Master’s thesis entitled *Decision Making Guidelines to Enhance Port Resilience to Flood Events*. Grace’s thesis explored the vulnerabilities of U.S. ports to extreme weather events and disruptions and proposed the development of a standard set of guidelines that can be used to create resiliency among the nation’s port system.

Following the completion of her thesis and Master’s degree, Grace was hired as a research associate by the Center for Decision Technologies at Stevens Institute of Technology. In this capacity, Grace worked in conjunction with the CSR to conduct a port resilience framework, data flows and critical systems study sponsored by the U.S. Coast Guard Research and Development Center (USCG RDC). The project resulted in two white papers entitled *Port Resilience Decision Process Framework* and *Port Resilience Decision Data Flows and Critical Systems*. The objective of the papers was to provide the USCG RDC with a high-level outline on the current state of practice and needs for Captains of the Port for port resilience decision-making and support.

At the end of the Port Resilience study, Grace was hired into the Analyst Development Program, at Analytic Services Inc. Analytic Services is a not-for-profit think tank located in Falls Church, VA, providing support to decision makers in national security, homeland security and broader Federal and state communities.

Alex Pollara joined the Maritime Systems fellowship program in June 2012 and completed his degree requirements to receive a Master of Science degree in Maritime
Systems with a Graduate Certificate in Maritime Security in May 2014. During Year 6, Alex conducted research leading to his Master’s thesis entitled *Application of portable Passive Acoustic system for boat detection and classification*. His thesis advisors included CSR researchers Dr. Alexander Sutin, Stevens Research Professor and Dr. Barry Bunin, Director Maritime Security Program.

Alex’s thesis contributed to the development and deployment of small passive acoustic recording systems that have been used in stand alone vessel detection and tracking experiments and in conjunction with multi-sensor experiments coordinated by the CSR.

Following the completion of Alex’s Master’s degree work, he applied and was awarded a fellowship to continue his research on the doctoral-level at Stevens Institute of Technology. Alex’s participation in the Maritime Security Doctoral Fellowship is detailed in section 1.3 of this report.

In August 2013, Chris Polacco, was awarded a position within the fellowship program. Chris is currently in the second year of his program at Stevens. Over the past year, Chris engaged in course work and participated as a team leader in the CSR’s 2014 Summer Research Institute. Throughout the eight-week program, Chris led a team of undergraduate and graduate-level students to develop maritime threat scenarios to be used for training exercises and in conjunction with the Center’s NaviHarbor and Maritime Simulator software. The team’s research outcomes resulted in exercise manuals that can be used for training and discussion-based tabletop exercises for law enforcement and emergency responders.

Through Chris’ role in the fellowship program, he has been given the leadership to develop maritime security threat simulations and assist in the integration of CSR’s Maritime Domain Awareness data streams (radar, environmental, acoustics) into the Center’s new NaviHarbor and Maritime Simulator.

Nicholas Haliscak was the first student to receive one of three fellowship awards made available through the Center’s 2012 DHS CDG award. He was recruited at the DHS OUP Career Pathways Conference for Future S&T Professionals in the spring of 2013 and was competitively awarded a fellowship to begin his graduate studies at Stevens Institute of Technology in January 2014.

In Year 6, Nicholas completed 18 credits towards his Master’s degree and conducted research as part of the Maritime Threat Scenario student research team in the Center’s 2014 Summer Research Institute. Over the next semester, Nicholas will work with Stevens professor, Dr. Brendan Englot, as he refines his Master’s thesis topic in the area of unmanned systems and is anticipated to engage in a field-based internship with the USCG Research and Development Center during the summer of 2015.
Hasan Shahid is the second student to have received a fellowship from the 2012 CDG award. He is an alumni of the CSR’s 2011 Summer Research Institute and was competitively selected by the Fellowship Review Committee to join the program in June 2014. During Year 6, Hasan served as a team leader on the Technology Integration and Synergies: Radar, Optics and AIS team. His team, which included engineering students from the University of Puerto Rico-Mayaguez, CITY Tech, and Stevens Institute of Technology was responsible for assessing the capabilities and limitations of the CSR’s new broadband radar system.

Under Hasan’s leadership, the team was able to integrate vessel detection feeds gathered from the broadband radar system onto a Google Earth™ platform. Once displayed and visualized in Google Earth™, the team was then able to validate vessel detections by comparing them to Automatic Identification System reports provided by Marine Traffic.com.

At the encouragement of CSR researchers, Hasan has submitted an abstract of the team’s research for consideration at the International Society for Optics and Photonics (SPIE) Defense and Security Conference taking place in April 2015.

1.4.2. Fellowship student engagement with CSR stakeholders

Over the past year, the CDG-funded fellowship students have regularly engaged in CSR meetings with stakeholders and have played key roles in the demonstration of the Center’s passive acoustic, broadband radar and maritime simulator capabilities to visiting guests. The integration of the fellowship students in all aspects of the Center’s research activities and meetings with stakeholders has contributed significantly to their professional development. The students are routinely asked to provide presentations and discuss their research with a range of industry and government professionals, thereby enhancing their communication skills, reinforcing their technical knowledge and advancing their networking capabilities.

The bulleted list below provides an overview of some of the many CSR activities and stakeholder meetings the fellowship students have participated in during Year 6.

- CSR facilitated meetings with NUSTL, USCG and NJ OHSP – June 2014
- Port Awareness and Prevention Course – NYPD- CTD – June 2014
- NJ OHSP Military to Civilian Communications TTX – June 2014
- Rear Admiral Michel / USCG visit – April 2014
Table 3 below provides a summary of the DHS CDG-funded student activities as they pertain to CSR research and stakeholder activities during Year 6.

Table 3. Summary of DHS CDG Fellowship Student Activities & Stakeholder Engagement.

<table>
<thead>
<tr>
<th>Student</th>
<th>Program Start</th>
<th>Background</th>
<th>CSR Research Activities and Stakeholder Engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chris Polacco</td>
<td>Aug. 2013 – expected graduation August 2015</td>
<td>B.Eng in Chemical Engineering from Stevens Institute of Technology, May 2013</td>
<td>Team Leader – CSR 2014 SRI. Led the Maritime Threat Scenario Development Team to create scenarios and exercise manuals. Facilitated meetings with NUSTL, NJ OHSP and USCG representatives to discuss scenario development. Engaged in the NJ OHSP Military to Civilian Communications TTX. Provided maritime simulator demos to visiting guests from USCG, NJ OHSP, PANYNJ, and NUSTL among other local, state, and Federal agencies.</td>
</tr>
<tr>
<td>Name</td>
<td>From Date</td>
<td>Degree Details</td>
<td>Accomplishments</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Hasan Shahid</td>
<td>June 2014 – expected graduation May 2016</td>
<td>B.Eng. in Electrical Engineering from Stevens Institute of Technology</td>
<td>Team Leader – CSR 2014 SRI. Led the Technology Integration and Synergies team to assess the capabilities and limitations of CSR’s broadband radar system. Submitted research abstract for consideration at the SPIE Defense and Security Conference. Provided demos of the Center’s broadband technology to visiting guests from USCG, CBP, PANYNJ, NUSTL, and NJ OHSP among other local, state, and Federal agencies.</td>
</tr>
</tbody>
</table>

**1.5. Summer Research Institute (SRI) 2014:**
CSR held its fifth annual Summer Research Institute, from June 2 to July 25, 2014 at the Stevens Institute of Technology campus in Hoboken, NJ. Since the program’s inception in 2010, 88 high-achieving engineering and science students from around the nation, including students from HBCU and MSI schools, have participated in the maritime security-centric summer research program. Collectively, SRI student participants have produced high quality research outcomes and assisted in the development and advancement of new tools and technologies that have contributed to the Center’s research and have had direct impact to the operational use of CSR stakeholders.

The 2014 summer research program included 18 student participants representing the following four universities: Stevens Institute of Technology, CITY Tech, Rutgers University and the University of Puerto Rico-Mayaguez.

To support student participation in the SRI 2014 program, CSR leveraged existing Stevens scholarship and fellowship programs and those of its academic partners to recruit students who could attend the SRI fully-funded through externally-fund resources. In 2014, 15 out of the 18 student participants attended the program through funding support from DHS Scientific Leadership Awards and through Stevens Scholars program.

The Stevens Scholars Program offers qualified students the opportunity to either participate in undergraduate research or pursue an accelerated program leading to a bachelor's degree in three years or a dual bachelor's /master's degree in four years. The Scholars Program is an invitation-only program in which undergraduates are encouraged to apply their knowledge and participate in hands-on research projects with Stevens faculty members. Students do not apply to the program; they are identified and selected during the undergraduate admissions process or after earning a minimum GPA of 3.8 after their first semester at Stevens. The summer research opportunities include stipends and on-campus residential housing.
CSR provided funding support for only three of the eighteen participants. The three students were selected through the Center’s academic partnerships with CITY Tech and Rutgers University and through the inclusion of a Stevens computer engineering student who had previously conducted work on the Center’s Magello response tool.

Table 4 below identifies the SRI 2014 student participants and the funding sources leveraged to support their participation.

**Table 4. SRI 2014 Student Participant List**

<table>
<thead>
<tr>
<th>UNIVERSITY</th>
<th>STUDENT</th>
<th>MAJOR &amp; DEGREE</th>
<th>Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITY Tech</td>
<td>Jonathan Abellard</td>
<td>Geology/Marine Sciences, Undergrad.</td>
<td>CSR</td>
</tr>
<tr>
<td>Stevens Institute of Technology</td>
<td>Yong Qi Chen</td>
<td>Electrical Eng./undergrad</td>
<td>Stevens Scholar</td>
</tr>
<tr>
<td></td>
<td>Robert Garvin</td>
<td>Electrical Eng./Undergrad</td>
<td>Stevens Scholar</td>
</tr>
<tr>
<td></td>
<td>Nicholas Haliscak</td>
<td>Maritime Systems / Grad.</td>
<td>DHS CDG Fellow</td>
</tr>
<tr>
<td></td>
<td>Beichen Li</td>
<td>Computer Eng./ Grad.</td>
<td>CSR</td>
</tr>
<tr>
<td></td>
<td>Reed Oberlander</td>
<td>Mechanical Eng./ Undergrad.</td>
<td>Stevens Scholar</td>
</tr>
<tr>
<td></td>
<td>Thomas O’Neill</td>
<td>Naval Eng./ Undergrad.</td>
<td>Stevens Scholar</td>
</tr>
<tr>
<td></td>
<td>Carrick Porter</td>
<td>Civil Eng./ Undergrad.</td>
<td>Stevens Scholarship</td>
</tr>
<tr>
<td></td>
<td>Gina Salmins</td>
<td>Computer Science/ Undergrad.</td>
<td>Stevens Scholarship</td>
</tr>
<tr>
<td></td>
<td>Dmitriy Savinskiy</td>
<td>Engineering Mgt./ Undergrad.</td>
<td>Stevens Scholarship</td>
</tr>
<tr>
<td></td>
<td>Hasan Shahid</td>
<td>Electrical Eng./ Undergrad.</td>
<td>Stevens Scholar</td>
</tr>
<tr>
<td></td>
<td>Monique Cerqueira</td>
<td>Maritime Systems/ Grad.</td>
<td>Stevens Scholarship</td>
</tr>
<tr>
<td></td>
<td>Zuidema</td>
<td>Naval Engineering</td>
<td>DHS CDG Fellow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SIT/Brazil exchange program</td>
</tr>
<tr>
<td>Rutgers University</td>
<td>Sarah Walsh</td>
<td>Mechanical Engineering and Mathematics / Undergrad.</td>
<td>CSR</td>
</tr>
<tr>
<td>University of Puerto Rico - Mayague</td>
<td>David Gonzalez</td>
<td>Electrical Engineering</td>
<td>UPRM/SLA</td>
</tr>
<tr>
<td></td>
<td>Luis Miranda</td>
<td>Industrial Engineering</td>
<td>UPRM/SLA</td>
</tr>
<tr>
<td></td>
<td>Juan Carlos Santos</td>
<td>Electrical Engineering</td>
<td>UPRM/SLA</td>
</tr>
</tbody>
</table>

1.5.1. Student Qualifications and Documentation

Participation in the SRI requires that students be actively enrolled in an undergraduate or graduate-level science or engineering degree program at an accredited university. Undergraduate students must possess a minimum GPA of 3.0, and graduate-level (Master’s and PhD) students are required to have a GPA of 3.5 or better.

This past summer’s participants were required to complete a CSR online application form and write a personal statement of interest.
In accordance with Stevens Institute of Technology, students were also required to demonstrate proof of health insurance and submit immunization records to Stevens Health Center prior to attending the program.

1.5.2. Summer Research Stipends and Housing

The SRI 2014 students received summer stipends up to $4,000 and were provided accommodations on-campus in Stevens Institute of Technology’s dormitory housing. Travel reimbursements up to $1,000, were also made available for transportation to and from the start and end of the program for students residing outside of New Jersey.

1.5.3. Program Administration

The day-to-day administration and coordination of the 2014 program was a team effort supported by Ms. Beth Austin-DeFares, CSR Director of Education, and Dr. Barry Bunin, Director Maritime Security Program and Chief Architect, Maritime Security Laboratory, under the executive leadership of Dr. Julie Pullen, CSR Director.

Dr. Bunin served as the lead faculty facilitator and curriculum developer, and Ms. DeFares functioned as the primary program and student coordinator.

SRI student team mentorship was provided by CSR research PI’s and Stevens faculty including, Dr. Julie Pullen, Director, CSR, Dr. Sasha Sutin, Research Professor, Mikhail Tsionskiy, Research Engineer, Dr. Alexander Yakubovsky, Senior Research Engineer, Ms. Grace Python, Research Associate, and by Stevens doctoral students Alex Pollara, Maritime Security and Talmor Meir, Ocean Engineering.

1.5.4. Program Format and Curriculum

The SRI program format is designed to provide a balance between in-class lectures, research based projects, professional development activities, and experiential learning opportunities in the field.

The first week of the 2014 summer research program was devoted to providing students with a comprehensive overview of the maritime domain, the role of the Marine Transportation System in global trade and to the U.S. economy, and sensor technology applications used in maritime and port security applications. Class lectures are designed to provide students with a framework in which they can begin to understand the relationships between public and private maritime stakeholders and the challenges of safeguarding and securing the nation’s coastal borders, ports, and inland waterways.

To complement lessons learned in the first few days of the program, the students participated in a field visit to the Hoboken and Staten Island Ferry Terminals to conduct a
visual observation exercise. The students were asked to take notes on perceived and observed security vulnerabilities, critical infrastructure along the Hudson River, and the presence of security personnel and assets along the waterfront, in terminals and aboard the public ferry lines. At the end of the trip, the students were asked to present and discuss their observations in a report-out session with the larger student group.

Having had a solid week of introductory lectures and opportunities to get to know each other through the observation exercise, the students were given their team assignments and were introduced to their respective mentors for the summer. Throughout the remainder of the eight-week program, the students would work with their teammates on a daily basis to research their projects, conduct experiments and to meet with relevant practitioners in the field.

The first half of **Week Two** included supplementary faculty and guest lectures, and hands-on demonstrations of the Center’s sensor technologies (e.g. Acoustics, Electro-Optics, HF Radar, and Satellites). Guest lectures for the week included a visit by Dr. Aldo Napoli, Center for Risks and Crisis, MINES Paris Tech. Dr. Napoli presented developments on a new maritime domain awareness tool developed by his Lab, that is being utilized to detect and track anomalies in vessel traffic along the coast of France.

Starting **Weeks Three - Seven**, the SRI program format shifted from time spent in the classroom, to time spent engaging in team research projects and field visits and meetings with CSR stakeholders and maritime practitioners. During Weeks Three – Seven, student teams also began to provide formal status updates on their research in the form of weekly presentations and power point slides. Each team was responsible for providing a twenty to thirty minute presentation describing their research project, the challenges they were addressing, the activities and experiments they were engaged in, and the research progress they were making.

SRI program guest speakers and field visits during Weeks Three – Seven are described in sections 1.5.5. Guest Speakers and 1.5.6. Field Visits and Meetings with Practitioners, of this report.

In **Week Seven**, the student teams began to synthesize their research and started to compile their final team research reports.

In **Week Eight**, the last week of the SRI program, students submitted their final reports and provided team presentations to an audience of CSR researchers and stakeholders, including representatives from CBP, NJ OHSP, NUSTL, PANYNJ, and USCG Sector New York.

Table 5 below illustrates the weekly schedule for the SRI 2014 program.
<table>
<thead>
<tr>
<th>Schedule</th>
<th>Topic</th>
<th>Faculty Guest Speakers</th>
<th>SRI 2014 Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEEK ONE</td>
<td>Sensor Technologies</td>
<td></td>
<td>Introductions &amp; tour of research labs &amp; facilities. Security observations - field visits to ferry terminals.</td>
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<tr>
<td>June 2 - 6</td>
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<tr>
<td>WEEK TWO</td>
<td>MDA/MTS Industry Overview</td>
<td>Aldo Napoli, MINES Paris Tech: Security and Safety of Maritime-oriented Energy.</td>
<td>NJ OHSP TTX</td>
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<td>June 9 - 13</td>
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<tr>
<td>WEEK THREE</td>
<td>Team Research Projects</td>
<td></td>
<td>Magello team meeting w/ USCG Sector NY. CBP Field-Visit Team status update presentations</td>
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<tr>
<td>June 16 - 20</td>
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</tr>
<tr>
<td>WEEK FOUR</td>
<td>Team Research Projects</td>
<td>Gerhardt Muller – LNG Safety and Security</td>
<td>NYPD-CTD- Port Awareness and Response Course. Status Update Presentations</td>
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<tr>
<td>Jun. 23 – 27</td>
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<tr>
<td>WEEK FIVE</td>
<td>Team Research Projects</td>
<td>Rae Zimmerman: Innovations for Robust Infrastructure Services in a Time of Extremes.</td>
<td>Scenario Development team - meeting with NUSTL/USCG –. Fourth of July Harbor Patrol aboard USCGC Sturgeon Bay</td>
</tr>
<tr>
<td>June 30 – July 4</td>
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<tr>
<td>WEEK SIX</td>
<td>Team Research Projects</td>
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<td>Status Update Presentations</td>
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<tr>
<td>July 8 - 12</td>
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<tr>
<td>WEEK SEVEN</td>
<td>Project Time</td>
<td></td>
<td>Magello team visit to OEM-Brooklyn, NY</td>
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<td>July 15 - 19</td>
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<tr>
<td>WEEK EIGHT</td>
<td>Team Reports</td>
<td></td>
<td>FINAL TEAM PRESENTATIONS</td>
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<tr>
<td>July 22 - 26</td>
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Table 5. SRI program schedule June 2 – July 25, 2014
1.5.5. Guest Speakers

SRI guest speakers provide professional insight into the current state of affairs and practice in the maritime homeland security domain. Student participants are strongly encouraged to ask questions and to take advantage of the opportunity to engage practitioners and homeland security experts in dialog as it pertains to their respective research projects and general academic and career interests.

This past summer’s guest speakers included:

- Dr. Rae Zimmerman, Center for Transportation Policy and Management, NYU;
- Mr. Gerhardt Muller, San Sail Inc.; and
- Dr. Aldo Napoli, Center for Research on Risks and Crisis, MINES Paris Tech

1.5.6. Field Visits and Meetings with Practitioners

*Figure 3. SRI 2014 student participants observe CBP field operations and cargo container screening at the Port of New York/Newark.*
Field visits to port environments and locations where maritime and homeland security practitioners conduct their day-to-day operations is a key feature of the CSR summer research program. The experience of visiting a new location and going behind the scenes to observe and learn the roles and responsibilities of practitioners and their organizations provide students with a real-world framework to better understand their research projects and the current state of practice and in homeland security.

During the 2014 SRI program, students participated in field-visits and engaged in activities with representatives from the following organizations:

- Customs and Border Protection (CBP) Tactical Operations Division – Field-visit
- DHS National Urban Security Technology Laboratory (NUSTL) – Field-visit
- USCG Incident Management Division – Sector New York - Meeting
- USCGC Sturgeon Bay – Fourth of July Harbor Patrol
- NYPD-Counterterrorism – Port Awareness and Prevention Course
- NYC Office of Emergency Management - Meeting

For the past three years, Customs and Border Protection (CBP) has hosted the Center’s SRI students for a comprehensive tour of the agency’s facilities at the Port of New York and Newark. On June 17, 2014, CBP welcomed CSR's summer research students for a discussion of the agency's mission areas and a tour of the organization's Tactical Operations Division. The visit, coordinated by Officer Bradford Slutsky, CBP Program Manager, included observations of the agency’s radiation portal monitors, high-energy mobile non-intrusive inspection (NII) equipment, and a tour of a Centralized Examination Station warehouse where agricultural products are examined and cargo is physically inspected and analyzed.

The engagement of SRI students in field visits and networking events with CSR stakeholders, have resulted in invitations for students to attend local, state and municipal training exercises. During the week of June 23, 2014, the students were invited to participate in a one-day Port Awareness and Response workshop hosted by the NYPD – Counterterrorism Division, at the NYPD Police Academy in NYC. The training session brought together a diverse group of maritime stakeholders and NYPD officers to enhance awareness of port operations and facilities in the New York City metropolitan area.

Presentations by NYPD, USCG and CBP representatives provided firsthand insight into the complexities of safeguarding the New York Harbor, including the city’s critical infrastructure and national landmarks, without impeding or interfering in the flow of commerce in and out of the areas’ ports, terminals and waterways. Training session
topics included overviews of the geography of the Port of NY and NJ, port regulatory functions and agencies, emergency response units and capabilities, and threats, risks and vulnerabilities.

In addition to the above land-based activities, the 2014 SRI group received a special invitation to engage in a patrol of the New York Harbor on the Fourth of July with the captain and crew aboard the USCGC Sturgeon Bay. The patrol included the clearing of vessels from the channel at the mouth of the East River and Hudson River and enforcement of a buffer zone between the Macy’s fireworks barges and commercial and private pleasure craft in the harbor. During the patrol, Lt. Kenneth Sauerbrunn, captain of the Sturgeon Bay, reviewed with the SRI students, the maritime security plans created in collaboration with the NYPD and members of the Area Maritime Security Committee to safeguard and secure the harbor during the national holiday event.

1.5.7. SRI 2014 Student Research Projects

Student participants in the 2014 summer research program were arranged into four separate teams. The student teams were organized according to expressed research interest, technical skills, degree levels, and general representation across the participating schools. Effort was also made to ensure that each team was diverse and multidisciplinary across the academic majors.

The SRI 2014 students were assigned to one of the following four research projects:

• **Magello Emergency Response Tool - End-user Test and Evaluation:** Students on the Magello team were responsible for evolving the tool to include data sets and custom layers tailored to emergency response and homeland security end-users.

• **Maritime Incident Scenario Development:** The students on the Scenario Development team created maritime threat scenarios to be used by organizations to prepare for and test their capabilities to prevent, respond to and recover from maritime crisis events.

• **Acoustic Signature Analysis for Automated Vessel Classification:** Students on the Vessel Acoustic Signature Analysis team were given the task of identifying and extracting unique acoustic features from a Stevens library of recorded vessel signatures. Using these extracted features, the team created a machine-readable data set to test and evaluate machine learning algorithms.

• **Technology Integration and Synergies: Radar, Optics and AIS:** The Technology Integration team was responsible for assessing the capabilities and limitations of various sensors and then integrating them to maximize situational awareness and surveillance.

1.5.7A. Magello Emergency Response Tool: End-user Test and Evaluation
Students on the Magello Emergency Response Tool Team were responsible for improving the tool’s functionality and for building out new data sets and customized layers through the test and evaluation of the tool in conjunction with CSR stakeholders. Originally developed by a team of students in the 2011 Summer Research Institute, Magello is a friendly Google Earth™ user interface platform that allows for various key environmental and oceanic data sets to be presented in a layered fashion. The user interface is a customizable, web-based tool that integrates oceanic and atmospheric forecasting, plume modeling and real-time information that can assist decision-makers and emergency responders to prepare for, respond to, and recover from an event.

The 2014 SRI Magello team assumed the responsibility for the documentation of the tool’s development and for soliciting end-user feedback to further enhance the tool’s capabilities. The team’s objectives for the summer were to interact with potential end-users and to gain in-depth understanding on their experience using Magello, and to build the tool into a national resource by incorporating data sets for new geographical areas beyond New York/New Jersey.

Under the mentorship of Talmor Meir, Stevens Research Assistant and Ocean Engineering doctoral candidate, Grace Python, Stevens Research Associate and former DHS CDG Master’s Degree Fellow, and Dr. Julie Pullen, Director, CSR, the team was able to convene meetings with the Incident Management Division at USCG Sector New York and with the Office of Emergency Management in NYC.

The meetings included the demonstration of Magello using hypothetical emergency scenarios to assess how end-users might navigate the tool and to document the list of...
steps they would go through to respond to the crisis within the first fifteen minutes to 24 hours following the event. The end-users were then given time to use the tool on their own and to provide feedback on their experience.

The demonstration sessions with the USCG Incident Management Division and the OEM resulted in customized layers and datasets for each of the groups. In the case of the Incident Management Division, a new category of layers was created under the name of “Coast”. Under the new category, users can select from a range of data overlays to include information regarding coastal areas of relevance and importance to the Coast Guard during pollution response and environmental clean-up missions. These overlays include: Areas of Responsibility (highlighted areas that distinguish responsibility between the USCG and the EPA), the Shoreline Sensitivity Index (highlighted areas that convey areas of priority for the USCG), Land Use areas (marked public-use areas along the coast), Hydro Lines (highlighted areas that indicate lesser known and less visible piers and other critical infrastructure), AIS and local port facilities. By combining all this data into one interface, the student team was able to tailor a solution for the Incident Management Division that would provide critical data for enhanced situational awareness and improved decision-making during pollution response and clean-up events.

Figure 5 below shows a display of the Shoreline Sensitivity Index data and the new Coast category in the left-hand navigation, developed with the input and feedback the Coast Guard.

Figure 5. Magello provides Shoreline Sensitivity for the New York Harbor.

Meetings with the Office of Emergency Management also provided valuable updates to Magello. OEM feedback inspired the students to incorporate new data sets and layers to include regional population counts, hospital locations and sewer overflow areas prone to flooding. These important layers are essential to emergency responders as they respond to events and coordinate plans for evacuations or the care of mass casualties.
In addition to creating customized overlays, the student team also expanded the tool to include data sets for San Francisco, CA and the island of Puerto Rico.

Details regarding the Magello Team project outcomes can be found in their final presentation slides made available on the CSR’s Summer Research Institute website at: http://www.stevens.edu/ses/summer-research-institute-2014.

Magello - Student Team members

<table>
<thead>
<tr>
<th>Student</th>
<th>Academic Discipline</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beichen Li</td>
<td>Computer Engineering</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td>Luis Miranda</td>
<td>Electrical Engineering</td>
<td>University of Puerto Rico-Mayaguez</td>
</tr>
<tr>
<td>Gina Salmins</td>
<td>Chemical Engineering</td>
<td>Stevens Institute of Technology</td>
</tr>
</tbody>
</table>

**Faculty Mentors:** Talmor Meir, Grace Python and Julie Pullen.

1.5.7B. Maritime Incident Scenario Development Team

*Figure 5. Students on the Maritime Incident Scenario Development Team prepare for their final team presentation at the culmination of the 2014 SRI program.*

Student’s on the Maritime Incident Scenario Development team were tasked with creating maritime threat scenarios involving maritime structures, vessels, and sites that might be vulnerable to attack due to their strategic, symbolic, or economic importance or physical characteristics.

The scenarios were to be planned from an attacker’s point of view taking into consideration the likely defenses of security measures and personnel.
The team’s objective was to program and simulate the scenarios using the Center’s maritime simulator custom software and to develop exercise manuals that can be used for emergency response training and discussion-based tabletop exercises.

In conducting their research, the students met with representatives of the USCG, NUSTL and the NJ OSHP for their input. Meetings with the homeland security practitioners allowed the students to focus on two key areas of concern: small vessel threats and the use of chemical agents in terrorist events.

A sub-group of the team also took initiative to explore the safety and security concerns for the refueling of Liquefied Natural Gas (LNG) vessels in the New York metropolitan area. Negative public perceptions and concerns over LNG vessels being targets for terrorists, inspired the scenario team to examine what guidelines could be developed or put into place to enhance the safety and security of LNG vessels in the metropolitan area.

Outcomes from the student team’s work resulted in the development of two exercise manuals, each designed to provide stakeholders with a useful tool in preparation for and in response to security threats. The exercise manuals were intended to provide scenarios that can be used to better understand how an organization/stakeholder will respond to threats and to identify strengths and vulnerabilities in their response efforts.

Details regarding the team’s project outcomes can be found in their final presentation slides made available on the CSR’s Summer Research Institute website at: http://www.stevens.edu/ses/summer-research-institute-2014

**Maritime Scenario - Student Team members**

<table>
<thead>
<tr>
<th>Student</th>
<th>Academic Discipline</th>
<th>School</th>
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<tbody>
<tr>
<td>Nicholas Haliscak</td>
<td>Maritime Systems</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td>Reed Oberlander</td>
<td>Naval Engineering</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td>Thomas O’Neill</td>
<td>Civil Engineering</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td>Chris Polacco</td>
<td>Maritime Systems</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td>Monique Cerqueira Zuidema</td>
<td>Naval Engineering</td>
<td>Stevens Institute of Technology</td>
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</table>

**Faculty Mentors:** Barry Bunin and Beth Austin-DeFares

1.5.7C. **Technology Integration and Synergies: Radar, Optics and AIS**
The research challenge for the Technology Integration and Synergies team included the use of sensors and technologies to accurately detect, track, and classify suspicious vessels. The technologies used in the summer research project included broadband radar, optical and infrared cameras, and data received from the Automatic Identification System (AIS).

As part of their research project, the team was also tasked with testing the effectiveness of the Center’s new broadband radar system. Newly acquired by the university, the system had yet been assessed relative to its strengths and limitations for situational awareness and security applications.

Through their research, the team found that while each system, e.g. optical and infrared cameras, AIS and broadband radar, has its advantages, they do not provide sufficient security and surveillance capabilities as stand alone solutions. For example, broadband radar has an extremely wide range but cannot classify vessels. On the other hand, optical cameras can classify vessels but they have a narrow field of vision and are ineffective at night. To mitigate the limitations of each system, the team determined that each technology needed to be used in coordination of each other.

The team’s final report documents their process for testing and evaluating the various sensors and technologies in detecting, tracking and classifying vessels passing through the Hudson River, and how the team integrated the tools to interface with each other to overcome the limitations of each system.

Details regarding the Technology Integration and Synergies Team’s project outcomes can be found in their final presentation slides located on the CSR’s Summer Research

<table>
<thead>
<tr>
<th>Student</th>
<th>Academic Major</th>
<th>School</th>
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<tbody>
<tr>
<td>Joe Nathan Abellard</td>
<td>Computer Engineering</td>
<td>New York City College of Technology (CITY Tech)</td>
</tr>
<tr>
<td>Yong Qi “Felix” Chen</td>
<td>Electrical Engineering/Mathematics</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td>David Gonzalez</td>
<td>Electrical Engineering</td>
<td>University of Puerto Rico-Mayaguez</td>
</tr>
<tr>
<td>Hasan Shahid</td>
<td>Maritime Systems</td>
<td>Stevens Institute of Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Mentors: Dr. Alex Yakubovskiy and Mikhail Tsionskiy</td>
</tr>
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1.5.7D. Acoustic Vessel Signature Analysis for Automated Vessel Classification

Figure 7. Sarah Walsh (Rutgers University), on the Acoustic Vessel Detection Team meets with Dr. Barry Bunin in the CSR Maritime Security Laboratory to discuss how to graphically display acoustic detection data.

The Vessel Acoustic Signature Analysis team was given the task of identifying and extracting unique acoustic features from a Stevens library of recorded vessel signatures. Using these extracted features, the team created a machine-readable data set to test and evaluate machine learning algorithms. These algorithms, in turn, will be used to
automate the classification process, improving the effectiveness of law enforcement agencies such as the USCG and CBP.

The team focused its research on the acoustic classification of small vessels, namely Panga boats and jet skis, as they are very challenging to detect with existing technologies in the field (e.g. radar). Also, due to their small size, speed and maneuverability, they are more likely to elude authorities when they are engaged in drug smuggling or other nefarious acts. The ability to classify these vessels based on their acoustic signature will aid the U.S. Coast Guard and CBP, among other law enforcement groups, in their ability to interdict these vessels before they reach their destination.

The team’s research included the analysis of acoustic signatures, the manual extraction of key features, such as frequency peaks, into machine-readable data sets, by vessel types.

The students then compared the results of their manual classifications to those performed using Machine Learning techniques (e.g. automatic classification algorithms). The team’s results showed that the automatic classification algorithms were able to correctly classify Panga signatures in three out of four instances, and that jet skis proved to be more easily identifiable than Pangas.

For additional information about the team’s project outcomes, please review their final presentation on the CSR Summer Research Institute webpage at: http://www.stevens.edu/ses/summer-research-institute-2014

### Acoustic Vessel Signature Analysis Team

<table>
<thead>
<tr>
<th>Student</th>
<th>Academic Discipline</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Garvin</td>
<td>Mechanical Eng.</td>
<td>Stevens Institute</td>
</tr>
<tr>
<td>Juan Carlos Santos</td>
<td>Electrical Engineering</td>
<td>University of Puerto Rico-Mayaguez</td>
</tr>
<tr>
<td>Dmitriy Savinskiy</td>
<td>Electrical Engineering</td>
<td>Stevens Institute</td>
</tr>
<tr>
<td>Sara Walsh</td>
<td>Mechanical Engineering</td>
<td>Rutgers University</td>
</tr>
</tbody>
</table>

**Faculty Mentors:** Dr. Barry Bunin, Dr. Sasha Sutin, and Alex Pollara

### 1.6. SRI Program Assessment

An assessment of the SRI 2014 program outcomes and lessons learned was conducted at the end of the summer research program in the form of a student survey. Feedback from the survey responses, together with the student team project outcomes, research reports and presentations, all indicate that the SRI was effective in meeting its program objectives and successful in creating positive research experiences and experiential learning opportunities for its students.
1.6.1 Student Survey Results

Ten out of the eighteen program participants completed the SRI student survey. The intent of the survey was to assess the impacts of the SRI’s curriculum, faculty mentorship and field based activities on the learning outcomes of the students and their enhanced interest in pursuing continued academic study and/or a career in the homeland security domain.

Overall, the student respondents rated the SRI “Excellent” in the following areas:
- Quality of the Program (60%)
- Faculty mentorship and guidance (70%)
- Quality of student teamwork (60%)
- Quality of field-trips (60%)
- Quality of guest lectures (50%)
- Quality of research (60%)
- Student ability to be innovative (70%)

When asked to identify the top three takeaways from the SRI some of the students commented:
- “The faculty mentors of this program have taught me how to motivate myself and be enthusiastic about my work, how to set goals and meet them in an efficient manner, and how to be an effective leader and recognize an opportunity.”
- “Conducting research in a diverse team really emphasized the multidisciplinary aspect of research. 2- Partaking in a research project concerned with challenges as significant as those pertaining to maritime security is extremely motivating. 3- Research skills are life skills!!!”
- “I have learned how to meet with professionals in my field and discuss our mutual interests. I have gained a better understanding of how technologies can be used in the field to enhance maritime security.”

When asked to describe areas that can be improved for the future delivery of the program, students commonly said:
- Too much time is spent on in-class lectures.
- Students need more time to work on their team projects sooner in the program.
• Some of the program lectures do not apply to all of the student research teams. Students should be able to attend or not attend lectures as they apply to their projects.

When asked how they would best describe the strengths of the SRI program, some students wrote:

• "The real strength of the SRI is its unique format that combines independent student research with access to industry leaders, enabling self driven research previously out of reach of undergraduate students."

• One great strength of the SRI is the faculty involvement in advising projects. Another is the quality of the education of maritime security.

• "The SRI is well organized and administered. The teams are very diverse, which encourages the multidisciplinary aspect of conducting research. The 8 weeks of the research period are carefully planned to keep students engaged and on task."

• "The largest strength of the SRI was the meetings with stakeholders and field visits. These opportunities were unique to the SRI and provided us with exceptional learning opportunities including understanding field operations in maritime security."

The program survey also takes into account the impact of the SRI program on inspiring student interest in education and careers in the field of maritime and homeland security. In a testament to the program’s effectiveness, ten out of the ten survey respondents said “Yes” to the following question “Has the SRI enhanced your interest in pursuing a career and/or further academic study in the field of maritime/homeland security?” Figure 8 below shows the student’s response regarding the SRI’s impact on their academic and career interest.
1.6.2 SRI 2014 Outcomes and Lessons Learned

The students worked in close collaboration with CSR researchers and had the unique opportunity to interact and engage with real-world industry and government maritime and homeland security leaders and practitioners. Through their experience in the summer research program, students gained a greater awareness of maritime security issues and the vital role of the marine transportation system to the nation’s economy. Because of their experience in the SRI program several of the students will now consider seeking jobs and careers in areas that will contribute and support to U.S. homeland security.

Overall, the SRI was effective in achieving the following outcomes:

- Student research reports, field experiments and weekly presentations demonstrated the student’s advanced knowledge and understanding of the maritime security domain.
- Students enhanced their professional skills by providing weekly research presentations and through networking opportunities with CSR stakeholders.
- Students developed strong professional bonds and friendships with each other.
- Students expressed enhanced interest in pursuing careers and/or advanced academic study in maritime/homeland security as a result of their participation in the SRI.

Lessons learned in this year’s program demonstrate that student research outcomes are positively affected by the following factors: the amount of time spent conducting research, collaborations and engagement with CSR researchers and industry and government practitioners, and access to state-of-the science tools and technologies.

1.6.3. Recommendation
The following recommendation for the future delivery of the SRI take into consideration conversations held between CSR researchers and administrators, and specific comments received in the student survey responses.

**Program Format:** CSR administrators must continue to refine the SRI program format to allow students sufficient time to work on their research projects.

1.6.4. Conclusion

Students learn about the maritime domain and the marine transportation system through faculty and guest lectures and most importantly through hands-on field-visits and one-on-one interactions with maritime and homeland security practitioners.

Student survey responses reflected the positive impacts of the CSR program on student skills, knowledge and interest in maritime and homeland security. Student reports, presentations and stakeholder feedback all point to the success of the 2014 summer research program in meeting its stated objectives.

1.7. Alumni Network and Student Achievements

CSR has actively worked to maintain communication and connections with its SRI alumni. CSR considers these students as ambassadors for the summer research program and more importantly as the next generation of maritime security practitioners and homeland security professionals.

CSR’s director of education has continued to stay in touch with the students and continuously provide them with information on relevant academic and professional career opportunities. It is through these continued communications that CSR has been able to track the impacts of the SRI on the continuing activities of its alumni participants.

The bulleted list below highlights recent SRI student alumni who are continuing to engage in homeland security related activities with the CSR.

- **Blaise Linn:** Blaise has participated in the SRI for three consecutive summers under the Stevens Scholar’s Program. Blaise is currently working on a senior design project in the area of passive acoustic detection systems, a project he first began in the SRI.
• **Carrick Porter**: Carrick has participated in the SRI for two consecutive summers. He recently applied and has been admitted into the Maritime Systems Master’s Degree program at Stevens.

• **Nick Monzillo**: Following Nick’s participation on the SRI 2013 CBP Trade Facilitation Case Study Team, he has continued to pursue opportunities to conduct research in support of CBP’s Office of International Trade. During the spring of 2014, Nick completed an independent study with CBP statisticians to improve the sampling efficiency of the agency’s Trade Compliance Measurement (TCM) program.

• **Kate Moyer**: Following Kate’s participation in the SRI 2013 program, she proactively sought out opportunities to continue to work with CSR researchers. In addition to completing an independent research project in the area of chemical detections, Kate has completed an application to participate in the DHS HS-STEM summer internship program.

### 1.8. Students Mentored and Supported by CSR

In addition to the three students supported by the CSR during the 2014 Summer Research Institute, the Center has also provided support in the form of a Research Assistantship to Talmor Meir a doctoral candidate in Stevens Institute of Technology’s Ocean Engineering Ph.D. program.

During Year 6, Talmor mentored and provided research guidance to a team of students in the Summer Research Institute and led the continued development of the Center’s Magello Emergency Response Tool. Tal’s leadership has resulted in Magello being demonstrated for representatives from the USCG Sector New York, the New York City Office of Emergency Management, and the USCG Research and Development Center.

Table 6 below provides an overview of the students supported by the CSR along with their respective accomplishments.

**Table 6. Students Mentored and Supported by CSR.**

<table>
<thead>
<tr>
<th>CSR Academic Partner</th>
<th>Students supported through DHS/CSR funding</th>
<th>Type of Support/Advisor</th>
<th>Accomplishments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
1.9. U.S. Coast Guard Auxiliary University Programs – Stevens Institute of Technology Detachment Program.

<table>
<thead>
<tr>
<th>Institute</th>
<th>Name</th>
<th>Year</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITY Tech</td>
<td>Joe Nathan Abellard</td>
<td>2014</td>
<td>Summer Research Intern – 2014 Summer Research Institute – Technology Synergies Team</td>
</tr>
<tr>
<td>Stevens Institute of Technology</td>
<td>Beichen Li</td>
<td>2014</td>
<td>Summer Research Intern – 2014 Summer Research Institute – Magello Emergency Response Team</td>
</tr>
<tr>
<td>Stevens Institute of Technology</td>
<td>Talmor Meir – PhD, Ocean Engineering</td>
<td></td>
<td>Served as a research mentor for the 2014 SRI Magello Emergency Response Team.</td>
</tr>
<tr>
<td>Rutgers University</td>
<td>Sarah Walsh</td>
<td>2014</td>
<td>Summer Research Intern – 2014 Summer Research Institute – Acoustics Team</td>
</tr>
</tbody>
</table>

Figure 9. Stevens USCG Auxiliary students join the captain and crew of the USCGC Sturgeon Bay for a patrol of the Hudson River.

Over the past year, the Stevens USCG Auxiliary program was officially recognized as an Auxiliary Detachment under the sponsorship of Flotilla 21, First District Southern Region. The designation was celebrated in a formal Planking Ceremony hosted by the CSR and governed by Commodore Vincent Pica, First District, Southern Region, CDR Laura Moose, Director Auxiliary Programs, Flotilla Commander, Bruce Ohlendorf, and Captain Gordon Loebl, Commander USCG Sector New York and Captain of the Port of NY/NJ.
The Stevens-based program is coordinated by CSR’s director of education and by Dr. Hady Salloum, Stevens Associate Dean for Research. The group meets once a month during the Stevens academic year, August – May. The program includes eleven student and faculty members and welcomes new members on a regular basis. As of this report, three new recruits are in the process of completing USCG Auxiliary membership paperwork to join the Stevens detachment program.

During the 2013/2014 academic year, Stevens Auxiliary members participated in several marine safety and security training events and performed civic service and outreach activities for the community. In one such event, the students were invited to participate in a harbor patrol with the captain and crew of the USCGC Sturgeon Bay. While on patrol, the students were able to observe first-hand the crew of the Sturgeon Bay perform a man overboard drill and were provided with a tour of the vessel to understand the mechanics of the ice breaker and to learn about sea vessel navigation systems and ice breaking missions in the Hudson River.

In a separate event, the Auxiliary students were invited to host an exhibit booth at the SUBMERGE! NYC Marine Science Festival. The day-long event was coordinated by the New York City Hall of Science, with the purpose of bringing awareness to marine science and New York City’s coastal waterways.

Working in conjunction with members from the USCG Auxiliary Flotilla 21, Stevens Auxiliary students prepared an exhibit featuring the impacts of water pollution on sea life and the environment. Throughout the day, the Auxiliary students provided hands-on demonstrations and examples of pollution collected from local beaches and waterways in the NYC metropolitan area, and distributed educational materials to encourage recycling and environmental awareness. According to the event organizers, more than 4,500 people attended the marine science festival held at the Hudson River Park in New York City.

Established in 2012, the Stevens USCG Auxiliary Detachment program is one of only eight university-based programs in the nation and is the only Auxiliary university program to be partnered with a DHS Center of Excellence.

2.0. Future Educational Opportunities and Plans

CSR will continue to grow and extend its educational program offerings with the inclusion of its new academic partners under the Center for Maritime Research. Plans are being made to develop and enhance the following program areas:

- The ongoing delivery of the Center’s Summer Research Institute.
- The development of new continuing education and professional development opportunities for maritime security practitioners.
• The continuous and on-going updating of Stevens Maritime Security curricula to reflect the current trends and maritime security technology needs in the homeland security domain.
• The continuation and inclusion of new Maritime Systems seminars delivered by CSR researchers and leading experts and practitioners in maritime and homeland security.
• CSR will continue to seek opportunities to host DHS Scholars & Fellows and MSI Summer Research Teams during the summer of 2015.

3.0 Education Milestones

**2014 Summer Research Institute:**
Outcomes from the SRI 2014 can be found in section 1.6.2. of the above report. CSR successfully delivered its fifth annual Summer Research Institute, from June 3 – July 26, 2013, on-campus at the Stevens Institute of Technology in Hoboken, NJ. Since the program’s inception in 2010, 88 engineering and science students, representing 17 U.S. universities, including MSI and HBCU designated schools, have engaged in the SRI.

The SRI 2014 student participants completed team research reports, presentations and research posters. Student participants engaged in hands-on research projects in collaboration with CSR PI’s and industry and government stakeholders. Copies of the students final team presentation can be found on the CSR website at [http://www.stevens.edu/ses/summer-research-institute-2014](http://www.stevens.edu/ses/summer-research-institute-2014).

The SRI program has had long lasting impacts on student participants. Over the past year, several students have continued to engage in independent research projects with CSR researchers and have proactively pursued DHS HS-STEM internships and have applied for admission into Stevens Maritime Systems Master’s Degree program.

**Maritime Security Doctoral Fellowship:**
CSR created a new Maritime Security Doctoral Fellowship program during Year 6. The objective of the fellowship program is to enhance the nation’s technical leadership through research and the development of new maritime security applications, strategies for maritime resilience and improved methods for emergency planning, preparedness and response. The fellowship was organized to provide full funding support and a monthly stipend for up to three years, for a student of notable achievement for whom the university assessed would make original contributions to theory and practice in the field of Maritime Security.

The fellowship was competitively awarded to Alex Pollara, a graduate of Stevens Maritime Systems Master’s degree program and Naval Engineering undergraduate program.
**Maritime Systems Master’s Degree Fellowship Program:**
During Year 6, two students successfully completed the CDG Master’s Degree Fellowship program to receive their Master’s degree in Maritime Systems with a Graduate Certificate in Maritime Security. One of the students is now employed fulltime in the Analyst Development Program at Analytic Services, Inc., and the other has been awarded a doctoral fellowship to continue his research and academic studies in Maritime Security.

**Maritime Security Seminar Series:**
CSR successfully engaged a broad audience of current and aspiring homeland security practitioners and members of the Stevens community in maritime security-centric seminars. The seminars covered a range of homeland security and maritime security focused topics, intended to bring greater awareness to the importance of the maritime domain to the U.S. economy and to the nation’s safety and security.

**USCG Auxiliary Program:**
During Year 6, the Stevens USCG Auxiliary program was formally recognized as a Detachment Unit under Flotilla 21, of the First District, Southern Region. The Stevens Auxiliary members met regularly throughout the 2013/2014 academic year and engaged in a harbor patrol with active duty USCG members. Student members also conducted civic service outreach through a USCG Auxiliary sponsored exhibit at the NYC Marine Science Festival. The Stevens Detachment currently has 11 members and is proactively recruiting new members.
E2E Maritime Domain Awareness

System Integration and Field Test and Evaluation

CSR MDA efforts over last 5 years have included improving and refining technology:

- **Satellite**: Target detection advances through rapid data acquisition and improved algorithms for wake and target detection.

- **HF Radar**: Multi-use of technology from ocean current analysis to vessel detection using common platform.

- **Acoustics**: Advanced from single hydrophone detection to multi-system detection with localization, and classification

Technology attributes that have been identified through prior experiments include:

- **Satellite**: SAR provides all-weather synoptic view, but via snapshots in time. Can provide cueing to other systems, but not continuous tracking

- **HF Radar**: Can provide continuous tracking of vessels to 10’s of kilometers, but cannot see small vessels (< 10 m air draft) nor provide classification information

- **Acoustics**: Most limited in range (~ 10 km) but can detect small and large vessels, underwater targets, and provide classification information

We undertook a technology integration experiment in fall 2013. A multi-layered experiment was performed Nov. 23, 2013 in lower New York Bay, with the following goals:

1. To compare detection capabilities of various technologies for common targets in the same venue

2. To explore application of a layered approach for port protection from a systems perspective

3. To investigate synergies among three technologies (acoustics, HF radar, satellite) to enhance overall detection capabilities

4. To identify technology gaps

Multi-Layer Multi-Technology (“Synergy”) Experiment

On the 23rd of November, 2013, researchers from Stevens and its CSR partners, the University of Miami CSTARS, and Rutgers University RUCCOOL undertook an experiment using multiple sensor platforms to detect vessels near Sandy Hook NJ. The
primary objective of this experiment was to identify synergies among Satellite, High Frequency (HF) radar, and passive acoustics in maritime domain awareness.

Rutgers University maintains several CODAR High Frequency (HF) radar arrays on the coast of NY and NJ. These systems are primarily intended for tracking ocean surface currents but can also be used to detect and track vessels. During the synergy experiment four HF radar stations were used: The primary two systems were 25MHz installations located in Port Monmouth NJ and Staten Island NY. The 25 MHz systems have the highest resolution and shortest range of the HF radar stations used. They have a range of approximately 10 miles and can generally detect vessels with at least 20 ft of air draft. These two systems together had coverage of nearly the entire Sandy Hook Bay and lower NY Harbor area. A 13 MHz system located in Belmar NJ and a 5 MHz system were also used to detect large vessels outside of the Lower NY Harbor area. All of these radar systems were operational throughout the experiment.

University of Miami maintains partnerships with several commercial satellite companies capable of providing images generated with both visible light and synthetic aperture radar. At 11:49 AM, 11/23/2013 one of these satellites was used to take a visible light image of the lower NY Harbor and Sandy Hook Bay. Much of the image was obscured by cloud cover, however a large portion of the test area was visible. This portion of the image was processed using algorithms developed by University of Miami to detect vessels. This information was then compared to AIS records for the area to determine which vessels detected by the satellite were transmitting AIS and to match these vessels with their information. By process of elimination this also determined which vessels detected were not transmitting AIS data.

Figure 1 shows the locations of the two 25 MHz radar installations (SILD, and PORT), the location of the passive acoustics buoy, and the coverage of the HF radar, Satellite, and passive acoustics system.

USCG Aux Flotilla 21 provided a crew and an 80 ft research vessel: the Lady B, for the experiment.

The experiment plan was as follows: First the Lady B was to deploy passive acoustics buoys at the test area. Next the Lady B would conduct a target run to test the passive acoustics, and HF radar tracking on a known documented target. The satellite image of the test area was taken during this phase of the experiment using visible light optics to detect the research vessel and other vessels in the area. Once the Lady B had completed its target run it would return to a standoff point near the passive acoustics system to observe and document vessel traffic in near the system for a two hour time span. Finally the Lady B would retrieve the passive acoustics system and return to port.
Figure 1: Coverage areas of the three systems used in the Sandy Hook synergy experiment. Satellite coverage is shown in blue, HF radar in green, and passive acoustics in yellow. The locations of the HF radar arrays and passive acoustics system are denoted by yellow thumb tacks. PASR stands for Passive Acoustic Recording System.

Since only one acoustics system was operational during the experiment, it was only possible to determine detection and bearing to passing vessels detected. Vessel location could not be determined acoustically. Data was compared among all three systems and AIS to find vessels that were detected by all systems, and those that were missed by some systems.

The primary goal of this experiment was to determine the potential for increased maritime domain awareness by tracking a vessel with multiple systems. Initially the plan had been to demonstrate this layered surveillance using the research vessel Lady B as a target for all three systems. The Lady B was successfully tracked by passive acoustics on several occasions. Unfortunately the Lady B proved too small a target for the HF radar to effectively track. A fast ferry, the Whaling City Express was therefore chosen to facilitated synergy research among the three systems. The Whaling City Express can be seen in Figure 2.
Figure 2: Image of the Whaling City Express, a catamaran fast ferry.

The Whaling City Express is a large catamaran ferry which transits between New York City, and points in New Jersey. As a passenger vessel, the Whaling City Express is equipped with an AIS transponder. Data from this transponder was recorded during the experiment and provided ground truth location of the vessel during the experiment.

The HF radar was the first system to detect the Whaling City Express. The vessel was detected by the Staten Island 25 MHz station as it exited the Verrazano Narrows on a southerly course. The Staten Island HF radar station tracked the vessel from 16:16 UTC until 16:26 UTC during which time the vessel transited the lower bay from the Verrazano Narrows towards Sandy Hook. At this point the Staten Island radar station lost contact with the Whaling City Express. The Port Monmouth 25 MHz radar array detected the Whaling City Express sporadically for some period of time afterwards.
Figure 3: Image showing Whaling City Express AIS track with times when vessel was tracked by passive acoustics Highlighted in orange. Yellow Azimuths indicate first and last tracked bearing to vessel.

The passive acoustics system detected the Whaling City Express at 16:25 UTC at a distance of 2.2km as it approached Sandy Hook. Passive acoustics was able to track the bearing of the Whaling city Express as it passed the system until 16:28 UTC when it moved out of tracking coverage of the system. Figure 3 shows the track of the Whaling City Express as it passed the passive acoustics system. The time when the passive acoustics detected and tracked the vessel are highlighted in orange along its AIS path.

The Whaling City Express was detected in the satellite image taken at 14:49. Its identity was confirmed by comparison with AIS. This comparison also indicated that the vessel had likely diverted slightly from the apparent track reported by AIS. Figure 4 shows the satellite image of the Whaling City Express. The vessel and its wake are denoted by a red oval. The reported AIS track of the vessel is shown as a white line. Note that in the image the vessel and its wake have already diverged from this course.

Figure 4: Satellite image of Whaling City Express, Vessel wake is circled in red, AIS data is shown in white.

The complete AIS track of the Whaling City express is shown in Figure 5 as a green line. Superimposed on the track are the detections of the vessel by the three systems: HF radar is shown as red dots, Satellite detection is shown as a yellow dot, and the AIS track is highlighted in orange during the times when the vessels bearing was tracked by passive acoustics. It is clear that the data from no single system would suffice to track the
Whaling City Express through its journey. In the absence of AIS, HF radar would have tracked the vessel through the northern part of the bay but lost it near Sandy Hook, and would not have given any information about the vessel identity. Passive acoustics would have detected the vessel and provided classification information, but would have given no further tracking once the vessel was out of the systems relatively small range. The satellite image would detect the vessel for an even shorter period of time, but provides a synoptic view of all vessels in the harbor, with and without AIS emissions.

Figure 5: Cross platform data fusion map showing ground truth AIS vessel track in green, HF radar detections in red, passive acoustics detection in orange, and satellite detection in yellow.

The benefits of a layered/data fusion surveillance approach using satellite, HF radar, and passive acoustic surveillance were demonstrated in this test conducted in NY Bay. Satellite can provide vessel detection in wide area but it is expensive and can provide surface imaging with large time gaps. HF radar cannot detect small boats. Acoustics can detect, track and classify small boat but only in limited range. The conducted experiments shows the advantages and drawbacks of the separate systems and
demonstrated improved abilities of the system fusion. For example acoustics detected and
classified 14 small boats that had no AIS and were not visible to HF radar. Joint abilities
were demonstrated by the persistent tracking of the Whaling City Express by all three
systems at various points during its journey. The potential for tracking handoffs between
the systems, where each system can cue the other for contacts to expect, is apparent. The
range of the satellite and HF radar are complemented by the classification capacity of the
passive acoustic system. The passive acoustic system and the satellite both demonstrated
their ability to detect small vessel which fall completely outside the scope of the HF
radar, and AIS due to their size. And finally the persistence of the HF radar, and passive
acoustics offer the potential to fill the time gaps between satellite overpasses.

We have worked on articulating the steps to implementation and evaluation in terms of
data flows on enterprise-wide systems—e.g., through Open Mongoose (NY/NJ testbed
radar data, continuous streaming in year 6) or other portals like the Environmental Data
Server (EDS) that serves WatchKeeper. Our year 6 efforts in regards to WatchKeeper are
described in the passive acoustics portion (section 7). Our prior successful transition to
operational usage of HF radar surface current data in SAROPS, where the platform for
serving the data was EDS, serves as a guide in our endeavor (NY/NJ testbed radar data,
continuous streaming to EDS in year 6). We conducted stakeholder events and briefings
about the E2E “Synergy” experiment overviewed above. Stakeholder meetings in year 6
addressed evolving opportunities and challenges in getting the technologies and data
streams into the field. Interactions with stakeholders surrounding the experiment and
experimental outcomes are described under Management Activities. Slides, movies and
a draft manuscript for publication in the MTS journal are available upon request.
Additional aspects of the experiment will be addressed in the E2E MDA sections below.
Project 1.1 – Satellite Radar Applications in the Coastal and Maritime Domain

Principal Investigator
- Dr. Hans C. Graber, Center for Southeastern Tropical Advanced Remote Sensing, University of Miami, Miami, Florida

Project Objectives
1. Continued exploration of the informational content of SpotLight, StripMap and ScanSAR modes on the accuracy of detecting vessels and the fidelity of discriminating vessel characteristics (i.e., container, cargo, tanker, fishing vessels, etc).
2. Continued detailed examination of the value of polarimetric (dual-pol and/or quad-pol) data from the new SAR sensors to improve vessel, wake and oil spill detection.
3. Explore amplitude change detection on successive pairs of imagery to determine new ship arrivals and old ship departures in port facilities as well as docking time periods.
4. Further development of radon transform for use of extracting ship wakes in noisy environments.
5. Continued tests of spiral development with other CSR teams will be conducted as they arise (e.g., New York Harbor for the Summer Research Institute). These tests will include surface vessels of varying types and sizes as well as the multi-tiered sensors described in the CSR project. These tests will allow us to layer satellite imagery onto other MDA data streams in the context of Stevens’ visualization center: the Maritime Security Laboratory.
6. Integration of vessel information with satellite imagery.

Research Milestones Met

1. Continued exploration of the informational content of SpotLight, StripMap and ScanSAR modes on the accuracy of detecting vessels and the fidelity of discriminating vessel characteristics (i.e., container, cargo, tanker, fishing vessels, etc).

Imagery sources were compared (radar & optical) resulting in an examination of 3m vs 5m resolution images focused on vessel size discrimination (ship length & width). A comparison with AIS is contained in synergy experiment (see 5. below).

2. Continued detailed examination of the value of polarimetric (dual-pol and/or quad-pol) data from the new SAR sensors to improve vessel, wake and oil spill detection.

In defining the synergy experiment and the needs of the other sensing modalities (ship time, etc.), it was determined that the experiment would extend for one day. The short
duration of the experiment meant that opportunities to collect data to pursue this facet were not available.

3. Explore amplitude change detection on successive pairs of imagery to determine new ship arrivals and old ship departures in port facilities as well as docking time periods.

The synergy experiment ended up being of short duration due to logistical/experimental considerations. So we were not able to exercise this aspect in the experiment. This is an approach we have demonstrated in the past and would like to apply to appropriate targets going forward.

4. Further development of radon transform for use of extracting ship wakes in noisy environments.

We continue to work with the Radon Transform (RT) mapping of the spatial domain of an image into the two dimensional Euclidean space (Radon, 1917). The RT is defined as

\[ f(\rho, \theta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g(x, y) \delta(\rho - x \cos \theta - y \sin \theta) \, dx \, dy \]

where \( g(x,y) \) represents the intensity level of the image at position \((x,y)\), \( \delta \) denotes the Dirac delta function, \( \rho \) the length of the normal from the origin to a straight line, and \( \theta \) represents the angle between the normal and the x-axis. The Dirac delta function forces the integration of \( g(x,y) \) along the line \( \rho = x \cos \theta + y \sin \theta \). Consequently, the RT yields the integrals across the image at varying orientations \( \theta \) and offsets \( \rho \) relative to the image center (Murphy, 1986). The main advantage of this operation is that it maps a straight line in the image space into a single point in the transform space. Detection of dark (bright) linear features in an image thus becomes detection of dark (bright) points in the Radon domain.

The work focused on examining radon transfer algorithms as applied to different radar platforms. Algorithm improvement focused on speed of processing. While examining the sensitivity of the Radon Transform to noisy environments, we have yet to test this approach to wake detection with very high-resolution imagery.

5. Synergy Experiment in New York Harbor (and Puerto Rico collections)

On 23 November 2013 we carried out a full scale synergy experiment of ship detection involving the multi-tiered approach of the CSR primary project goal: satellite wide-area situational awareness and surveillance with moderate to high-resolution; HF radar with medium range for transitioning and passive acoustic monitoring for small scales and confined areas. Satellite electro-optical and synthetic aperture radar sensors were used for this one day experiment. The optical image around midday became a trigger for the dusk pass of SAR. A compromise of high resolution (~1m spatial resolution) versus footprint coverage was made since focus was on the outer harbor area and approaches of
the port of New York. All detected vessels were handed off as input to HF radar and acoustic monitoring.

The five-satellite constellation RapidEye with multispectral sensors provided an optical view of the AOI on 2013-11-23T16:49:28Z. Figure 1 shows a multi-view image separating the spectral bands for better detection accuracy of the outer port of New York. A total of 45 ships were detected. Correlation with AIS data about ± 10 minutes of the imaging time revealed that 25 targets did not broadcast on AIS (Figure 2).

Figure 1: RapidEye multispectral image collected on 2013-11-23T16:49:28Z over the outer port of New York observes 45 ships.

Figure 3 shows an example of several ship detections readily correlated with AIS data and also observed by HF radar as the vessels either approached or departed the port. The detected position and the interpolated course from AIS are remarkably close.

Figure 4 shows the all weather, day and night radar image from TerraSAR-X collected at dusk on 2013-11-23T22:43:22Z. At that time 16 targets were observed and 2 targets were not associated with an AIS message. Figure 5 highlights the strength of SAR detecting not only a pilot boat just 28 ft x 9 ft in size, but also the channel markers delineating the waterway.
Figure 2: RapidEye multispectral image collected on 2013-11-23T16:49:28Z shows 25 ships without AIS data correlation.

Figure 3: Three detected vessels: 2 cargo ships (Maersk Chicago and Tokyo Express) and a harbor pilot boat. Shown are their detected positions and ± 10 minutes of AIS path around the collection time.
Figure 4: TerraSAR-X microwave 3m stripmap image collected on 2013-11-23T22:43:22Z shows 16 targets detected (left) and 2 ships observed without AIS data correlation (right).

Figure 5: A small towing vessel, “Bering Dawn” and channel markers detected on this TerraSAR-X 3m stripmap image.

Both optical and radar satellite sensors provide rapid and accurate situational awareness picture of vessel traffic inside and offshore of NY/NJ harbor. Very high resolution imagery (<1m) is possible, and maybe a good MTI sensor capable of classifying vessel type. Detected vessels were positively correlated with AIS although a fair number of unknown vessels did not transmit AIS message. More frequently AIS messages are found
to be spoofed providing false positional data. However, SAR can detect such vessels. Combined with HF radar and acoustics provides layered and persistent MDA monitoring system for improved port security.

**Ship Detection Exercise in the Mona Passage:** Four Cosmo-SkyMed images were collected on 23 & 27 June 2014 in support of the HF radar testing in the Mona Passage.

### 6. Integration of vessel information with satellite imagery.

In collaboration with USCG’s District 7 – Miami, Florida, District 14 – Honolulu, Hawaii, District 11 – Alameda, California, and District 13 - Seattle, Washington, image collections of selected AOIs were made during 28 September and 1 November 2013 (“Coastal Hollywood”). Satellite imagery from RadarSat-2 using Standard and Wide Standard Mode in dual polarization mode (HH/HV) were downlinked at CSTARS and analyzed for ship detections. This data-set was valuable for applying the algorithm approaches to real applications, in addition to demonstrations like the synergy experiment. Results were delivered in near-real time as OTH-GOLD, KMZ, and PDF files via email to the appropriate USCG District. During the approximately 1 month long exercise 52 RadarSat-2 images were downlinked and processed. Table 1 shows a quick overview of the results. Overall nearly 270 ships were detected from the 52 imaging events. The results were briefed to District 7 personnel. This data-set afforded the integration of vessel information from AIS emitters with satellite imagery, and also illuminated non-AIS emitters.

<table>
<thead>
<tr>
<th>District</th>
<th>AOI</th>
<th>Imaging Events</th>
<th>Ship Detects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D7 – Miami</strong></td>
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<td></td>
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<tr>
<td></td>
<td>Georgia Shelf</td>
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<tr>
<td></td>
<td>Blake Escarpment</td>
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<tr>
<td></td>
<td>Blake Plateau</td>
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<tr>
<td></td>
<td>Puerto Rico/Caribbean</td>
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<td><strong>D14 – Honolulu</strong></td>
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<td>Palmyra Atoll Region</td>
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<td><strong>D11 – Alameda</strong></td>
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</table>

*Table 1: Image collection and ship detection breakdown for “Coastal Hollywood”.*
Funding for the RadarSat-2 imagery was provided by the National Geospatial-Intelligence Agency (NGA) through their “Open Ocean Surveillance” program. Collection strategies were developed with USCG personnel.

Figure 6 shows the locations off the Florida coast where collections for “Coastal Hollywood” took place and the locations of all the targets detected.

Most of them could be validated by satellite AIS and were ruled out as “dark targets”. Figure 7 shows an example how satellite ship detections are validated against satellite AIS data. There are two targets detected in the SAR image and AIS shows a possible candidate prior to image collection. Based on the speed and heading of the vessel the semi-circle shows its possible position during the image collection time. Target 11 appears inside the semi-circle. The AIS message from the pre-collection position belongs to the “Bahama Spirit”. Therefore, Target 11 is likely the “Bahama Spirit”, a self discharging bulk carrier, built in 1995 with dimensions 180 m x 32 m and gross tonnage of 26,792 t as depicted in Figure 9.

Figure 10 shows a similar example, but two AIS message were available at the time of analysis, thus determining more unambiguously the detected vessel. With
Figure 7: Two targets detected in SAR image. A pre-collection AIS message provides speed and heading to draw a semi-circle with possible positions given this information. Only Target 11 fits the criterion well enough to belong to vessel at pre-collection position.

Figure 8: The AIS message from the pre-collection position belongs to the “Bahama Spirit”. The shape and size of the satellite detection corresponds well with the dimensions of the named vessel.

pre- and post-collection AIS messages two semi-circles can be drawn, one projecting forward and the other backward. Then the two positions and their times can be used to interpolate the possible position during the imaging event. However, it is likely that the interpolated and actual detected position don’t match as is the case here. Apparently Target 1 slowed down and changed heading as
Figure 9: Photo of the Bahama Spirit, a self discharging bulk carrier.

Figure 10: Pre- and post-collection messages are used to better define the possible position of Target 1 in this scenario.

well as sped up again during the two message positions and hence does not coincide with the detected position.

Figure 11 shows the imaging events and detected vessels in the Palmyra Atoll region within District 14 (Honolulu, Hawaii) area of responsibility.
South of the Dominican Republic there were many dark targets, and a similar procedure of AIS overlay was produced.

7. Attend CSR and End-User Meetings and Workshops

CSR Coordination Meeting, 3 February 2014
Stakeholder Meeting, 4 February 2014
Meeting with Rear Admiral Michel and other USCG personnel in Hoboken, NJ on 28 April 2014; Briefing to Rear Admiral Michel, USCG on CSR activities and capabilities.

Metric for Success

1) implementation of integrated multi-sensor system;

Progress toward the successful implementation of the integrated multi-sensor system to demonstrate operational utility and relevance to the end-users has been demonstrated in the synergy experiment. Synergy experiment results are available as slides, video and a manuscript in preparation. We are engaged in continued discussions with RDC for how to introduce these results to improve data-streams into command centers.

2) 100% detect change to targets of all sizes, range, scale;

It has been found that 100% change detection for vessels greater than 25 ft. is achieved with an appropriate imaging mode. For smaller vessels, the orientation of the wake matters in significant ways. Detection is nearly 100% for wakes in direction.
of satellite overpass (azimuth), and 50% for paths oriented normal to the satellite path (range).

3) 50% discrimination of wakes in sea state;

For the images we have examined, this has been achieved – with the caveat that accurate sea state measurements are essential, but not always attainable.

References


Project 1.2 – Development of a Multi-use Surface Current Mapping and Vessel Detection Capability for SeaSonde Multi-static High Frequency Radar Networks

Principal Investigators
• Dr. Scott Glenn, Institute of Marine and Coastal Sciences, Rutgers University
• Dr. Jorge Corredor, University of Puerto Rico, Mayaguez

Project 1.2.1 Rutgers University (S. Glenn, PI)

Project Objectives

Year 6 Goals:
• Improve the real-time vessel detection software in the three testbeds (New York Harbor, Alaska and Puerto Rico) to generate detection statistics
• Collect the datasets needed to develop the Level 1 and 2 association methodologies for improved detection statistics
• Improve detections based upon feedback from the Naval Research Laboratory evaluation of the data before it is passed to Open Mongoose
• Test multistatic capability of the HF radar network to generate simultaneous detections in monostatic and bistatic mode

Research Milestones Met

Rutgers outlined five tasks for this project year:

1. **Operate 13 MHz shore based network with AIS receivers outside Delaware Bay urbanized test bed.**

When the work plan for Year 6 was written in February 2013, we were still dealing with the after effects of Hurricane Sandy. We had lost the station at Sea Bright, where we had been conducting real time vessel detection. No sites were operating in New York Harbor in February 2013. So we envisioned running the real time software from the sites outside Delaware Bay because of the large amount of ship traffic present. However, we were able to install a 5 MHz radar at Hempstead, NY and the 13 MHz radar at Belmar, NJ in May 2013 and the operation of these sites was on-going in year 6. We also used the 25 MHz radar at Port Monmouth, NJ to study small vessel detection and operated real time licenses at the radar stations in Puerto Rico (Club Deportivo and Fura Anasco).

![Figure 1: Time line showing where the real-time software was operated during the progress period.](image-url)
Resiliency Levels. We assembled statistics on the real time delivery rates for the radar stations where we operated the real time license. The results are given in Table 1. The vessel detection aspect of the radar is on par with the 80/80 metric that the Coast Guard had presented for the delivery of real time surface currents. The delivery statistics are lower for the remote sites in Puerto Rico but that is understandable. Table 2 provides resiliency levels for the various components of the vessel detection chain.

Table 1: Real time vessel detection delivery statistics for Year 6. The number of days that data was delivered (operational column) and the total number of days the site was operated for vessel detection (total column) along with percentages.

<table>
<thead>
<tr>
<th></th>
<th>Operational</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belmar</td>
<td>149</td>
<td>160</td>
<td>93%</td>
</tr>
<tr>
<td>Hempstead</td>
<td>372</td>
<td>411</td>
<td>91%</td>
</tr>
<tr>
<td>Port Monmouth</td>
<td>154</td>
<td>167</td>
<td>92%</td>
</tr>
<tr>
<td>Club Deportivo</td>
<td>49</td>
<td>82</td>
<td>60%</td>
</tr>
<tr>
<td>Fura Anasco</td>
<td>61</td>
<td>98</td>
<td>62%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>785</td>
<td>918</td>
<td>86%</td>
</tr>
</tbody>
</table>

Table 2: Resiliency levels for network components

<table>
<thead>
<tr>
<th>Vessel Detection Component</th>
<th>Resiliency Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>SeaSonde HF radar hardware</td>
<td>High</td>
</tr>
<tr>
<td>SeaSonde Vessel Detection Software</td>
<td>High</td>
</tr>
<tr>
<td>Communications</td>
<td>Medium</td>
</tr>
<tr>
<td>Power</td>
<td>Medium</td>
</tr>
<tr>
<td>Infrastructure (enclosure, stable shore line)</td>
<td>Medium</td>
</tr>
<tr>
<td>Data Visualization</td>
<td>Medium</td>
</tr>
<tr>
<td>Trained Operators</td>
<td>High</td>
</tr>
</tbody>
</table>

2. Maintain vessel detection data stream access to Open Mongoose

We maintained a dialogue with Mr. Daniel Newton of the Naval Research Laboratory on the data flow and quality. Real time data was delivered to NRL for the entire progress period. The 5 MHz radar at Hempstead, NY was the main focus of data ingest by NRL.
3. Conduct vessel detection test in Arctic test bed in cooperation with University of Alaska Fairbanks

We conducted a vessel detection experiment in conjunction with the University of Alaska Fairbanks (UAF) from August 1, 2013 to October 31, 2013. We utilized the 5 MHz radars at Point Barrow and Cape Simpson (Figure 2). We submitted a final report to UAF on June 30, 2014 entitled “Expanding USCG Maritime Domain Awareness Capabilities in the Arctic: Vessel Tracking and Communications”. We published a paper in the Marine Technology Society Journal on this experiment, which is given the Documentation section of this report.

![Site study map for the 2013 summer field season. Radars were operated at Wainwright, Barrow and Cape Simpson Alaska from July to October 2013. The location of the Beaufort and Chukchi Sea are shown as well.](image)

We also conducted a test case this past summer. A Russian navy ship was shadowing the research vessel Westward Wind on August 27, 2014. A photo of the vessel was taken by a crewmember of the Westward Wind at 08:55 am local time (16:55 GMT), which is shown in Figure 3. We processed data from the 5 MHz radar at Point Lay, Alaska for the same time period. The output is shown in Figure 4 where 4 unique tracks were identified and labeled in the figure. The AIS data provided by Alaska Marine Exchange (Figure 5) was correlated with the vessel detection data. Object 3 was identified as the Westward Wind and object 4 was identified as the Russian naval vessel. There were no other
vessels in the vicinity of the Westward Wind at 08:55 am (Figure 5) so we concluded that object 4 was the Russian navy ship.

![Photo of the Russian navy ship](image)

*Figure 3: Photo of the Russian navy ship taken from the Westward Wind at approximately 8/27/14 08:55 am (16:55 GMT). The Westward Wind was 108 km NNW of Point Lay, Alaska at this time.*

![Detection plot from the radar](image)

*Figure 4: Detection plot from the radar at Point Lay from 14:00 to 20:00 GMT on August 27, 2014. The subplots are from top to bottom are range (km), range rate (m/s) and bearing (degrees CWN).*
4. **Conduct multistatic vessel detection test in tropical test bed with mobile bistatic transmitter in Mona Passage, Puerto Rico**

We conducted a vessel detection experiment in the Mona Passage from June 2-8, 2014. The team installed and tested a 13 MHz bistatic transmitter from the cliffs of Mona Island and aboard the M/V Mariangie (Figure 1). We were testing different deployment configurations to see which were optimal for increased radar coverage. Two SeaSonde HF radar stations deployed on the west coast of Puerto Rico received the signal from the transmitter. In the 2014 experiment, we focused on detecting vessels that were visible to both radars simultaneously. We operated the real time vessel detection software on each of the two radars in Puerto Rico and mapped the vessel detection data in real time. We would like to thank the Puerto Rico Department of Natural and Environmental Resources for assisting us with the site selection and logistical planning with the operations on Mona Island.
The naming convention for the radar combinations is given in Table 3. For instance, CDFU was designated as the data source where the CDDO site was the receive station and FURA was the transmit station. There were a total of five data streams, two monostatic and three bistatic.

Table 3: Naming convention for the combination of transmit and receive stations for the experiment.

<table>
<thead>
<tr>
<th>Receive Station</th>
<th>Transmit Station</th>
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<tr>
<td>CDDO</td>
<td>CDDO, CDFU, CDMO</td>
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<tr>
<td>FURA</td>
<td>FURA, FUMO</td>
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The results from the experiment are summarized in a PowerPoint slide deck entitled “Mona Island Experiment Results” and in the report “Evaluation of High Frequency Radar for Vessel Detection”. Figure 8 provides a summary of the vessels that were detected and by which radar station. There were 11 instances where a vessel was detected by 3 of the five detection streams. The mean detection time for the monostatic cases was on the order of 2 hours.

<table>
<thead>
<tr>
<th>#</th>
<th>MMSI</th>
<th>Vessel Name</th>
<th>Vessel Type</th>
<th>Country</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>DDSO</th>
<th>PULA</th>
<th>DORU</th>
<th>CDMO</th>
<th>PUMO</th>
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<td>23993300</td>
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<td>Cargo</td>
<td>Norway</td>
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<td>1</td>
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<td>MYHARLEY</td>
<td>Tug</td>
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<td>3</td>
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<td>3</td>
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<tr>
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<td>Bulk Carrier</td>
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<td>45</td>
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<tr>
<td>17</td>
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<td>ELOUI</td>
<td>Container</td>
<td>Marshall Islands</td>
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<td>25.53</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**Figure 8:** Vessel detection results from the 2014 Mona Island Experiment. The columns from left to right are vessel number, mmsi, vessel name, vessel type, country, length of vessel, width of vessel. The remaining columns show if a vessel was detected (yes 1, no 0, not processed blank) by a particular data stream.

The detections by the radar were compared against ground based AIS and satellite AIS. Satellite AIS was very sparse when compared to ground based AIS and HF radar.
provided vessel detections in AIS data gaps. The maximum detection range of the radar was examined and found between 30 and 65 km.


Rutgers participated in the New York Harbor Synergy experiment November 22-24, 2013. We concentrated our analysis of the HF radar data to coincide with the times of the satellite overpasses at 16:49 and 22:42 GMT on November 23. We utilized the 5 and 25 MHz radars for this detection experiment. The results from the detections at the time of the 16:49 satellite pass are shown in Figure 9. Here we wanted to show that the HF radar provides vessel position information for a considerable length of time beyond that of the instantaneous satellite information. For instance the average length of detection for the 5 MHz system was 139 minutes.

We also concentrated on the association problem of merging position information from separate radar detections. We utilized the Tokyo Express for the test case. The raw detection data as well as the Level 1 association data from the radars at Hempstead, NY; Port Monmouth, NJ and Staten Island, NY were merged into a single product and validated against the vessel position information from AIS. The results are shown in Figure 10.

![Figure 9: Detection plot of the vessels in vicinity of the satellite overpass at 16:49 GMT November 23, 2013. The time length of the detections (x axis) for each vessel (y axis) is shown for the 5 MHz radar at Hempstead, NY (red), 25 MHz radar at Port Monmouth, NJ (green) and Staten Island, NY (blue).](image-url)
Figure 10: Track of the Tokyo Express as it entered NY Harbor. The blue line indicates the track of the vessel from AIS and the red line shows the track of the vessel from the merged detections from the radars HEMP, PORT and SILD. The green line shows the Level 1 Association data.
**Other Notable Achievements**

In a coordinated effort between Rutgers, New Jersey Department of Environmental Protection (NJDEP), and the U.S. Coast Guard, an underwater glider was recovered off the coast of New Jersey (NJ). The Rutgers/NJDEP glider was recovered using the Coast Guard Cutter Finback, led by Officer in Charge, BMCS M.D. Buckman. The U.S. Coast Guard is evaluating what autonomous underwater vehicles (AUVs; Slocum gliders, Wave Glider, etc.) will be of use to them in their operations and assessing whether their current assets (cutters, patrol boats, helicopters) can accommodate these AUVs (see article here: [http://www.uscg.mil/acquisition/](http://www.uscg.mil/acquisition/)).

![Figure 11: Screenshot of the glider recovery from the Coast Guard Acquisition web site.](image)

Dr. Hugh Roarty and Dr. Julie Pullen travelled to California July 22-23, 2013. They were given a tour of the Air and Marine Operations Center and met with Mr. Jeff Mayer to discuss adding HF radar, satellite and acoustic vessel detection data streams to the operations. They also visited USCG PACAREA.
Figure 12: Dr. Hugh Roarty (left) and Dr. Julie Pullen (right) visited the Air and Marine Operations Center in Riverside, California on July 22, 2013.
Metrics for Success

Progress toward the successful implementation of the integrated multi-sensor system to demonstrate operational utility and relevance to the end-users was achieved in the Synergy experiment described in this section and elsewhere in the report. It also produced, through layering with satellite and acoustic data in the Stevens Laboratory, a testbed for displays of data streams that have different coverage, space and time scales.

Spatial and temporal coverage for the NY/NJ sites was over 90%. The remote location of Mona Island and challenges of powering the system were expected to lead to initially lower data delivery rates and coverage than was achievable in the urban NY/NJ testbed. Over 60% spatial and temporal coverage was achieved. We aim to increase that coverage in the future.

In relation to association, Version 1.4.3 of Ship Association code is currently running on the sites with real time vessel detection software. The Ship Association code performs the Level 1 association. Level 1 Association combined detections from multiple FFT lengths and backgrounds onto a single time series with lower uncertainties. A test case of Level 1 association was performed for the Calusa Coast for June 11, 2012. In this test case Level 1 association achieved the desired goal of reducing the bearing uncertainty before passing the data onto a tracker. The current status of the association process is summarized in the attached paper “Methods of Associating CODAR SeaSonde Vessel Detection Data Into Unique Tracks”.

Documentation

The papers that we authored in this period are:


## Resources Leveraged

<table>
<thead>
<tr>
<th>Institution</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid Atlantic Regional Coastal Ocean Observing System</td>
<td>Admin Assistance, electronic data processing, web support, technical support for the 41 site, operational, regional HF Radar network</td>
</tr>
<tr>
<td>NOAA IOOS Program National Surface Current Mapping Plan</td>
<td>CODAR station loan brokering, data coordination with the U.S. National Network, operating frequency permissions</td>
</tr>
<tr>
<td>UCSD Coastal Observing Research and Development Center</td>
<td>Web hosting, Data quality control for the national HF Radar network.</td>
</tr>
<tr>
<td>CIMES Operating in the Arctic: Supporting USCG Challenges through Research</td>
<td>Expanding USCG Maritime Domain Awareness Capabilities in the Arctic</td>
</tr>
<tr>
<td>New Jersey Board of Public Utilities</td>
<td>Ran vessel detection software on these radar stations in southern NJ after Hurricane Sandy destroyed the northern NJ stations</td>
</tr>
</tbody>
</table>
Project Objectives

The continuing objective of the year 6 UPRM HF Radar work plan was:

· Maintenance, upgrading and operation of the HF Radar network on the Mona Passage, and

· Provision of local support for the coordinated spiral development cycle in CSR’s tropical HF Radar testbed in Puerto Rico.

Specific tasks included:

· Maintenance of the 2 CODAR units on loan currently emplaced at CDDO and FURA

· Maintenance of the AIS at Magueyes Island and Mayaguez campus

· Continued engagement with FURA and USCG

· support to Rutgers in monostatic vessel detection and tracking tests with the two-shore based Radars already in operation

· support to Rutgers in vessel detection and tracking tests of the reconfigured bistatic transmitter running on shore power at Mona Island

· Maintenance of the AIS page (“Ship Tracker”) and

· Maintenance of a dynamically updated map of surface currents in the Mona Passage

Research Milestones Met

As proposed, the FURA and CDDO stations were operated continuously (with only short maintenance related interruptions) and AIS service was maintained throughout the reporting period. A dedicated web page mirroring output from the national network at CORDC, NOAA’s HFR page and Rutgers’ page is continuously

Our initial proposal for year 6 included hosting a one week hands-on workshop for UPRM CSR staff, technicians and students to address deficiencies in local software expertise. Due to scheduling conflicts however, the course was held during year 5 (May 29-31, 2013). Dr. Hugh Roarty of Rutgers COOL travelled to Puerto Rico for this purpose.

With assistance from our colleagues at Rutgers, several major upgrades were performed at the FURA and CDDO stations including:

- Installation of remote WebPowerSwitch switches
- Relocation of the FURA Rx antenna to the roof of the Police station
- Installation of new Tx antenna and transmit cable at FURA, which alleviated the high-reflected power issue we had been dealing with at the site
- GPS antenna replacement at FURA
- Cable replacements and cleanout at both sites
- Antenna pattern measurements at FURA and CDDO over the period Monday, 5/12/14 through Saturday, 5/17/14

A second Mona Passage experiment was conducted in a collaboration between the Caribbean Coastal Ocean Observing System (CariCOOS) and Rutgers University Coastal Ocean Observing Laboratory (RUCOOL) over the period. A transmitter was tested in two different locations in order to obtain data that would help determine optimal sites for radar coverage in the Mona Passage, an area characterized by heavy marine traffic. The antenna was installed and operated in two different settings, a cliff facing Puerto Rico’s west coast and aboard the M/V Mariangie during similar time intervals.

The experiment had two main objectives considered critical in further validation of new applications for HF radar systems, namely;

i) Vessel detection and tracking

ii) Bistatic Radar Operation
UPRM personnel played an important role in working the logistics associated with the Mona Experiment implemented Mona Island is known for its extreme environment, high temperatures and strong winds, all of which could have compromised the operation if careful planning was not taken into consideration. Both the M/V Mariangie and The Puerto Rico Department of Natural and Environmental Resources (DRNA) were fundamental assets in the installation and completion of the experiment. Coordinating joint efforts with the latter and identifying the necessary resources for successfully completing the experiment were, in its totality, amongst UPRM responsibilities. Technical details of ship detection and tracking using the 2 monostatic emplacements at FURA and CDDO and the Tx bistatic antenna operating under autonomous power at Mona is available in the complementary report from Rutgers.

Additional milestones met during the no cost extension period of July 30 – September 30:

A major breakthrough was the installation of dedicated telemetry capabilities using directional antennas feeding directly to the facilities of a local marine communication company (Schafer & Brown electronics Inc.). This has freed the project from the vagaries of monthly fees paid through UPRM to AT&T using cellular modems.

Unanticipated problems: Heavy surf at the Mojacasabe site resulted in a short circuit and burnout of the Tx unit at Mojacasabe. Extended repair time at CODAR, and evolving priorities with the Mona Passage experiment taking on greater relevance, resulted in abandonment of this site.
1. Overview

The Year 6 effort presented in the current report seeks to further increase our understanding of the various threat signatures in different environments, and use this understanding to further the improvement of signal processing to provide longer detection distances, more accurate localization and reliable classification. The presented report includes description of Stevens acoustic signatures library collected by CSR and algorithms for acoustic signatures features extraction. The extracted features are used for surface vessel classification. The new algorithm for acoustic signature detection based on analysis of coupled harmonics (Harmonic Line Association) was developed and investigated.

In addition, the CSR team investigated and fused new information from all varieties of sensors (acoustic, radar, and day/night cameras), maritime waterway databases, weather and tidal data, and other governmental and commercial data for persistent water side surveillance. We have developed software for pointing and zooming of optical camera to the acoustically, radar or AIS selected target.

The developed passive acoustic methods of surveillance have been implemented in portable acoustic recorders. This system was applied to monitoring of security zones around the Verrazano Bridge. It was also used for the recording of illegal activities that may occur near the shore. The latter tests, focused on the needs of CBP and ICE, were conducted at the California shore.
2. Collection of acoustic signatures library

Since the multiplicity of systems used in this experiment make for a complex user interface, work was begun on an integrating system which would display all systems simultaneously, and allow the user to select the subscreen of most interest. The SPADES system position together with bearing to an acoustic target is shown in Figure 2.1.

A lot of acoustic signatures together with optical, radar, infrared images and AIS data have been collected in the Hudson River this year. Figure 2.2 below shows the situation when many ships were presented.
Students from Stevens Summer Research Institute organized a detailed library of acoustic signatures of chosen vessels. By using the various MSL capabilities, the students carefully searched for clean acoustic signals, signals that are unaltered by interference or external noise that may distort the signature behavior of the vessel. These samples were then analyzed, categorized and entered into a database that can be accessed by maritime security personnel to determine what type of vessel is passing even when it cannot be seen by the naked eye or with visible light cameras. The results of this data collection, which include the acoustic signatures both raw and processed, and video, photographic, and infrared images, are stored in a data base, referred to as the Acoustic Library. Different parameters and valuable information are obtained from the processed signals, such as spectrograms, DEMON signatures, high quality videos, photo and infrared images and sound files. This Library allows for further research and analysis. Figure 2.3 shows the example of the data in the library.
3. Passive Acoustic Feature Extraction and Classification

3.1 Introduction:
One of the foremost concerns for maritime law enforcement is the current lack of reliable methods for detecting, and tracking the activity of small vessels. Such vessels are not required to emit Automatic Vessel Identification System (AIS) information, and are often too small to be tracked by marine radar. The only reliable methods of monitoring these vessels are eyes on observation, and observation through electro-optical cameras. Both of these techniques require personnel to be tasked to monitor continuously [1]. This makes monitoring small vessel traffic extremely resource intensive, and a significant gap in maritime domain awareness. Potential threats from small vessel range from the extreme, such as drug smuggling and terrorist attacks, to the mundane occurrence of recreational boaters venturing into areas they do not belong. Despite programs like the United States Coast Guard's (USCG) Operation Clear Channel collisions between large commercial
vessels and pleasure craft improperly operating in shipping channels are common events [2].
The threats posed by small vessels are further complicated by their popularity. In 2010 there were approximately 11.1 million small vessels registered in the United States alone. Most of these vessels are intended for recreation. In addition to being able to detect track and identify these ubiquitous vessels it is important to develop a capacity to determine whether they are engaged in suspicious behavior. Determining the intent of small vessels via technology is a key point in the Department of Homeland Security's 2011 Small Vessel Security Strategy [3].

Passive acoustic detection technology offers the ability to track these small vessel, and any other vessel generating sound on or under the water. Passive acoustics operate by detecting and analyzing the sound energy generated by objects in the surrounding environment. Using well established signal processing techniques passive acoustic technology can be used to automatically detect and track vessels in the maritime domain. Using advanced knowledge of the physics underlying vessel sound generation it is also possible for a skilled operator to identify the type of vessel responsible for a particular sound [4].

The level of skill required to make this classification is beyond the budget of most maritime law enforcement organizations. Prior to the adaptation of passive acoustics for maritime security purposes it is essential that the process of vessel classification be automated. This will likely be achieved through the application of machine learning algorithms to vessel signature data. Machine learning algorithms are a family of algorithms used to generate mathematical models to predict the identity of unknown data based on information about prior, data with known identities. Machine learning algorithms have been used in speech recognition, image recognition, and search engine web sites. Several studies have suggested that there is potential for their successful application to automatic classification of vessels based on passive acoustic data.

In order to facilitate this work an experiment was undertaken on a freshwater lake in New Jersey. Four common types of vessel were recorded under a range of operating conditions. The goal of this experiment was to collect data to support development of a prototype system for automatically classifying vessels based on their passive acoustic signatures. Details of this experiment are discussed in chapter 2.5 of this report. The acoustic signals of several small vessels were recorded while operating under a wide range of speeds, loads, and at varying distance in order to fully capture the acoustic characteristics of each vessel. From the data collected in this experiment four vessels, of particular interest to law enforcement were selected for classification analysis. These vessels were two common speed boats (blue chaser, and white whale), of the kind often sold for recreation, a jet ski, and a panga. Images of all three vessels are shown in Figure 2.15. Pangas are a type of fishing boat popular along the Pacific coast of central American and in the Caribbean. In addition to their legitimate use for fishing and transportation pangas are very popular among smugglers. Due to their high speed and low profile in the water pangas are difficult to detect and difficult to interdict, and are of special interest to law enforcement. Jet skis present a similar challenge to pangas in that
they are fast, maneuverable, and difficult to detect on radar. Furthermore, jet skis are ubiquitous throughout the United States and Caribbean, and can be difficult to spot even when they are within visual range of an observer. The remaining two vessels are representative of the type of small outboard pleasure boats found in nearly all North American water ways. In addition to being able to detect and identify these vessels it is important to be able to distinguish them from the panga which is quite similar in configuration but is used prolifically in illegal smuggling operations.

3.2. Feature Extraction

Acoustic recordings were made using the SPADES system developed at Stevens. Data from four hydrophones were sampled in 16 bit at 200 kHz. Detailed records of vessel operating characteristics were kept throughout the experiment and were used to select optimal time periods to use for classification work. The raw acoustic data from a single hydrophone was processed using several methods as explained below. Special care was taken to use only the best data with high ratios of vessel signal to noise.

3.2.1 Spectrum

The frequency spectrum is a fundamental piece of information used for vessel classification [4]. The spectrum is calculated by taking the Fourier transform of a discrete time signal. Figure 3.1. shows a block diagram of the frequency spectrum calculation used in this analysis:
First the signal is low pass filtered to 1 kHz to prevent aliasing and down-sampled to 2 kHz. The signal is then passed through a Hanning window of length 2048 samples with 1024 samples overlap. The FFT of the signal is taken and the square of the absolute value computed to determine the frequency spectrum.

A vessel emits sound into the water at specific frequencies which are characteristic of that vessel. Many of these frequencies will appear as a sequence of harmonic peaks. Harmonic peaks are integer multiples of some base or “fundamental” frequency. Figure 3.2 shows an example frequency spectrum. Note the fundamental frequency circled in red and the following harmonic peaks circled in green.
The position of the harmonic peaks must be an integer multiple of the fundamental frequency. It is therefore less important to know their location than it is to know magnitude. The design and configuration of a vessel will have a significant impact on which peaks are emphasized and which are suppressed. In the case of Figure 3.2 the harmonics are all apparent but this is not always the case. For this reason the magnitudes of the fundamental frequency peak, and the magnitude of the spectrum at the estimated location of the first two harmonics have been used as features for classification in our analysis. Additionally the location of the maximum frequency spectrum peak has been included as a feature. In order to determine the values of these features the average spectrum of a 10 second time span was taken from a period with good signal characteristics: low noise, and prominent harmonic peaks.

### 3.2.2 Detection of Modulation on Noise (DEMON)

As a propeller rotates in the water tiny bubbles form along its low pressure edge in a process called cavitation. These bubbles generate broad band high frequency noise as they expand and collapse. This high frequency noise is modulated in amplitude by the rotation of the propeller [5]. The frequencies of modulation can be extracted using the DEMON algorithm. The block diagram in Figure 3.3 shows the steps of the DEMON algorithm.
First the signal is band pass filtered with pass band 40 kHz-55 kHz. The root of the square of each sample is taken and the signal is down-sampled to 1 kHz. The mean is then subtracted from the down-sampled signal. The signal is passed to a Hanning window of length 2048 samples with 1024 samples overlap. The DEMON spectrum is then found by taking the square of the absolute value of the FFT of the signal.

The information contained in the DEMON spectrum is related to the propeller rotations, number of propeller blades. This method is of great importance in shallow water applications of passive acoustics. The low frequency band in which vessels generate sound often contains high levels of noise. Additionally low frequency sound like that produced by most vessels does not propagate far in shallow water. By demodulating the high frequency cavitation sound which does propagate, and exists in a frequency band with lower ambient noise it is possible to retrieve the low frequency sound characteristics of the vessel in particular the fundamental frequencies of the DEMON spectrum and the frequency spectrum are closely related [6].
A sample DEMON spectrum is shown in Figure 4 this spectrum was produced using the same raw data as Figure 3.2. Note the prominent peak at or 20 Hz. DEMON spectra also generally have a higher ratio of signal to noise compared to frequency spectra. For this analysis the location of the fundamental frequency, and the magnitude of the spectrum at the fundamental and its first two harmonics were taken as features for classification. Additionally the location of the maximum DEMON spectrum peak has been included as a feature. In order to determine the values of these features the average spectrum of 10 second time spans were taken from time periods with good signal characteristics: low noise, and prominent harmonic peaks.

Figure 3.4: DEMON Spectrum generated from same data as Figure 2.

3.2.3 Cepstrum
Harmonic peaks are found to recur at intervals equal to the fundamental frequency. Cepstrum determines the period of repetition of peaks in the frequency spectrum or quefrequence. This is particularly useful in cases where the harmonic peaks may be obscured by ambient noise which occurs at more random intervals. Peaks in the cepstrum spectrum correspond to the repetition frequency of signal frequency peaks in the spectrum. The Cepstrum algorithm is shown in Figure 3.5:
Cepstrum can be calculated for both frequency and DEMON spectra. First the signal is converted to decibels and normalized by subtracting the mean. Then the squared absolute value of the FFT is taken. The result is the Cepstrum spectrum [7]. An example Cepstrum spectrum shown in Figure 3.6. This spectrum was calculated from the frequency spectrum shown in Figure 3.2. Note the Cepstrum peak at quefrequency \( q = 0.05 \) corresponds to a frequency of \( 1/q \) or \( \sim 20 \) Hz. This can be verified from the spacing between peaks in Figure 3.2.
Figure 3.6: Example Cepstrum spectrum. Quefrequency shown on the x-axis in seconds, magnitude on the y-axis. Note prominent peak at .05 or 20Hz corresponding to the fundamental frequency shown in Figure 2.

The maximum value of the Cepstrum of the DEMON and frequency spectra have been included in the feature set for this analysis. Additionally the Cepstrum of both spectra has been used to determine their fundamental frequencies.

3.2.4 Fundamental Frequencies Algorithm:
Up to this point we have discussed the value of determining the fundamental frequency but have not demonstrated a method to reliably automatically do so. This is a key problem for the process of feature extraction. Often the fundamental frequency may be obscured in the Frequency or DEMON spectra, and many peaks may occur in the Cepstrum corresponding to different multiples of the fundamental period. Often the fundamental frequency may be readily determined by the human eye much more easily than it may be determined by computation. Since the overall goal of this research is an automated vessel detection algorithm it was crucial that determination of the fundamental frequency be automated. The following aspects were determined to be essential to determining the peak which was the fundamental frequency [4]:

• It should be a peak in both the Spectrum and its Cepstrum.
• It should be a factor of many significant peaks in the frequency or DEMON spectrum and have few if any peaks which are a factor of it.
• In the Cepstrum spectrum it should be part of a family of peaks which are factors of each other or have each other as factors (“factor family”)
• It should be a local maximum within a frequency band of some width

Based on these constraints the following algorithm was developed to determine the location of the fundamental frequency as shown in Figure 3.7:
The factor family step in the fundamental frequency determination algorithm is simply process for determining whether one of two peaks is a factor of the other. If the peak under examination is a factor of the other peak a value of 1 is returned. If the other peak is a factor of the peak under examination a value of minus one is returned. If there is no relationship between the two peaks a value of 0 is returned. An error tolerance of 1Hz is allowed to account for slight variations in peak location caused by noise. A block diagram of the factor family algorithm may be seen in Figure 3.8.
The factor family output is an indexed list of which peaks in a spectrum each peak is related to. To determine the likely fundamental frequency in the spectrum we simply take the sum of the factor list for each peak. The greatest value will be the peak which is a factor of the most other peaks and has the least number of peaks that are factors of it. In order to determine how related a peak is in the Cepstrum spectrum the peak locations are first converted from period to their reciprocal frequency. The factor family of each peak is then taken and the number of non-zero values counted for each peak. Peaks in the Cepstrum with no relation to other peaks are then discarded as being the result of noise. The final step in the determination of the fundamental frequency is determining the Cepstrum peak which most closely matches the likely fundamental identified in the spectrum. The Cepstrum peak location is a more reliable indication of fundamental frequency because it represents the period of repetition of multiple peaks in the spectrum and is thus more robust variations in peak location due to noise. In order to accomplish this matching between Cepstrum and spectrum, a peak gravity term has been introduced:

$$G = \frac{Me_{cep}M_{spec}}{r^N}$$

Where $r$ is the distance between the frequency of the Cepstrum peak and the likely fundamental frequency from the spectrum (in Hz). $N=1,2$ depending on the signal to noise ratio of the Cepstrum spectrum. $Me_{cep}$ is the magnitude of the Cepstrum peak relative to the threshold specified earlier, and $M_{spec}$ is the magnitude of the spectrum at the frequency of the Cepstrum peak. Figure 3.9 shows a block diagram of the Cepstrum peak gravity algorithm.
The Cepstrum peak which returns the highest value of G is considered to correspond to the location of the fundamental frequency. Once the fundamental frequency of a spectrum is determined the features discussed in previous sections can be extracted based on the location of the fundamental frequency. Figure 3.10 shows the results of the algorithm in the frequency spectrum and Cepstrum from Figure 3.2. Figure 3.11 shows the results of the algorithm in the DEMON spectrum and Cepstrum from Figure 3.4. Note the agreement between Figures 3.10 and 3.11 regarding the location of the fundamental frequency.
Figure 3.10: Figure displaying results of fundamental frequency detection algorithm on data from Figure 3.2. The normalized frequency Spectrum is displayed in the upper plot and its Cepstrum spectrum is displayed in the lower plot. The vertical red lines denote the location the algorithm has determined for the fundamental frequency/period. Vertical black lines in the frequency spectrum denote the anticipated location of harmonics.

Figure 3.11: Figure displaying results of fundamental frequency detection algorithm on data from Figure 3.4. The normalized DEMON Spectrum is displayed in the upper plot and its Cepstrum spectrum is displayed in the lower plot. The vertical red lines denote the location the algorithm has determined for the
3.2.5 Estimated Error Rate:
Visual inspection of plots to affirm accurate fundamental frequency location determined that there was an error rate of approximately 20% for both frequency and DEMON spectra. In most cases where results from one spectrum were bad, results from other were good. Figure 3.12 shows an example of a frequency spectrum in which the fundamental frequency was incorrectly determined. Figure 3.13 shows the corresponding DEMON spectrum in which the fundamental frequency was determined correctly.

Figure 3.12: Figure displaying results of fundamental frequency detection algorithm on frequency spectrum data for which the fundamental frequency was not correctly identified. The normalized frequency Spectrum is displayed in the upper plot and its Cepstrum spectrum is displayed in the lower plot. The vertical red lines denote the location the algorithm has determined for the fundamental frequency/period.
Figure 3.13: Figure displaying results of fundamental frequency detection algorithm on DEMON spectrum from same time as Figure 3.12 for which the fundamental frequency was correctly identified. The normalized frequency Spectrum is displayed in the upper plot and its Cepstrum spectrum is displayed in the lower plot. The vertical red lines denote the location the algorithm has determined for the fundamental frequency/period.

Since it was found that the majority of samples contained reliable features from either the frequency or DEMON spectrum it was decided not to remove samples which might have contained some bad data.

3.2.6 Feature Statistics:
Due to the errors described above, and the decision not to clean the data sets, the mean values of the various features are an unreliable statistic for examining the behavior of the features over a range of vessel conditions. This is particularly true for features like the fundamental frequency since, when incorrectly determined, it tended to be much higher than the true value. In order to examine the behavior of the features under various conditions it was determined that the mode of frequency value features was a more representative statistic. The following tables show the modes of the frequency related features: DEMON fundamental period (ffd), DEMON cepstrum maximum (cdmax), DEMON spectrum maximum (dmax), frequency spectrum fundamental frequency (ff), frequency spectrum cepstrum maximum (cmax), and frequency spectrum maximum (smax). Where multiple modes are present an extra row has been include, if no mode was found for a feature the corresponding cell was left blank. Data shown is for the panga vessel only.
Table 3.1: Values of feature mode for frequency related features taken for panga vessel under different loading conditions

<table>
<thead>
<tr>
<th>Vessel Load</th>
<th>ffd</th>
<th>cmax</th>
<th>dmax</th>
<th>ff</th>
<th>cmax</th>
<th>smax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>0.031969</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
<tr>
<td>Heavy (without 2 barrels)</td>
<td>0.031969</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
<tr>
<td>Light</td>
<td>0.031969</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
</tbody>
</table>

Table 3.2: Values of feature mode for frequency related features taken for panga vessel operating at various engine rpm.

<table>
<thead>
<tr>
<th>Engine RPM</th>
<th>ffd</th>
<th>cmax</th>
<th>dmax</th>
<th>ff</th>
<th>cmax</th>
<th>smax</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>0.031969</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
<tr>
<td>3200</td>
<td>0.077924</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
<tr>
<td>3550</td>
<td>0.099902</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
<tr>
<td>3600</td>
<td>0.015984</td>
<td>0.011988</td>
<td>58.88097</td>
<td>0.015984</td>
<td>0.010989</td>
<td>121.3305</td>
</tr>
<tr>
<td>5000</td>
<td>0.15385</td>
<td>0.011988</td>
<td>45.49893</td>
<td>0.023977</td>
<td>0.011988</td>
<td>166.8294</td>
</tr>
</tbody>
</table>

Table 3.3: Values of feature mode for frequency related features taken for panga vessel operating at various speeds

In general modes could not be found for spectrum magnitude related features. This is likely due to constructive or destructive interference of environmental noise. For these features the mean values are shown in the tables below. Features shown are the magnitudes of the first three DEMON peak locations (df1, df2, df3) and the magnitudes of the first three frequency spectrum peak locations (f1, f2, f3).

Table 3.4: Values of feature mean for magnitude related features taken for panga vessel under different loading conditions

<table>
<thead>
<tr>
<th>Vessel Load</th>
<th>df1</th>
<th>df2</th>
<th>df3</th>
<th>f1</th>
<th>f2</th>
<th>f3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>3.005302</td>
<td>1.577869</td>
<td>1.083601</td>
<td>2.877756</td>
<td>1.359242</td>
<td>2.956665</td>
</tr>
<tr>
<td>Heavy (without 2 barrels)</td>
<td>3.279467</td>
<td>2.387891</td>
<td>0.794699</td>
<td>3.51681</td>
<td>0.338167</td>
<td>1.096522</td>
</tr>
</tbody>
</table>

Table 3.5: Values of feature mean for magnitude related features taken for panga vessel operating at various engine rpm

<table>
<thead>
<tr>
<th>Engine RPM</th>
<th>df1</th>
<th>df2</th>
<th>df3</th>
<th>f1</th>
<th>f2</th>
<th>f3</th>
</tr>
</thead>
<tbody>
<tr>
<td>3200</td>
<td>3.329628</td>
<td>2.617526</td>
<td>0.962921</td>
<td>7.397117</td>
<td>5.793703</td>
<td>3.702584</td>
</tr>
<tr>
<td>3550</td>
<td>3.189612</td>
<td>0.912632</td>
<td>1.152084</td>
<td>2.117613</td>
<td>0.500961</td>
<td>0.412671</td>
</tr>
<tr>
<td>3600</td>
<td>3.055866</td>
<td>2.056445</td>
<td>0.958828</td>
<td>3.19352</td>
<td>1.217699</td>
<td>2.96559</td>
</tr>
<tr>
<td>5000</td>
<td>3.180018</td>
<td>2.549873</td>
<td>1.395541</td>
<td>2.982913</td>
<td>0.734599</td>
<td>0.92219</td>
</tr>
</tbody>
</table>

93
3.3 Pre-Processing:

**Synthetic Minority Oversampling Technique:**
Under-representation of a particular class will result in poor classifier performance on that class. This is particularly important when one class has a very small number of samples compared to other classes. An imbalance in class representation in a data set may lead to a classifier which is biased against that particular class which will perform poorly. Out of 469 samples in the original data set only 28 are of the Jet Ski class, and only 42 are of the blue chaser vessel. It is clear that the Jet Ski and blue chaser are underrepresented compared to the other classes of vessel. Several methods exist for up-sampling minority classes. Synthetic Minority Oversampling Technique (SMOTE) is a widely used method for generating synthetic data points based on existing minority data. SMOTE develops synthetic data points by interpolating values at random distances between nearest neighbors in the feature space [8].

The size of the minority classes Jet Ski, and blue chaser were increased by 600% and 300% respectively, using SMOTE. The majority class panga was also randomly down sampled by 50% to create a more even distribution of samples across the vessel classes. This resulted in the data set described in the table below. Data not kept in the down sampling of the panga class was held in a separate data set to use in later testing.

<table>
<thead>
<tr>
<th>Vessel Speed (kts)</th>
<th>df1</th>
<th>df2</th>
<th>df3</th>
<th>f1</th>
<th>f2</th>
<th>f3</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>3.084472</td>
<td>1.811779</td>
<td>1.000166</td>
<td>3.062296</td>
<td>1.064386</td>
<td>2.419511</td>
</tr>
<tr>
<td>21.5</td>
<td>3.329628</td>
<td>2.617526</td>
<td>0.962921</td>
<td>7.397117</td>
<td>5.793703</td>
<td>3.702584</td>
</tr>
<tr>
<td>34</td>
<td>3.180018</td>
<td>2.549873</td>
<td>1.395541</td>
<td>2.982913</td>
<td>0.734599</td>
<td>0.902219</td>
</tr>
</tbody>
</table>

*Table 3.6: Values of feature mean for magnitude related features taken for panga vessel operating at various speeds*

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Original Data Set</th>
<th>After SMOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet Ski</td>
<td>24</td>
<td>144</td>
</tr>
<tr>
<td>Panga</td>
<td>281</td>
<td>140</td>
</tr>
<tr>
<td>Blue Chaser</td>
<td>42</td>
<td>126</td>
</tr>
<tr>
<td>White Whale</td>
<td>122</td>
<td>122</td>
</tr>
<tr>
<td>Total</td>
<td>469</td>
<td>532</td>
</tr>
</tbody>
</table>

*Table 3.7: Data Set Composition before and after application of SMOTE and down sampling to balance class populations.*

**Training and Testing Data Sets:**

In order to provide for both training and testing of classification and dimension reduction methods the new data set was randomly separated into a training data set and a testing data set. 2/3 of the data set was used to construct the training set and the remaining 1/3 was used in the test set. The table below shows the distribution of samples in each data set by vessel type. Additionally the pangas only data set is show.
Table 3.8: Data set composition by vessel class.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Training Data</th>
<th>Test Data</th>
<th>Pangas Only Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>panga</td>
<td>93</td>
<td>47</td>
<td>141</td>
</tr>
<tr>
<td>jet ski</td>
<td>92</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>blue chaser</td>
<td>88</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>white whale</td>
<td>81</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>354</td>
<td>178</td>
<td>141</td>
</tr>
</tbody>
</table>

3.4 Dimension Reduction:

For most machine learning algorithms the computational cost of training increases with the number of features (dimensions) used. For this reason it is often desirable to reduce the number of dimensions into a smaller set which preserves the maximum amount of information. Additionally many dimension reduction algorithms had the benefit of representing data in dimensions which may be more advantageous for classification as will be shown shortly. Several techniques exist to accomplish this task. Two methods are demonstrated in this paper: Principle Component Analysis (PCA), and Linear Discriminate Analysis (LDA).

3.4.1 Principle Component Analysis:

PCA is a method of dimension reduction which returns the data in the dimensions which represent the maximum amount of variance. That is to say, the first principle component will be the dimension that represents the largest portion of the variance, the second principle component the second largest variance and so on. An illustration of this principle may be seen in Figure 3.14.

![Figure 3.14: Illustration of PCA algorithm showing original data to left with Principal Components shown as dashed lines. Data after rotation shown to right.](image)

Note x and y, the original dimensions, and x’ and y’ the principal components of the data set. It is clear that the variance of the data along x’ is much greater than the variance along y’, x, or y. In the left hand image, the data set has been transformed from its original coordinates in the x and y dimensions to its coordinates in the x’ and y’
Dimension reduction is accomplished by simply leaving out the principle components which do not represent a significant proportion of the total variance. In order to determine the principal components the Eigenvectors of the covariance matrix are taken and placed in descending order according to their corresponding Eigenvalue. The Eigenvalues are proportional to the total variance represented by each Eigenvector. The Eigenvectors with sufficiently high Eigenvalues are then combined into the principal component matrix. The data may then be transformed into the principal component dimensions by taking the product of the data set and the principal component matrix. It should be noted that at no point in PCA is classification of the data taken into account. PCA looks only at the total variance within the data set. For this reason the resulting dimensions may not represent the data in a way that is optimal for classification [9].

Principal component analysis was run on the training data set and the resulting principal components were used to reduce the dimensions of the training, test, and pangas data sets. It was found that 99.9% of the total variance in the data set could be represented by the first two principal components. Figure 3.15 shows a bar graph of the percent of the variance explained by each principal component:

![Figure 3.15: Percent variance explained by each principal component in descending order. Note >90% of total variance explained by first two components.](image)

Each data set was therefore transformed into these two principal components for use in classification. The resulting data sets have been shown in the scatter plot in Figure 3.16. Each sample has been colored according to its corresponding vessel type in order to show how the principle component analysis separates the data.
It is clear from visual observation that the resulting data is poorly separated in these dimensions. Classification results of this data set will be shown in a later section.

3.4.2. Linear Discriminant Analysis:
As we have seen PCA does not always represent the data in dimensions optimal for classification. LDA is an algorithm which seeks to do just this by representing the data in dimensions which provide the greatest separation between different classes. This concept is illustrated in Figure 3.17 where a two class data set is shown in dimensions x and y. LDA identifies the single dimension which best separates the two classes: \(x'\). The data is then projected into this single dimension where the separation between the two classes is clear. The dimensions that best separate the data are determined in similar fashion to principle components. First the weighted sum of covariance matrices of the individual classes is taken, this is the within class scatter matrix \(S_W\). can be thought of as a measure of how tightly clustered the samples of the individual classes are. is then subtracted from the covariance matrix of the total data set to find the between class scatter matrix \(S_B\). represents the variance between the individual classes in the data set. Finally the product of the matrix inverse of \(S_B\) and \(S_W\) is found, and its eigenvectors and eigenvalues are determined. From this point the LDA proceeds in much the same manner as PCA: the eigenvectors are sorted according to the magnitude of their eigenvalue. The only difference is that rather than choosing a number of eigenvectors to keep according to the percent of the variance represented, in LDA the number of eigenvectors retained is generally one less than the number of classes in the data set [9].
Figure 3.17: Illustration of LDA. Original data shown on left with linear discriminate drawn as a dashed line. Data after transformation shown on the right. Note class separation in single dimension as opposed to two in original data.

LDA was applied to the three original data sets: train, test, and pangas. The resulting data set consisted of three dimensions, scatter plots of which may be seen in Figures 3.18 and 3.19. Note that the different vessel types are much better separated in these plots than was seen in Figure 3.16 for the PCA data.

Figure 3.18: Scatter plot of first two dimensions determined by LDA. Data points color coded by vessel type. Note class separation of Jet ski and blue chaser.
3.4.3 Normalization:
Many classification techniques require that data be normalized prior to input. This entails subtraction of the sample mean and division by the sample standard deviation of each feature. This is done to ensure that features with different measurement scales do not receive undue weight in classifier training. Normalization is typically carried out after statistical analysis since, by its nature, normalization obscures the original statistical characteristics of the data.

3.5 Machine Learning Classification:

3.5.1 Support Vector Machines:
Support Vector Machines (SVM)’s are a family of linear classifiers first proposed by Vapnick in 1992. They have gained popularity in recent years due to their ability to provide good classification on noisy data sets. The application of SVMs to classification problems in passive acoustics has been demonstrated for land vehicles [10] and vessels [11]. In general SVM’s operate by determining a boundary which maximizes the distance between the boundary and representatives of either of two classes. This boundary (referred to as a margin), and the decision boundary are defined by the data points that sit along the edge of the margin. These points are called support vectors and are retained for classification. An illustration of this process may be seen in Figure 3.20.
This approach works well in theory unless the classes in a data set are not linearly separable. SVM solves this problem through kernel methods: by projecting the data to a large number of new dimensions it is often possible to achieve linear separation of the data classes. Several kernel functions exist for this purpose, each is best suited for different types of data. Three of the most common are linear functions, polynomials (Poly), and the radial basis function (RBF) [12]. SVM’s based on each of these three kernels were evaluated using the data sets developed by PCA and LDA. In total 6 different combinations of dimension reduction and SVM classifier were evaluated.
3.6 Results:

### 3.6.1 Comparison of Classifiers

A comparison of all three SVM kernel functions on the PCA and LDA data sets was conducted. The results of this analysis may be seen in Tables 3.9 and 3.10.

#### Table 3.9: Accuracy of SVM classifiers with different kernel functions in prediction of training, test, and pangas data sets using PCA data.

<table>
<thead>
<tr>
<th>Classifier</th>
<th>Train</th>
<th>Test</th>
<th>Pangas</th>
</tr>
</thead>
<tbody>
<tr>
<td>linear</td>
<td>63.6%</td>
<td>62.9%</td>
<td>91.5%</td>
</tr>
<tr>
<td>poly</td>
<td>51.7%</td>
<td>56.2%</td>
<td>31.9%</td>
</tr>
<tr>
<td>rbf</td>
<td>66.7%</td>
<td>64.0%</td>
<td>76.6%</td>
</tr>
</tbody>
</table>

In table 3.9 we see that the classifiers have performed relatively poorly on all three data sets (with the exception of the linear kernel SVM on the pangas data set). The RBF kernel SVM has performed better than the linear and polynomial kernels on both the training and test set though only marginally so.

#### Table 3.10: Accuracy of SVM classifiers with different kernel functions in prediction of training, test, and pangas data sets using LDA data.

<table>
<thead>
<tr>
<th>Classifier</th>
<th>Train</th>
<th>Test</th>
<th>Pangas</th>
</tr>
</thead>
<tbody>
<tr>
<td>linear</td>
<td>83.6%</td>
<td>84.3%</td>
<td>74.5%</td>
</tr>
<tr>
<td>poly</td>
<td>85.9%</td>
<td>82.6%</td>
<td>85.1%</td>
</tr>
<tr>
<td>rbf</td>
<td>89.3%</td>
<td>86.0%</td>
<td>83.0%</td>
</tr>
</tbody>
</table>

Examination of Table 3.10 shows that all SVMs of each of the three kernel types have performed uniformly better in classifying all three of the LDA data sets. Again we see that the RBF kernel has performed marginally better than the linear and Poly kernel on the training and test data sets. Without further research it is not possible to say how significant this difference in accuracy is. However based on this analysis it appears that the RBF kernel SVM achieves the best results in general classification.

### 3.6.2 Comparison of PCA and LDA:

Looking at Tables 3.9 and 3.10 the difference in performance between the PCA, and LDA data sets is very apparent. It is clear that the PCA data set does not lend itself to producing classifiers with good accuracy in prediction. To determine the nature of this failure we look to 3.11.
Table 3.11: Vessel class prediction accuracy of RBF kernel SVM for PCA data set.

Here we see that the RBF classifier has performed relatively well at predicting the Jet Ski class vessel and quite poorly at predicting the other three classes of vessel. Recalling Figure 3.16 it is not difficult to see why this would be the case. Jet Ski samples are tightly clustered with relatively little overlap from other classes meanwhile the remaining three classes of vessel all overlap each other significantly. This is not the case in the LDA data sets where the vessel classes were better separated. The result is a classifier with a more uniform ability to predict each vessel class and better accuracy overall as shown by Table 3.12.

Table 3.12: Vessel class prediction accuracy of RBF kernel SVM for LDA data set.

Figure 3.21 confirms the analysis of results from the classifiers trained and tested on the PCA data set. Here we see correct classifications scatter plotted as x’s and incorrect classifications scatter plotted as o’s. Both markers are color coded by vessel. It is obvious that the classifier has associated distinct regions with each vessel class. Unfortunately, due to the poor separation of the classes in the PCA data set, many samples from other classes fall within these regions and are therefore misclassified.
Figure 3.21: PCA test data set showing correctly classified (x) and mis-classified (o) data points color coded by vessel type. Note large number of mis-classified samples throughout feature space due to poor class separation.

Figure 3.22 shows the same plot for the LDA data set. Here we see again that the classifier has identified distinct regions corresponding to each class. In this case there is relatively little overlap between the classes and only a handful of samples near the boundaries of these regions, or outliers altogether, are misclassified.

3.6.3 Classification of SMOTE Data vs. Original Data:
When working with synthetic data it is important to verify that the synthetic data is being classified accurately at a similar rate to the original data. Put simply it must be made certain that the synthetic data is not making classification significantly easier or harder.
Table 3.24 shows a comparison of the classification error rates and accuracy for synthetic and original data. It is clear from this table that the synthetic data is behaving similarly to the original data in classification. For the purpose of this analysis there appears to be no significant difference between the two data types.

Table 3.24: Comparison of classification error between synthetic and original data using results from RBF SVM with LDA data sets.

<table>
<thead>
<tr>
<th>Data</th>
<th>TRUE</th>
<th>FALSE</th>
<th>Totals</th>
<th>Percent Incorrect</th>
<th>Percent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMOTE</td>
<td>57</td>
<td>8</td>
<td>65</td>
<td>12.3</td>
<td>87.7</td>
</tr>
<tr>
<td>Original</td>
<td>96</td>
<td>17</td>
<td>113</td>
<td>15.0</td>
<td>85.0</td>
</tr>
</tbody>
</table>

3.6.4 Classification Accuracy by Vessel Type:

A final step in the analysis of classification results is to determine whether there is any significant pattern in the mis-classification of any of the vessel classes. For instance if the classifier predicts one vessel significantly more than the others it may be evidence that the classifier is biased towards that vessel and must be adjusted to improve results. If two vessels are consistently mis-classified as each other it may indicate that they are not separable with the features used in the classifier. It may also indicate that these two classes are too closely related to be reliably distinguished and should be considered to belong to the same class.

Table 3.25 shows the confusion matrix of the RBF kernel SVM on the LDA test data set. A confusion matrix is a grid with the correct vessel class indicated in the left hand column, and the class samples were classified indicated in the top row. Cells representing correct classifications are found on the diagonal and have been shaded green for clarity. Table 3.26 shows the confusion matrix of the same classifier operating on the panga only data set.

Table 3.25: Confusion matrix for LDA test data with RBF kernel SVM. Correct class shown on vertical, class predicted shown on Horizontal. False positives below the diagonal, False negatives above the diagonal.

Table 3.26: Confusion matrix for LDA panga data with RBF kernel SVM. Correct class shown on vertical, class predicted shown on Horizontal. False positives below the diagonal, False negatives above the diagonal.

Based on the data in Tables 3.25 and 3.26 it seems that the RBF SVM classifier has achieved good general classification with the LDA data sets. It appears that the classifier has a slight tendency to mis-classify the panga as the blue chaser. This is to be expected.
based on the observed overlap between the two classes, however it is not so significant as to justify grouping the two vessels together or including additional features in the analysis.

3.7 Conclusion:

This report has outlined a successful prototype process for automatically distinguishing between several vessel types of specific interest to maritime law enforcement. This process relies on passive acoustic technology and as such overcomes many of the limitations of existing technologies for detecting and identifying small vessels. Through this analysis several conclusions relevant to further research into the development of this tool have been made:

The combination of a spectrum and its Cepstrum may be used to reliably automatically extract the fundamental frequency and harmonic peak magnitudes of the spectrum. These features may be extracted from both the frequency and DEMON spectrum with 20% error rate. These errors may not occur in the DEMON and frequency spectrum from the same time period and so are not fatal to the extraction of useful information. These features in combination with the maximum of the DEMON and frequency spectrum and the maximum of their respective cepstrum have been shown to be useful for vessel classification over a wide range of vessel operating conditions.

In cases where a minority class is present synthetic oversampling has been demonstrated in conjunction with down sampling of the majority class. This was done to prevent classifier bias. The resulting synthetic data has been demonstrated to be classified at similar rates of accuracy to non-synthetic original data. This indicates that SMOTE may be useful in future applications for enabling the classification of vessels for which relatively little data exists. This should prove a valuable tool, particularly in the detection of smuggling vessels which may be heavily modified.

Two methods of dimension reduction have been evaluated using the same data set to determine whether either presents an advantage in application to vessel classification. The results show that LDA enables classification accuracy approximately 20%-25% greater than PCA. This is likely due to fundamental differences in the underlying dimensions the two methods extract from the data. In general it is recommended that future studies employ LDA, particularly when similar small vessels are to be classified.

SVM classifiers were evaluated using linear, Poly, and RBF kernels. It was found that the RBF kernel SVM performed generally better than the linear and Poly kernel SVM on both data sets. The RBF Kernel SVM also provided the best classification across each individual class. While important the difference in classification accuracy was not great enough to definitively determine whether the RBF kernel SVM has a significant advantage over the other two kernel types. Further analysis will be required to make this distinction.

Moving forward with development of the automatic vessel classification tool several steps are recommended. First the integration of an algorithm to automate the detection and selection of optimal raw data to be processed for classification. Efforts to develop
alternative feature extraction methods are discussed in the Chapter 4. Only one family of classifier has been evaluated in our analysis. While results from the SVM family of classifiers are very promising it will be necessary to evaluate many other families of classifier in order to determine which is best for the current vessel classification problem. It is also possible that an ensemble of different classifiers may be employed. Finally, as this prototype method is scaled up to include additional vessel classes it will be important to develop a method to reliably determine whether a new vessel should be grouped into an existing class of vessels, or represents its own unique vessel class.

4. Ship detection and classification based on harmonics line association method

4.1. Objectives

During the previous 4 years of CSR project Stevens advanced the development of algorithms of acoustic signal processing for ships detection, tracking and classification in harbor for use in the SPADES acoustic sonar system. In standard sonar signal processing target detection, tracking and classification are performed step by step in time: first the target get detected and tracked, and only then classification processing starts. Ships classification is based on the propeller-induced harmonics content in signal spectrum.

Let us define an acoustic surveillance system as a part of a harbor security system, which includes surveillance, decision making (should the target be considered as a threat to a valuable asset) and provide information for response. The following fig.4.1 is to explain how the surveillance system interacts with a whole security system.

![Fig.4.1. Surveillance-to-response interaction](image)

To understand how the whole system works in time and space, let’s suggest that the possible threat is a fast boat which is approaching the sonar from the long range. Then the boat is changing its course unexpectedly and starts heading toward some valuable asset (for example, a cruise ship terminal) which is close to the sonar. While the time counted from the first acoustic contact with the target is increasing, the distance from the target to the valuable asset is decreasing.
SPADES detection range for a fast boat is up to 20km in deep water but only about 1500m in a very shallow water. When the target is first detected, the sonar cannot tell what the target is. It cannot even tell it is really a boat.

If a potentially threat boat runs at 26 knots speed, the time between “target detected at 1500m range” and “threat boat reached its destination” is only 120 sec. In the above said “step-by-step” signal processing chain initial tracking and target classification usually takes about 20 sec (time to make sure we have a reliable track + time to detect time-frequency stable harmonics). Only then can the sonar tell a target’s type (class). From distance to asset point of view 20 sec at 26 knots speed means about 300m. This example shows that in the shallow water harbor time spent for signal processing is critical. If acoustic signal processing can provide a target classification at the same time that detection is made, that would improve the system performance by that amount and allow more time to intercept the target.

The following fig.4.2 illustrates the problems that make such algorithm improvement quite difficult. The image is a spectrogram (intensity vs frequency and time) of sound measured by one of the hydrophones of the SPADES system. Bright lines are propeller-induced harmonics – peaks in sound spectrum. The frequency of every harmonic varies with time because of Doppler Effect and also because of boat maneuvering. To classify the target, we need to detect harmonics in image. We need more than one harmonic detected to be able to prove that there is a group of harmonics and to evaluate the fundamental frequency (the first harmonic). Let us explain what this spectrogram image tells about the harmonics detectability.

When the target is too far from the sensor (zone C), all the harmonics are below noise level, and the target is undetectable. When the target is close to the sensor (zone A), many harmonics (bright parallel lines in spectrogram) are well above the noise level, and the target is not only detectable but also can be classified based on harmonics content. In zone B usually only one strongest harmonic survives a propagation loss in shallow water, so the target is barely detectable and cannot be classified.
There have been a number of scientific efforts to restore harmonics hidden in noise (see references [4]), but all the known results were able to restore lost harmonics in zone A, not in zone B. These are not really practical results, as in zone A the target can be classified even if only part of harmonics are present. During the 6th year of CSR project Stevens developed an algorithm which solved the problem for zone B and enabled the target classification in this zone.

4.2. Algorithm description

The algorithm consists of two parts. Part 1 aims to improve the signal Signal-to-Noise Ratio (SNR), which is significantly affected by the shallow water propagation. Part 2 is the harmonics line association algorithm.

Let us first explain part 1. In the case shown fig.4.2, the first harmonic (fundamental frequency) is about $f_0 = 90$Hz, and all the other harmonics have frequencies $f_m = m f_0$. It is clearly visible that the only harmonic which survived the propagation is the 3rd harmonic (270Hz). The reason why harmonics of order higher than 3 faded is the frequency-dependent attenuation is: the higher the frequency, the greater the attenuation is. The reason why the harmonics below 200Hz faded is more complicated. It is a modal type of propagation in shallow water [13]. For the frequencies less than 200Hz the wavelength is greater than 7m, which for the shallow harbor is greater than water depth at the shore slope where the sonar installed. When the water depth is less than half a wavelength, the sound cannot propagate in the water directly and it propagates mostly
though the bottom sediment (that type of propagation often referred to as "leaky modes"). Stevens experiments in Hudson River and Hopatcong Lake installation show that signal attenuation in such conditions is 20dB or more greater for frequencies below 200Hz than for frequencies 200 to 500Hz. It is difficult to measure that attenuation because of low frequency noise. Stevens developed an adaptive frequency equalization algorithm based on attenuation measurement via 2D smoothing of spectrogram (smoothing is used to eliminate the data masking by the noise).

Fig.4.3 shows an example of the algorithm results in case of NYPD fast boat in Hudson River, at about 700m distance from SPADES. The left panel is a 2D smoothed spectrogram, showing more than 20dB loss in frequencies below 200Hz compared to frequencies between 200 and 400Hz. The right panel show the spectrogram after adaptive equalization. One can see that harmonics below 200Hz became visible.

![Fig.4.3. Spectrogram of NYPD fast boat. Stevens experimental data, Hudson River.](image)

That makes signal better, but it is not enough to restore all the lost harmonics at distance about 1000 m or more.

Part 2 of our new algorithm aims to answer the question: if we see a single peak frequency component of a signal, is that frequency a harmonic of some unknown fundamental frequency? That algorithm is (similarly to known previous publications) is based on a multi-hypothesis detection test of signal cyclostationarity [14]. Briefly speaking, known cyclostationarity test algorithms are based on the following idea: if we suppose that the signal is a set of harmonics of fundamental frequency $f_0$, what would be a correlation between an observed signal and a model signal simulated from the $f_0$ hypothesis? A number of hypotheses are verified in parallel, and if for some value of $f_0$ the correlation coefficient exceeds a given threshold, than that hypothesis is accepted. This is a statistical criterion, which in fact does the time averaging of the above said correlation “similarity” between the observed and model signals.

Our approach is different and relies on the following key points:
1. Work individually with every time cross-section of the spectrogram, with no time averaging.
2. Add up the energy of hidden peaks and so associate it into total energy of the cyclostationary signal.

We proposed two different versions of the harmonics line association algorithm: The first version is based on a **hidden harmonics association**. If at a given time “\( t \)” any (with no thresholding) local frequency peak \( f_m \) is found, that peak conjectured to be a possible harmonic of the unknown fundamental frequency \( f_0 = f_m/n \). If any other peak (for the same “\( t \)” that satisfies that \( f_0 \) hypothesis found, its energy is added up to the energy of the original peak at \( f_m \). That gives us a total energy of the signal in “\( t \)” time slot of spectrogram. The number of possible hypotheses for \( f_0 \) is limited by the (experimentally known) minimal fundamental frequency for a given classes of boats. Frequency for the associated peaks search is limited by the (experimentally known) maximum detectable harmonics frequency in harbor acoustics propagation conditions. The following fig.4.4 shows an example result. Top panel (a) is a usual spectrogram, bottom panel (b) a spectrogram after the hidden harmonics association. White and red dots are the automatic detections provided by the Time-Frequency-Stable Peaks Detector developed by Stevens in scope of the previous CSR project years and improved during the Year 6.

![Fig.4.4. Scenario: Hopatcong Lake, jet ski. a) Stable peaks detected in original (equalized) spectrogram b) Stable peaks detected after hidden harmonics association](image)

Let us analyze how this version of the algorithm works.

1) It cannot tell a true fundamental frequency, because all the hypotheses considered equal.
2) It detects hidden harmonics. For example, in fig. 4.4(a) the true fundamental frequency $f_0 = 90\text{Hz}$ was detected up to 90s (500m from target). With associated harmonics detector it got detected up to 60s (1250m from target).

3) It also detects sub-harmonics – frequencies proportional to fractions of a fundamental frequency, like 135Hz which is $3f_0/2$. These tones really exist in propeller sound [15]. Sub-harmonic 135Hz got detected up to 30s (1625m from target).

4) It creates “salt and pepper” noise, visible between the found harmonics and sub-harmonics and below the true fundamental. That kind of noise is not a problem. It could be easily filtered out using image denoising processing [16].

5) It can detect the signal as “signal with harmonics, with fundamental frequency typical for the boat” within all the target ranges where initially we’ve been able to find only one tone. Therefore, the algorithm can provide the desired “pre-classification with first detection” feature.

6) It is still not a final classification into desired specific classes like “ferry”, “fast boat”, etc.

The second version of the algorithm is a **blind harmonics association**. It is based on the same idea of harmonics energy association, but the list of hypotheses to try is fixed. It is a list of frequencies $f_{0p}$ from suggested minimum to maximum possible fundamental frequencies for a given classes of boats, with frequency increment equal to the frequency resolution of spectrogram. As the length of hypotheses list is the same for every time slot $t$, it is sufficient to say that the blind harmonics association algorithm result is a nonlinear transform of the input spectrogram $I(t,f)$ into “fundamentalgram”:

$$E(t,f_{0p}) = \mathcal{H}I(t,f).$$

Fig. 4.5 shows an example result. Left panel (a) is the result of the above said nonlinear transform. Right panel (b) is the same image (just in different color map) with overlapped results of time-frequency stable peaks detection shown as dots.
Let us analyze how this version of algorithm works.

1) It enables detection of true fundamental frequency as the longest (in time) branch of harmonic lines up to the 30s (1625m).
2) It creates a lot of (shorter) false fundamental frequency lines.
3) To enable an automatic detection of the true fundamental frequency, we need an image processing which can dilate the detection points into uninterruptable curves, and then to select a longest one. That could be done by using the edge detection image processing.

4.3. Conclusions

- Algorithms have been developed for the harmonics line association, which enables a target classification at the very moment of first detection, e.g. at about 50% better range than traditional signal processing method. That substantially improves threat detection time and enables earlier response.

- Preliminary to harmonics line association and/or peak detection, it is useful to equalize a spectrogram using our new adaptive equalizer, in order to improve a harmonics-to-noise ratio.

- Two algorithms presented for harmonics line association are complementary. The first one detects harmonics and sub-harmonics at long range, but is unable to tell the true fundamental frequency. The second detects the true fundamental frequency at long range, but creates more false peaks. Both algorithms require an image post-processing, which is
quite straightforward and could be done by using well known image processing methods.

- The results achieved are new, as all the previously published algorithms were unable to restore harmonics hidden in noise at range to target where only one harmonic is detectable in the original spectrogram.
5. Tipping and queuing of data from several sensors. Camera guided by other sensors.

Stevens approach to persistent surveillance which includes detecting, tracking, and classifying small vessels addresses the maritime security vulnerability gap by improving the assessment of the risk posed by these vessels. In 2013/2014 we continued to investigate, research, and fuse new information from all varieties of sensors (acoustic, radar, and day/night cameras), maritime waterway databases, weather and tidal data, and other governmental and commercial data.

One of the ways for data fusion is application of passive acoustic for tipping and queuing of optical/IR cameras to acoustically detected targets. The pointing and zooming of the camera to the target allows more accurate target classification. The pointing and zooming a visual camera on a target was also conducted using information from AIS or radar. The software for pointing and zooming of optical camera to the acoustically detected targets was developed. We also developed software for detection of moving boats on the water surface.

It is well known that regular cameras can not have good resolution and large angle of view at the same time. With one camera we can either see a big picture but with little details, or if we want more details we have to narrow the angle of view and look at a small picture. However, when we look at the river with multiple vessels it is often equally important to see the whole river with all vessels and at the same time to see the details of a particular vessel.

To overcome such limitations, the video camera installed in Stevens Institute of Technology Maritime Security Laboratory (MSL) was paired with other sensors, such as underwater acoustical hydrophones, AIS (Automatic Identification System), and radars. All mentioned sensors provide us big picture of the whole region of interest with all vessels in it. Software that processes the data from the sensors picks up one vessel and provides its coordinates or bearing to the video camera. The video camera then programmatically turns towards the selected vessel, zooms in on it and follows its movements. At the same time, the video is recorded providing us a capability to analyze the images of the detected vessels in non real-time mode.

Results of camera guidance by underwater acoustics or AIS were presented in the CSR year 5 report. Those results have demonstrated the following capabilities of the software and hardware:

- Remote camera control;
- Accurate camera guidance towards a location determined by another sensor;
• Stable work of camera, acoustical sensors and AIS in different weather conditions.

Also a vast library of images of passing vessels was collected. Since then a new local AIS receiver with antenna and new radar were installed in MSL. AIS provides us completely reliable information about locally passing vessels in real-time without depending on any outside AIS data feed.

All sensors described above (acoustics, radar and AIS) have their limitations when we need to classify a detected object:

AIS has complete information about a vessel only when such a vessel carries an active AIS transmitter. However, if the AIS is not transmitting, or a vessel doesn’t have it, which is the case of many small and fast moving boats, then there is no information at all.

Acoustical sensors, microphones and hydrophones, provide some information about detected object. There are many works that try to extract meaningful signals from acquired sounds – with various level of success.

With radar we can only know if there is some object at a certain place – it will look like a spot on a map without any characteristics. Also radars may have false positives, reporting an object where there is a spurious reflection, waves or even nothing present.

Adding video capabilities to such sensors can greatly help in classification of detected objects, though it might not be fully automated at this time.

The two optical cameras were used in combination with radar and AIS. The specific different software was developed for these cameras.

5.1. Tipping and queuing software for Foscam FI8620

The camera that was mostly used in this project was Foscam FI8620 (Figure 5.1).
The Foscam FI8620 camera has remote Pan-Tilt-Zoom capabilities and can be controlled over the internet. It has 10 times optical zoom and provides medium-quality pictures sufficient to show all detected vessels, though without small details.

There are two ways of controlling this camera:

1. Move it left, right, up or down or
2. Specify several preset positions and move camera among these preset positions.

The first way is convenient if we just need to move the camera, but it has a drawback in that the camera will not know its own position and hence, will know only approximately where it is looking at. In this project it is important to point the camera as precisely as possible, so the second way of control was selected.

Foscam FI8620 has 16 possible presets. The whole angle of camera view was divided horizontally in 16 even smaller angles, and each small angle was assigned a preset camera location. Google Earth interface was used to show how the camera preset positions were chosen (Figure 5.2).

As it is shown on Figure 5.2, the whole angle of camera view is marked by two yellow pushpins, and white lines depict the edges of smaller angles. The point where all white lines intersect is the center of the camera's view.
lines intersect is where the camera was installed, on a patio of the MSL in Stevens Institute of Technology. Intermediate zoom was used for all presets.

A camera-guiding algorithm would then work as follows:

1. The camera-controlling software would expect latitude and longitude coordinates of a detected object. Such coordinates could be provided by another program that processes the data from acoustical sensors, AIS or radar. Manually specified coordinates would work as well.

2. As soon as the latitude and longitude coordinates are received, the software would analyze to which of the smaller angles of Figure 5.2 these coordinates belong.

3. Once the angle is found, the software sends a command to the camera to turn to the corresponding preset position.

Steps 1-3 are repeated while a vessel is present in the area of detection. If a vessel would pass by Stevens Institute of Technology and would be detected in all locations, then the camera would automatically follow it through all 16 presets.

Once the object is lost and no new coordinates are received for some time (e.g. 20 seconds), the camera would go to its central position and will wait there until it will receive the new coordinates.

Some examples of vessels detected by radar and tracked by video camera are shown on Figure 5.3. There were many detected and recorded vessels during the tests in MSL and the whole collection of the images of such vessels is quite large. It includes ferries of all kinds typical for Hudson River estuary, tug boats, cruise ships, sail boats, various go-fast boat, barges and other kinds of ships. The recordings were also done during different times of day and night and in different light and weather conditions.

The vessels are sometimes not central in the pictures because the camera only had 16 preset positions, and the vessel could be anywhere within the preset angle.
Of particular interest in vessels detection is the detection of small fast moving vessels. Despite the possible radar difficulties in detecting such vessels, in many cases they were still detected and followed by the video camera (Figure 5.4).
5.2. Software for Canon VB-H41.

To address the low resolution and limited positioning capabilities of Foscam FI8620 another camera, Canon VB-H41 (Figure 5.5) was also installed and tested in Stevens Institute of Technology MSL.

Figure 5.4. Example of small vessels detected by radar and tracked by guided camera.

Figure 5.5. (left) Canon VB-H41 camera, (right) camera dome.
It is a much better camera. It also has remote Pan-Tilt-Zoom capabilities and 20 times optical zoom, and it can be precisely pointed at any position with accuracy of 0.01 degree.

To control this camera by other sensors as the previously described camera, first a spatial calibration procedure has to be completed as described below. This procedure was designed and implemented in Stevens Institute of Technology.

Spatial calibration of VB-H41 consists of the following steps:

1. Mount the camera with its foundation being horizontal. The camera can be mounted facing down or up. Slight inclination is allowed as it will not seriously affect the calibration. For the conducted tests, the camera was mounted facing down on the MSL patio, and was able to clearly monitor the river and some part of the sky.

2. Measure and record camera GPS location with altitude;

3. Using camera controls point the camera at some calibrating object with known GPS location;

4. Record the GPS location of that object including altitude. The camera will automatically record its Pan and Tilt, and will verify if the recorded tilt is matching the angle between altitudes of the camera and calibrating object.

5. If the verification in Step 4 is correct with error of less than 1 degree, the calibration is correct. It is then recorded in the calibration file.

After the calibration is done, when the camera-controlling software receives a 3-dimensional GPS coordinates from radar, AIS, or any other positional sensor, it compares them against the calibration of the camera and calculates the Pan and Tilt corresponding to the received GPS coordinates. After Pan and Tilt are calculated, they are sent to the camera, turning the camera towards the received GPS coordinates.

On Figure 5.6 we can see some examples of the vessels recorded by Canon VB-H41. These images have a better resolution, colors and details in comparison to the images received by the camera Foscam FI8620. In many cases the vessel’s name is clearly visible.
The library of recorded vessels is again quite large, but now the images are much more detailed. In many cases the names of the vessels are clearly readable when the full 1920 by 1080 pixels image is observed. For the purpose of including more images in this report, the images are minimized, but the names on some vessels are still readable. Visual detection techniques were also applied to helicopters and planes and some results are shown on Figure 5.7. Good positioning capabilities of Canon VB-H41 made it possible to point the camera towards planes and helicopters and record their images in
high resolution. It was practically impossible to make images of aircraft with such resolution with Foscam FI8620.

For detection of flying objects, visual detection is one of the most promising methods. In such approach the flying object is first detected on a low-resolution picture or roughly by acoustic sensors, and then using motion detection methods the camera view is automatically adjusted and zoomed on a moving object. This approach is in the development both for vessels and for flying objects.

The main problems that appear for visual vessels detection are:

1. River waves. River surface is constantly moving and has to be separated from vessel movement.

2. Wake waves. Such waves have many features of a moving object.

3. Sun glare. In case if sun or bright lights are present on the other side of the river, a glare from them would blind the camera to some degree.
If these problems are mild (calm weather, no direct sun exposure, etc.), then the described problems could be solved by the application of general image processing techniques. However, in severe cases an additional research might be necessary.

The main problems that appear for visual detection of flying objects are:

1. Speed of the objects. Depending on the algorithm, speed of a moving object and its appearance in the consequent video frames could affect its visual recognition as a moving object.

2. Clouds and fog. In many cases when visual detection of river vessels is still possible, clouds and fog could obviously block the flying objects from camera view. In general flying objects are further away from the observing camera. They look smaller and hence are more difficult for visual detection.

5.3. **Intensity difference method for motion detection on river surface.**

Besides the automated control of different cameras and their guidance by other sensors (acoustics, AIS and radar) there was also a need to automatically recognize moving vessels on the video in real-time. This task is slightly different from the standard motion detection algorithms since the background of the moving vessels is also not stable and moving all the time.

To deal with that, special software was developed in Stevens Institute of Technology, which is capable of detecting moving boats on a constantly changing water surface (with waves). This software involves several different methods to recognize what is actually moving on the image.
In this method the original image is first converted to grayscale (Figure 5.8, top right). A grayscale image uses only variations of black and white and represents the intensity of light in each pixel. This operation reduces the effect of moving waves and the amount of calculations since it processes 8-bit data instead of 24-bit data while having mostly the same results. Then the image is subtracted from the grayscale of previous image and only the pixels with the difference higher than a certain threshold are displayed (Figure 5.8, bottom left). A certain noise filtering has to be performed – if the threshold is too low, a lot of noise will be detected along with the actually moving object. If the threshold is too high, then much less noise will be detected, but moving object may not be detected either [17].

The noise filtering is done in several steps:

1. The software finds clusters of pixels with intensity above a certain threshold. Such pixels should be located not far from each other. A predefined gap between pixels is allowed.

2. Only clusters that have more pixels than predefined threshold are displayed.

3. Clusters found in Step 2 are displayed only if they are present on several consecutive frames. This largely eliminates randomness of noise from waves.
5.4. **Edge detection and intensity method for optical motion detection**

The edge detection and intensity method is similar to the intensity difference method. The original image is again converted to a grayscale image. The next step is edge detection. In terms of image processing, an edge can be described as a sharp contrast in the intensity between pixels. The edge detection process removes pixels which do not need to be processed while retaining the structural identity of the image.

The method of edge detection used in the program is Sobel edge detection. Sobel detection uses a gradient to detect edges by identifying the maximum and minimum of the first derivative of the image. The Sobel operator performs a two-dimensional spatial gradient measurement on an image using a pair of 3x3 convolution masks, one estimating the gradient in the x-direction (columns) and the other estimating the gradient in the y-direction (rows). The Sobel detection produces a binary image (edge is 1 or white and no edge is 0 or black).
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After the Sobel detection, areas of no interest, such as buildings, and any background noise are filtered from the image. Background noise is determined by calculating the average intensity of the water. Any pixels with a similar intensity are considered noise. A
morphological close is then used to fill in the shape of the vessel. This leads to slight expansion of shapes in the image. A morphological close can successfully reconstruct the shape of a vessel without significantly altering the original boundary shape [18]. The result is shown on Figure 5. 9, bottom right picture.

5.5. Saturation method for motion detection

The saturation method follows a very similar process to the edge detection and intensity method. Instead of converting the input image to a grayscale image, the input is converted to an HSV, or hue, saturation, and value, image instead. Hue refers to the pure color a pixel resembles. All tints, tones, and shades of a color have the same hue. For example, red, pink, and a darker shade of red all have the same hue. Hues are defined by a number between 0 and 1. This value corresponds with a position on the color wheel. For example, 0 is red while 1/6 is yellow and 1/3 is green. Saturation is the measure of the pureness of a color with respect to white. A pure red would have a saturation of 100%, white would have a saturation of 0%, and a tint of pink would have saturation between the two values. Value refers to how light or dark a color is. Pure black has a value of 0 and colors with more light have higher values.

Figure 5. 10: Saturation method: input image (top left); HSV image (top right); binary image after removing areas of no interest (bottom left); noise filtering and morphologic close (bottom right).
After converting the input to an HSV image, areas of no interest are removed. The image is then converted to a binary image. Pixels with a saturation value above a specified threshold are converted to white while pixels below the threshold are converted to black. Next, areas of no interest and background noise are filtered; a morphological close is used then to reconstruct the shape of the vessel. The process is depicted in Figure 5.10.

All three methods of motion detection demonstrated similar results. They all are capable of simultaneous detection and tracking of multiple vessels and understanding their relative size and speed. Depending on the applied threshold in noise filtering all methods may or may not detect small vessels. In many applications the camera had to move and follow a moving vessel and recognize it in different backgrounds, so intensity difference method was mostly used. Also the software would recognize if the motion of a detected object would follow a certain path or would be random. The random objects are then filtered out [19].

5.5 Examples of automatically detected vessels.
Many different vessels were automatically detected and tracked by the described software. Some of them are shown as an example on Figure 5.11.
As it is shown on Figure 5.12, the software is capable of simultaneous detection of multiple vessels even when the weather is not really cooperating.
During slight rain when the visibility is still ok, but rain drops cover significant part of the camera dome, the program is also capable of detection of moving vessels and separating them from water drops.
6. Acoustic surveillance in the security zone of the Verrazano Bridge

6.1. Introduction:
There is significant concern within the maritime law enforcement community about the current lack of solutions for tracking small, fast vessels which do not carry AIS beacons. Small vessels are ubiquitous in the United States with several million purchased each year. Vessels such as speed boats and jet skis often cause problems when they venture into shipping lanes and other high traffic areas can cause collisions with other vessels and disruptions to shipping.
Due to their small size recreational vessels are difficult to detect on radar, a trait which has made them a favorite vehicle for smuggling and other criminal activities. It is also feared that terrorist organizations may make use of small vessels to mount attacks on critical maritime infrastructure. This very real possibility became apparent as a result of the USS Cole incident when a small vessel rammed a US destroyer (the Cole), and exploded killing 17 sailors.
One of the many responsibilities of the US Coast Guard is to police maritime safety and security zones. These are areas designated to be off limits to all vessels for both the safety of the vessels and infrastructure. Currently this monitoring is done with eyes on cameras and vessel patrols, both costly and inconsistent methods of surveillance. Small vessel intrusions into these security ones are common as this report demonstrates. Most intrusions are benign, either due to ignorance of the law, or uncertainty about the boundaries of the zones.
Passive acoustic systems can and have been used to automatically track vessels, SCUBA divers, and other marine objects. Since they rely solely on sound generated by the object itself passive acoustic technology is also very stealthy, and has minimal impact on the environment. The purpose of this experiment was to demonstrate that passive acoustic technology developed at Stevens Institute of technology is a viable supplement to these methods.

6.2. Previous Experiment:
In August 2013 researchers from CSR partnered with the USCG to test the feasibility of detecting and tracking vessels in maritime security zones using passive acoustics. The first experiment deployed two simple passive acoustic recording arrays (Passive Acoustic Signal Recorder or PASR arrays) near the Brooklyn side of the Verrazano Bridge. Unfortunately, while these arrays succeeded in detecting hundreds of vessels it proved impossible to accurately track their location due to improper orientation of the systems on the bottom. Figure 6.1 shows the tracking area achieved during the 2013 experiment.
A decision was therefore made to repeat the experiment at a later date using an improved system to overcome the issue of system orientation. A new 4 hydrophone array was designed (PASR360) which could provide vessel bearing information in 360 degrees. This in addition to the two original PASR arrays would allow the accurate location of vessels. Figure 2 shows the planned location of the PASR and PASR360 arrays on the Staten Island side of the Verrazano Narrows. Figure 3 shows the vessel tracking coverage anticipated based on this arrangement.
Figure 6.2: Planned PASR and PASR360 locations denoted with red dots. Staten Island side of the Verrezano Narrows.

Figure 6.3: Estimated tracking coverage based on array locations shown in Figure 2 shaded green. Array locations shown in red.
6.3. Equipment:

6.3.1 PASR:
Each PASR buoy consists of a single Zoom Handy Recorder modified to accept an auxiliary battery pack of 4 C cell batteries. Two Aquarian H2a hydrophones are connected to the Handy recorder via the built in auxiliary microphone jack. Data is recorded on 32 GB micro-SD cards in 16 bit with a sampling rate of 44.1 KHz. Given these parameters the PASR system is capable of recording two channel audio continuously for approximately 48 hrs.

Each Handy Recorder is enclosed in an Otterbox waterproof container modified to allow connection of the hydrophones. The entire recording assembly is mounted to a steel frame with zip ties. The recorders and waterproof case are mounted in the center of the frame and the hydrophones are mounted on uprights at either end. Figure 6.4 shows the PASR system prior to deployment.

![Image](image)

Figure 6.4: PASR buoy aboard research vessel prior to deployment. Note hydrophone mounted to upright and water proof box connected to frame denoted with red and blue arrows respectively.

6.3.2 PASR360:
After the 2013 experiment it became apparent that an improvement on the current system hardware was needed in order to dependably track vessels in security zones. In particular it was deemed important that the system should have more than one hydrophone pair for vessel tracking in 360 degrees. This was accomplished by constructing two of the recording systems used in the PASR system and attaching them to a frame with four 4’ arms with the hydrophones mounted to 2’ uprights at the end of each arm. This new frame was constructed from aluminum 8020 extruded tubing. Figure 6.5 shows a diagram of the PASR 360 from above with hydrophone and water proof box locations noted.
6.3.3 Cell Phone Cameras:
One of the major changes to this experiment over past experiments was the use of smart phones to record photographs of vessel traffic. Photos taken by cell phones are encoded with meta-data including the GPS coordinates and time at which the image was taken. High end smart phones may also encode information regarding the phones orientation and camera information.
This information included in the images enabled Stevens Researchers to accurately match AIS and photo data. Furthermore it is expected that further work using image processing techniques may allow these images to become a third source of tracking information for vessels.

6.3.4 Video Camera:
A Canon handheld video camera was used to record video during times of heavy vessel traffic in order to make certain that no vessels went un-documented. This camera was mounted to a tripod and remained stationary throughout the experiment. Due to its limited battery life (two hours) the camera was only turned on when needed.

6.3.5 AIS:
Rutgers Coastal Observation Laboratory maintains an AIS antenna on Staten Island capable of monitoring vessel traffic within the area of the experiment. Data was recorded for the 24 hour period beginning at midnight the data of the experiment. Figure 6.6 shows a map provided by Rutgers which depicts vessel traffic as a heat map. This was used to verify AIS coverage of the experiment area.
6.4. Experiment Day:
Throughout the day AIS data was recorded by Rutgers University. Two observers were stationed on a lookout point above the system to photograph vessels in the vicinity for later use.

The systems were placed in the water beginning at 12:30 local time and were in place and calibrated by 14:00. It became apparent during calibration of the systems location that the PASR360 system had begun to drift quite rapidly in the strong currents under the bridge. The decision was made to leave the system in the hope that it would come to rest and might still yield good tracking data if re-calibrated for location later in the day. It was also apparent that one of the PASR systems had drifted slightly from its initial position but had come to rest in a reasonable location and so was left in place. The research vessel was then docked for several hours at the nearby Coast Guard Station NY.

At approximately 16:30 the observation group reported that a USCG vessel had arrived on scene and proceed to remove one of the systems from the water and appeared to have taken it away.

At approximately 17:00 the research vessel returned to the area to begin retrieving the
buoys. All three buoys were found and retrieved however both the PASR 360 and the PASR buoy that had been handled by the USCG vessel had drifted far from their initial location. The PASR 360 array had drifted a full kilometer over the course of the day. Figure 4 shows the initial and final location of each system as color coded pins.

![Deployment and retrieval location of each system denoted by color coded pins marked “start” and “end”](image)

It is clear that over the course of the experiment the PASR360 array had drifted nearly a kilometer from its intended location. The PASR buoy deployed on the North side of the bridge also drifted rapidly downstream after being dislodged.

### 6.5. Passing vessels and signatures collected

Over the course of the experiment approximately 78 unique vessels were documented operating in the area of the experiment. Rutgers AIS system recorded a total of 21 AIS transmitting vessels passing through, or near the experiment area over the course of the day. These were primarily commercial vessels: fast ferries, tugs, and large container ships. Two of these vessels were firefighting vessels from FDNY and JCFD, and one law enforcement vessel NYPD 315 was also recorded. A full List of AIS contacts recorded can be found in the Appendix. Figure 9 is a collage of some of the vessels photographed which were transmitting AIS in the area during the experiment.
Over the course of the experiment several vessels not transmitting AIS were also detected and documented. These primarily consisted of small pleasure craft. Additionally law enforcement vessels which do transmit their location but not on public AIS were recorded. Of particular note was the vessel hereafter designated 001. A small white fishing vessel approximately 25 ft. in length which was at anchor in the security zone for several hours during the course of the experiment.
Figure 6.9: Collage of non-AIS transmitting vessels documented during the experiment.
6.6. Examples of acoustic signatures and tracking

6.6.1 Unknown Vessel 001:

Figure 6.10: A small speed boat which loitered in the security zone for several hours before leaving.

Figure 6.11: Spectrum and DEMON spectrum of unknown vessel 001. Note high frequency harmonics indicating a small fast boat. Frequency shown on the x-axes in Hz, magnitude shown on the y-axes in dB.

Figure 6.12: Corrollelogram showing time delay of sound from unknown vessel 001 for use in tracking. Time is shown on the x-axis while delay is shown on the y-axis in ms.
6.6.2 Unknown Vessel 002:

Figure 6.13. A small speed boat which passed very close to the security zone heading south through the Narrows.

Figure 6.14. Spectrum and DEMON spectrum of unknown vessel 002. Note high frequency harmonics indicating a small fast boat. Frequency shown on the x-axes in Hz, magnitude shown on the y-axes in dB.

Figure 6.15. Corrollelogram showing time delay of sound from unknown vessel 002 for use in tracking. Time is shown on the x-axis while delay is shown on the y-axis in ms.
6.6.3 Elektra:

Figure 6.16. Elektra, a large roll on roll (RO-RO) car carrier vessel which passed through the experiment area heading south.

Figure 6.17. Spectrum and DEMON spectrum of Elektra. Note low frequency harmonics indicating a large slow moving vessel. Frequency shown on the x-axes in Hz, magnitude shown on the y-axes in dB.

Figure 6.18. Corrollelogram showing time delay of sound from Elektra for use in tracking. Time is shown on the x-axis while delay is shown on the y-axis in ms. Note the disruption at 14:30 caused by the passage of the research vessel between Elektra and the system at high speed (loud) which temporarily obscured tracking for Elektra.
6.7. Time Delay of Arrival Tracking:

An important concept in passive acoustics is the tracking of sound sources based on the time delay between the arrivals of a sound at two transceivers (hydrophones). The following chapter briefly explains how the correlograms from section 4.6 can be used to determine the location of a vessel. Knowing the delay in time of arrival between the two hydrophones we may make use of the known speed of sound, and distance between the hydrophones to calculate the angle between the central axis of the hydrophones and the sound source. The bearing angle $\alpha$ is calculated by the following formula:

$$\alpha \approx \arccos \left( \frac{TDOA \cdot c}{L} \right)$$

Where TDOA is the time delay of arrival between hydrophones, $c$ is the speed of sound, and $L$ is the distance between hydrophones as shown in Figure 20.

![Figure 6.19](image)

*Figure 6.19. Calculation of bearing angle to sound source from hydrophone pair. Hydrophones shown as rectangles sound source shown as black circle.*

Each hydrophone pair yields a bearing angle to the sound source. Using the bearings from two or more hydrophone arrays in different locations it is possible to triangulate the sound source location as shown in Figure 20. This step requires that the orientation and location of each array is known with a great deal of accuracy in order to produce meaningful results.
By continuously recalculating the location of a sound source over time a track of the vessels previous locations can be plotted. This is typically done with the aid of a Kalman filter to smooth out any noise in the measurements. An example of a track calculated in this manner is shown in Figure 23:

![Figure 6.21: Example of vessel track calculate by repeatedly calculating vessel location by triangulation over time. Passive acoustic arrays shown as red dots, vessel track shown as red line, green shaded areas denote tracking coverage area.](image)

### 6.8. Conclusion:

The primary goal of this experiment was to demonstrate small passive acoustic recording systems being used to track vessels within USCG designated maritime security zones. To this end three light weight passive acoustic recording arrays were deployed in the water near the security zone of the Verrazano Narrows Bridge. Over the course of the experiment vessel traffic was monitored and documented by AIS and by observers with cameras. Many vessels were documented in the area during the experiment. Of these vessels nearly 25% were transmitting AIS. 12% the total vessels observed were law enforcement vessels not transmitting AIS. The remainder were primarily small private vessels.

Vessels were detected and documented using a combination of photographic, AIS, and acoustic data. The acoustic signatures and tracking data are discussed above. This information demonstrates the potential usefulness of passive acoustics to enhance maritime domain awareness for the USCG. The signatures collected will also be used in vessel classification research to provide a decision aid to USCG personnel.

Although many vessels were successfully recorded and data otherwise useable for tracking was recorded, the actual tracking of vessels was not possible using the data gathered. This was due to high currents at the experiment site proved much stronger than anticipated, and the anchoring for two out of three recording arrays failed and the systems
drifted throughout the day. As a result triangulation and tracking of recorded vessels was not possible. This experiment set out to capitalize on lessons learned from the past. In particular that more hydrophone arrays with expanded tracking ranges were needed in order to accomplish vessel tracking in security zones. In order to achieve this a 4 hydrophone array, PASR360 was constructed which would allow tracking of vessels in any direction. In the process new challenges were discovered: in particular the need to design better systems for deploying and retrieving arrays, and an improved system of anchors in order to better hold the arrays in place in strong currents. This information will be applied to future iterations of this experiment as well as to other systems currently under development at Stevens Institute of Technology.

7. Suggestion for implementation of acoustic sensors to the WatchKeeper program

The goal of the Stevens Passive Acoustic Vessel monitoring project is to develop a tool for M.D.A.. Such a tool would fill a gap in maritime law enforcement’s current M.D.A. toolkit: allowing groups like the USCG to track small vessels which are invisible to AIS and radar. In order for this system to be useful, it must fit with day-to-day USCG operations.

With this in mind, CSR researchers reached out to USCG Sector NY; building on existing relationships with Sector NY personnel they conducted a series of interviews. Researchers also observed operations in the command center. The researchers paid particular attention to USCG’s Watchkeeper system. Watchkeeper is a geographic data display tool capable of integrating data from many sources. Watchkeeper is the best niche for Stevens Passive Acoustic technology in the USCG command center. Watchkeeper does not currently incorporate any non-law enforcement data streams. Stevens Passive Acoustic systems have demonstrated functional capacity to detect, track, and classify vessels. The system still needs development before it can meet the standard of law enforcement. For these reasons, USCG Sector NY and CSR agreed that in the interim Watchkeeper would integrate a test data stream. This was to establish the legal and technical process for Watchkeeper to accept outside data streams such as Stevens Passive Acoustics. A series of experiments were also carried out to demonstrate the value of Stevens Passive Acoustic vessel detection for MDA. The outcomes of these experiments are detailed in part 6.

Stevens MSL operates a network of cameras for research purposes. These cameras overlook the Hudson River from the roofs of campus buildings. The cameras cover an area for which Sector NY does not have good visibility. USCG personnel expressed interest in gaining access to these feeds. To provide value to USCG Sector NY as well as establish a process it these camera feeds were used as the test data stream.
This process is ongoing, but, several results are already clear. Watchkeeper accepts outside data streams by design. The technical aspect of the trial was simple. Exchange of emails and information with USCG Research and Development showed that Watchkeeper only needs IP address’ and passwords to connect to the feeds.

Establishing the legal framework for bringing outside data streams into Watchkeeper proved to be the most difficult task. New data streams must go through a series of approvals to ensure that they are secure and valuable. The value of the system was already established from the outset. Determining who at USCG Sector NY had ownership of Watchkeeper required significant correspondence. Working with these personnel, CSR researchers determined that an MOU between USCG Sector NY and CSR was the appropriate legal documentation for the camera data stream. CSR and USCG Sector NY agreed on language for the MOU. It went to USCG D1 Legal approval in May 2014. Pending this approval integration of the camera feeds into Watchkeeper is on hold.

Concurrent with these efforts, CSR researchers applied insights from USCG Sector NY to the planned Passive Acoustics interface. One frequent comment was that the command center could not handle any new systems. “No new screens please” was the sentiment expressed by one USCG watch-stander. It was clear that the data presented by Stevens Passive Acoustics needed fit in the Watchkeeper display.

Watchkeeper already displays AIS data with blue force tracking for USCG vessels. This display consists of moving markers showing the position of vessels. Selecting the markers displays a range of information about the vessel. Rather than design a new display scheme, CSR researchers reasoned that it was best to adopt the one already used for AIS.

![Figure 7.1: Screenshot of proposed Passive Acoustic Vessel Tracking interface in Magello. Passive Acoustic detections shown as green diamonds. AIS detections shown as white diamonds. System locations and coverage shown in red and yellow respectively.](image-url)
Figure 7.1 shows a concept of the display a watchstander would see. A passive acoustic system is deployed around the Statue of Liberty. Green diamonds denote vessels detected with passive acoustics. When selected vessels display classification and tracking information.

One concern shared by USCG Sector NY was the need to visualize the limits of the system. The yellow shaded area represents the detection range of the system. Another concern was that the new data should not duplicate existing data and clutter the display. This led to a requirement that the system must only display vessels not shown by AIS. White diamonds show the location of AIS equipped vessels Figure 7.1. Red markers show the locations of the hydrophone arrays.

CSR has been working on its own data display tool for first responders called Magello. CSR created a demonstration of the new Passive Acoustics interface in Magello. This demonstration is the source of the screenshot in Figure 7.1. Magello is used to display the layer to USCG stakeholders and other law enforcement. Feedback about the interface, and its implementation has been generally positive.
References:


11. Guangzhi Shi; Junchuan Hu; Mei Han; Yuyang Li, "Underwater acoustic target recognition based on multi-timeslice demodulation line spectrum


Project 1.4 – Decision Support Research

Principal Investigator
• Jeffrey V. Nickerson Center for Decision Technologies, Stevens Institute of Technology

Overview

An examination of environmental and operational data feeds was undertaken in relation to USCG needs. Data feeds were assessed and prioritized based on their utility to tactical, day-to-day Coast Guard operations. The vessel tracking and environmental data sets were identified as highly relevant to daily Coast Guard operations. Currently, the Coast Guard has two major systems for tracking vessels, Watchkeeper and Vessel Traffic Systems, or VTS. Watchkeeper displays vessels on a Geographical Information System (GIS) background using the Coast Guard’s Automatic Identification System (AIS) data feed. Vessel Traffic Systems, which are generally limited to use in port regions with high vessel traffic, track vessels using AIS, radar, and other available systems. However, both of these platforms are expensive to own and operate, which means they are not ubiquitously adopted. An open source alternative, like Magello, may increase the adoption of decision-support tools for a higher number of Coast Guard Sectors. Magello was the focus of the development work to support the visualization studies. AIS and HF radar data sets were sought and integrated into the existing visualization platform (Magello).

In addition, groups within USCG were identified and targeted as end-users for particular developments in visualization research. Extensive engagement with the oil spill response group (Incident Management Division) from Sector NY allowed the development of visualization layers that could assist in operational decision-making. These overlays include: Areas of Responsibility (highlighted areas that distinguish responsibility between the USCG and the EPA), the Shoreline Sensitivity Index (highlighted areas that convey areas of priority for the USCG), Land Use areas (marked public-use areas along the coast), Hydro Lines (highlighted areas that indicate lesser known and less visible piers and other critical infrastructure), AIS and local port facilities. By combining all this data into one interface, the layers provide critical data for enhanced situational awareness and improved decision-making during pollution response and clean-up events.
These layers include areas of responsibility for EPA and USCG.

**Metrics for Success**

1. Reaching a shared understanding primarily with the key stakeholder, the U.S. Coast Guard, in written form, of the decision-making processes that surround the use of information for search and rescue applications.

   *We engaged in extensive conversations with the Incident Management Division surrounding decision-making during incident response. The results were encapsulated in a synthesis summary.*

2. Reaching an understanding of an important hypothesis to test, such as “users more rapidly develop a rescue plan or path when weather-related information layers can be readily displayed.”

   *We proposed the hypothesis that weather and ocean-related layers, in combination with layers such as EPA/USCG Areas of Responsibility and Shoreline Sensitivity would facilitate decision-making.*

3. Creating a written plan for an experiment that tests the hypothesis.

   *A plan was prepared to evaluate the hypothesis in relation to decision-making.*

4. Creating a platform that can run the experiment(s) in an online environment.

   *Magello served as the platform.*

5. Designing subsequent experiments that seek to clarify the results obtained.
We hypothesized that additional capabilities allowing users to annotate and share notes and photos in a common viewer would facilitate decision-making during an incident.

6. The outcome of these efforts will be a report in the form of at least one academic paper detailing the method used, the results, and the implications of the results, as well as a discussion of future research.

   Paper prepared.

Project 1.4.2

Principal Investigator

• Bobbie Reagor, Monmouth University

Overview

Monmouth researchers have been exploring and developing potential sensor feeds that could flow into a situational awareness tool. These sensor feeds include water quality, flooding and several other NOAA-derived datasets. We worked with the Summer Research Institute teams to examine and develop a case for including these other datasets to allow for more robust information streams. The platform we considered was Magello.

Metrics

1. Conduct a gap analysis

   Monmouth continued to engage with the Summer Research Institute to coordinate inputs to Magello. Motivated by the recent sewage spill in the Hudson River, an analysis was conducted to identify and examine the fidelity of water quality sensors in the region that derive from multiple sources, such as RiverKeeper. This complements the addition to Magello of Air Quality Egg data for PM2.5, and allows a seamless representation of air/water quality across the atmosphere/ocean interface. Likewise, an examination of water level data deriving from Monmouth’s FloodView and other sources was conducted. The enhancement of Magello by adding more variables of interest to maritime emergency responders was a key benefit of this effort.

2. PI’s attendance at workshops and meetings

   PI participated in CSR-related coordination activities.
3. Continue to leverage existing RRI and UCI research

*This work draws on emergency response expertise and projects within Monmouth’s Rapid Response Institute and UCI.*

**MTS Resiliency: Port Resilience Project**

**Principal Investigators**
- Mr. James B. Rice, Jr., MIT Center for Transportation and Logistics, Massachusetts Institute of Technology
- Mr. GM Matt Mattingley, The Mattingley Group

**Project Objectives**
The project objectives for Port and Supply Chain Resiliency research continue as follows:
- Identify critical processes and systems of the MTS that need to be resilient
- Identify methods for making critical MTS processes and systems resilient.

Continuing the work conducted in Years 1-5 on port resilience, the Port Resilience team focused Year 6 efforts on developing and leveraging the contributions to-date, specifically the Port Mapper tool and application. The team continued some studies on inland waterways.

Specifically through the Year 1 – 5 work, the team integrated information and data gathered into a model that was developed into a tool called Port Mapper. The Port Mapper was subsequently developed into a web-based application for exploring implications of port closure scenarios and the general and specific resiliency of the national port network. This application has been effectively used by the USCG in response to recent port disruptions. During Year 6, the team planned the following efforts:
- Develop the Port Mapper tool and online application,
- Leverage the Port Mapper tool and online application, and
- Continue studies of inland waterways.

**Year 6 Research Milestones**

1. **Develop and Leverage the Port Mapper tool and online application:**

   **Progress**
   In Year 6, the work focused on further developing the Port Mapper tool to address the needs of the USCG for its use in disruption response. The initial plans for Year 6 also included continued study of inland waterways in addition to the Port Mapper development efforts. However, the research team amended their efforts to focus resources on the development of a Port Resilience Decision Framework Toolkit (PRDFT) together with the USCG.
The PRDFT project entailed studying the port resilience decision-making processes, data sources, and decision support systems used by the United States Coast Guard (USCG) Captain-of-the-Port (COTP) in both planning and response to potential disruptions to port operations. The technical approach outlined in the USCG RDC Project Description (USCG 2013) identified 5 tasks for the research team:

1. Define and Prioritize Port Resiliency Decisions
2. Identify Information Requirements for the Selected Critical Decisions
3. Identify Present Sources of The Task 2 Information
4. Identify Existing Information Gaps
5. Document the Results and Approach

The research team (comprised of Jim Rice and Kai Trepte of Massachusetts Institute of Technology, and Prof. Jeff Nickerson and Grace Python of Stevens Institute of Technology), together with contributions from Prof. Rick Luettich of the University of North Carolina and Kaethe Beck of Purdue University, and the team conducted the study executing the tasks and has documented the observations and findings in two white papers as follows:

1. Port Resilience Decision Process Framework - A white paper which contains (a) the identification and prioritization of the decisions impacting port resiliency, which USCG Sector Commanders / Captains-Of-The-Port (COTP’s) and Port Authorities may be called upon to make during both the Port Resiliency Planning/Preparedness and Post-Incident Phases of a disruption.

2. Port Resilience Decision Data Flows and Critical Systems - A white paper which describes the data sources, information systems and information gaps between the desired and current information available to make the port resilience decisions. This would include as possible identification of a set of tools that may address the information and decision-support gaps described in this and the Port Resilience Process Decision Framework. Together the two white papers intend to provide a high-level outline for the current state and needs for COTP port resilience decision-making and support.

Together the two white papers provide a high-level outline for the current state and needs for COTP port resilience decision-making and support. The insights make for an informed and data-based guideline for further development priorities and needs for the Port Mapper and other tools that may be able to support COTP resilience decision-making. This will serve as the foundation for Phase II tool development work as well as tool transition into the USCG toolkit.

Port Mapper Overview
The MIT Port Resilience team has worked to understand the capacity constraints that affect the potential resilience of the Maritime Transportation System in the US. Via
this work, the team developed a spreadsheet-based tool that addresses some of the key questions:

- Where could cargo move to if there were a disruption at a major US port?
- What other ports handle the same cargo types as the disrupted port?
- How far away are those ports?
- Does the US system of ports have enough capacity to handle a disruption to a major US port?
- How much additional port capacity is necessary for the US ports to handle a disruption and avoid significant delays and costs to the US economy?

As noted in previous reports, the Port Mapper tool enables users to assess the ability of the domestic US ports to absorb cargo that may need to be reallocated to different domestic ports from disrupted ports. This analysis can be conducted at the level of Standard Industry Classification (SIC) code. Among other capabilities, the tool can:

- Identify the distance and the average number of stops required to relocate volume from a disrupted port (this only applied to the volume in port at the time of disruption);
- Identify the maximum current capacity utilization in order for the remaining ports to absorb the volume from any one port closure. For each commodity class, a calculation can be made of the maximum level of capacity utilization of all other ports serving that commodity class in order for the remaining ports to absorb the displaced volume;
- Identify options for reallocating SIC code-level cargo to various ports across the system of ports in the domestic US;
- Develop scenarios for various disruption situations and assess options for cargo reallocation; and
- Serve as the foundation for more robust disruption scenario development for policy makers and planners.

The Port Mapper does not currently have all the analytical functionality as the spreadsheet-based tool, as this was developed as a beta version to demonstrate the potential and serve as a basis for soliciting input on future development needs and interests. The application can be accessed by visiting: http://portmap.mit.edu/ApplicationOverview.htm

Funding for this work came from CSR and was supplemented by approximately $50,000 by the Integrated Supply Chain Management Program at MIT. These developments were reviewed on several different occasions with various representatives of several US government agencies (DHS, USCG, MARAD, NMIO). The specifics of the tool and web-based application are described immediately below.

Port Mapper Application Current Capabilities
At present, the Port Mapper application is set up to plot and link ports based on the commodities that they handle. The user makes two selections:
- Choice of state or choice of SIC Group/SIC Family or SIC Description
- Choice of all ports or top ten ports, or a specific port by name (note that once you select a specific SIC type, only those ports that handle that SIC will be displayed)

Once the selections are made, the system displays results, plotting and linking the ports handling the SIC from either the specific port selected or the largest port handling that commodity if All Ports or Top 10 Ports was selected.

A few examples may help illustrate the possibilities. If one were interested in knowing which ports in the US handle Radioactive Materials, the user would select Chemicals - 3281 Radioactive Material and ALL, which would display all ports handling that particular commodity, displaying the shortest distance path from the largest port to every other port in the continental US that also handles that commodity.

If a user were interested in knowing the Top 10 ports that could handle containers if the Port of Savannah were closed, the user would select SIC Group called Container and Top 10, and identify Port of Savannah as Port to Fail. In response, the system would display the top 10 port options for containers with shortest-distance path shown from the Port of Savannah. The user has several options for viewing the various potential ports for reallocation.

During Year 5, several additional features were added to the Port Mapper Application:
- Scenario report providing a full list of all relevant ports organized by port name in alphabetic order, showing relevant cargo volumes from past years
- Scenario report on the same page as the Port Map making it easier for users to view the map and scroll to data without page change
- Distances from the disrupted port to other potential relocation ports are calculated and displayed

2. **Continue Studies of Inland Waterways**

**Progress**

As noted above, the initial plans for Year 6 included continued study of inland waterways in addition to the Port Mapper development efforts. However, the research team amended their efforts to focus resources on the development of a Port Resilience Decision Framework Toolkit (PRDFT) together with the USCG.

Inland waterway issues were studied through the PRDFT project with focus on the San Francisco Bay area ports, particularly the Port of Stockton as well as the Port of
Houston. Waterway issues and criticality of the system resilience were highlighted by the exceptional work done by USCG Sector San Francisco and their MTS Recovery Specialist, Mr Jerry Bynum on understanding risk and risk impacts, as well as by the Sector Houston USCG personnel in their active and effective engagement with waterway users for disruption and impending disruption management. Sector San Francisco Captain Stump and Sector Houston Captain Penoyer have created effective systems for understanding and managing risk among the users of their respective inland waterways, and these can be useful guidelines for adoption elsewhere throughout the USCG. Both have similarly created cultures that value and recognize the importance of port resilience.

Collaborations/Engagement

a. Core team of James B. Rice, Jr. and Kai Trepte of MIT collaborated with Jeff Nickerson and Grace Python (Stevens Institute of Technology), and Mr. Matt Mattingley (The Mattingley Group) on various elements of the work.
b. Port Authority of Charleston
c. Port Authority of San Francisco, Port Authority of Oakland, Port Authority of Stockton
d. America Association of Port Authorities

Resources Leveraged

• US Coast Guard Research and Development Center
• US Coast Guard Operating Ports kindly supported the PRDFT project
  a. Sector New York
  b. Sector San Francisco
  c. Sector Houston

Documentation

Through Year 6, the following preliminary draft reports and white papers were in process or were completed:

3. "An initial exploration of port capacity bottlenecks in the USA port system and the implications on resilience" by Kai Trepte and James B. Rice, Jr., *The International Journal of Shipping and Transportation Logistics, Vol. 6, No. 3, 2014*

4. Forthcoming in the Asian Journal of Shipping and Logistics, co-authored with Ioannis Lagoudis and Jason Salminen “Port Investment Strategies Under Uncertainty: The Case of a Southeast Asian Multipurpose Port”; a variant of this paper was accepted for the IAME 2014 Conference


7. Revisiting Port Capacity: A practical method for Investment and Policy decisions; by Ioannis Lagoudis and James B. Rice, Jr., 2011


10. Supply Chain Risk Management: Failure Mode Focus for Resilience, by James B. Rice, Jr., paper submitted at July 2011 Supply Chain Security Conference at Imperial College in London;


15. DRAFT White Paper - The Impact of Port Disruptions on Water and Land Travel Distances, by Kai Trepte, Research Associate, MIT CTL, Summer 2010

16. DRAFT White Paper - An Exploration of Port Growth in the United States, by Kai Trepte, Research Associate MIT CTL, Summer 2010

17. DRAFT White Paper - Port Investment and Resilience, by Kai Trepte, Research Associate, MIT CTL, Fall 2009

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**Stakeholder Events**


Presentations included: Stevens video and acoustic surveillance capabilities, the integration of Rutgers University's HF Radar vessel detection feeds into Coast Guard operational systems, decision support systems led by Drs. Jeff Nickerson and Liz Lennon, and strategies for port resilience led by CSR PI Jim Rice from the Center for Transportation and Logistics at MIT.


April 2014 - Research review meeting with Rear Admiral Michel, Capt. R. Thomas (USCG HQ), J. DiRenzo and USCG R&D reps.

**Other Stakeholder-Related Activities**

U.S. Coast Guard Long-term Strategic Planning "Evergreen" workshop - CSR Director participates as subject matter expert

CSR and NUSTL board NYPD Harbor Unit vessel for a patrol of the NY Harbor - The joint harbor patrol highlights the linkages between NUSTL and CSR on the federal level and the NYPD Harbor Unit, on the local and regional law enforcement and emergency response level.

Visit to brief CBP AMOC, and hosted return visit by AMOC personnel

Visit to brief USCG PACAREA

Discussions on research portfolio with NUSTL staff (hosted at Stevens and at NUSTL)

Discussions on research portfolio with NYPD staff (hosted at Stevens and at NYPD)
See Education section of report for field trips and exercise participation

Management Activities

The Center management, led by the CSR Director, conducted strategic planning and project oversight. Activities included the preparation of project reports, plans, proposals, papers, presentations, stakeholder events, and the coordination of activities at the partner institutions, government labs, and other DHS Centers of Excellence (COEs).

Research/project status update meetings were held on a ~monthly basis involving the management team and PIs and more frequently on a project basis to coordinate particular activities (such as the synergy experiment). Coordination was conducted by phone and e-mail. The management committee met in person April 2014 and in September 2014. Additional reviews of the projects were conducted in the Stakeholder Events.

The Port Resiliency Project spanned across several COEs (CSR, CVADA, CHC) and necessitated frequent interaction. Team calls of project personnel were organized approximately biweekly. Team calls including USCG stakeholders were held approximately monthly. Port visits including management were conducted during the project. Management contributed to the research design and report documents throughout the stages of the project.

The CSR Director interfaced with entities both within and outside of Center, and incorporated input from USCG Research and Development Center (RDC), the Advisory Committee (SEAC), the Program Manager and other bodies and individuals relevant to the research and education endeavors of the Center.

The CSR Director participated in COE Directors’ Meetings and disseminated outcomes of those meetings to CSR partners via phone calls, e-mails, and in-person meetings.

The CSR Director disseminated the Center’s research data and results through coordinated stakeholder meetings and presentations/discussions at stakeholder locations and events. These were undertaken to elicit feedback, generate interest in Center work, and motivate and facilitate new research directions and transition pathways. Transition-related topics drove the interactions and discussions with most of the stakeholders.

In year 6 these included:

• Panel convener, U.S. Coast Guard/VACCINE National Strategic Maritime Risk Stakeholder Meeting
• Portfolio discussions with USCG Research and Development Center
• Visits to AMOC, PACAREA, LANTAREA, JIATF-South, USCG Headquarters
• Visits to NYC Office of Emergency Management, USCG Sector NY, NUSTL, CBP, Maine Information Analysis Center (MIAC)
• Hosted visits by MDA experts
• Meetings with Marine Corps
• Department of State International Visitors Program: Borders & Maritime
• Speaking at Maritime Domain Awareness workshop, Santiago & Valparaiso, Chile, International networking exchange program organized and funded by Chile's National Commission for Scientific and Technological Research (CONICYT)
• Briefings to ABS, Transas & Ocean Aero executives
• Briefings and discussions with Sandia National Lab
• Discussions on MSI collaboration opportunities with New York City College of Technology, CityTech

Visits to AMOC, PACAREA and sector commands afforded a view of the situational awareness tools in use and the existing data feeds, so that the Center efforts can be better integrated with decision-support tools. Discussions involved transition plans for data feeds, laying the groundwork for the commands to receive data streams from the Center.

Many of these events led to new ideas and opportunities in the maritime security space. For instance the MDA workshop in Chile (although not funded using Center resources) provided a forum to discuss remote and mobile platform sensor (e.g., satellite, acoustics, radar) technologies applied to illegal fishing surveillance around remote islands and coastlines. Engagement with the Chilean Navy and Air Force on these topics generated an enhanced understanding of the global common challenges and possible novel solutions. Approaches discussed included trial campaigns to apply MDA resources to the illegal fishing problem, and data sharing through the US Navy-funded “International Collaborative Development (ICODE) of Open Source Tools for Enhanced Maritime Domain Awareness (MDA) Program” software: [https://github.com/ICODE-MDA](https://github.com/ICODE-MDA).

Dissemination of research and education outcomes and results was also conducted through the Center’s annual report and monthly newsletters. Management produced the annual report and, with the Director of Education/Outreach, created the content for the
monthly newsletter. Copies of the Center’s approved annual reports are made available to the public on the CSR website at http://www.stevens.edu/ses/csr/publications-reports/annual-reports, and on the MIREES webpage on the DHS OUP HSUP website at https://mirees.hsuniversityprograms.org/centers-of-excellence/mirees/.

Each month CSR shares information about its research, field-based activities, accomplishments and student achievements in its monthly electronic newsletter. The Center has cultivated an active contact database of close to 700 individuals representing DHS component agencies, local, state and Federal emergency response groups, industry practitioners and academic partners.

The Center’s newsletter has been an effective communications and outreach vehicle. Items in the newsletter often inspire stakeholders to reach out to the Center Director for additional information about research projects (e.g. Port Resilience Decision Framework), to extend invitations to participate in stakeholder events (e.g., NJ OHSP), and to facilitate introductions with other relevant stakeholders. (e.g. VADM Parker and Rear Admiral Michel)

An archive of the Center’s newsletters can be found on the CSR website and on the HSUP website.

The Center has also created factsheets on the Center’s tools and technologies (e.g., Magello, Port Mapper, SPADES, HF Radar) for distribution to stakeholders and guest visitors, and for marketing collateral at DHS events. The fliers provide an overview of the tool/technology and its use in the field, a bulleted list of the tool’s capabilities, and a point of contact.

Transition and IP-related:
The CSR Director and several PIs participated in a DHS S&T Technology Transition Workshop to develop pathways to transition our port resiliency tools to the Coast Guard, and engaged in a DHS data-sharing workshop.

A licensing agreement with Sonardyne for passive acoustics was announced. We are working closely with Sonardyne to help them develop a commercial product and as such, we have conducted a joint trial in the UK in December of 2014 to collect acoustic information on potential targets using an environment that is representative of a typical operational environment. Also, we have been contacted by potential US as well as international customers that have a need for a passive acoustic system for their maritime security applications. We are coordinating these requests with Sonardyne and hope that they will be able to build a commercial product in the next year and be able to test it with navies and port agencies.  

(No patents were generated in Year 6.)
DHS CDG Fellowship program:
The Director of Education interacted with the DHS CDG Fellows on a daily basis and convened monthly meetings to review student progress in the program and adherence to the fellowship program requirements.

Summer Research Institute:
The Director of Education is responsible for coordinating and overseeing the planning and delivery of the Center’s Summer Research Institute. Throughout the planning process, the director met weekly with Dr. Barry Bunin, SRI Curriculum Coordinator, to discuss prospective research projects, field visits, and to plan the Center’s student recruitment efforts. During the SRI program, student research activities and project status updates were conducted and reviewed on a weekly basis.

An assessment of the SRI program is conducted annually in the form of a student survey and meetings with the CSR Director and research PI’s to ensure that the program’s objectives are met. Follow-up and on-going email communications are maintained between the Director of Education and the SRI program alumni. Follow-up correspondence has resulted in SRI alumni seeking and obtaining internship and employment opportunities.

USCG Auxiliary Detachment:
The Director of Education coordinated monthly meetings of the Stevens USCG Auxiliary Detachment members. The monthly meetings included Auxiliary course trainings, community outreach planning and scheduled activities with USCG active duty personnel. (e.g. Lt. Kenneth Sauerbrunn, USCGC Sturgeon Bay).

Advisory Board Activities:
CSR’s Science and Education Advisory Committee (SEAC) meetings were convened via email and phone calls as needed throughout Year 6. The SEAC provided guidance and strategic planning. SEAC committee members have played an important role in facilitating connections with industry and government stakeholders, and in E2E Stakeholder and industry meetings in YR 6.