Dr Ray Buettner
Director, CRUSER

http://CRUSER.nps.edu
https://www.facebook.com/CRUSER.CoI
# Report Documentation Page

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<td>Naval Postgraduate School, Consortium for Robotics and Unmanned Systems Education and Research (CRUSER), Monterey, CA, 93943</td>
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Standard Form 298 (Rev. 8-98)  
Prepared by ANSI Z39-18
UnderSecretary of the Navy Work – 1 Feb 2011:

“...to shape generations of naval officers through education, research, concept generation and experimentation in maritime applications of robotics, automation and unmanned systems......”

“......provide a DoD-wide community of interest to exchange research and experimentation results”
Oversight

- Sponsor: SECNAV
- Funding: ONR

Off Campus Steering Group

On Campus Advisory Board

Coordination

- Ray Buettner
  Director
- Dr. Timothy H. Chung
  Director of Research and Education
- Carol O’Neal
  Director of Innovation and Concept Development
- Lisa Trawick
  Operations Manager
- Lyla Englehorn
  Program Manager

CRUSER Col

- NPS Faculty/Students: 311
- DoN: 283
- Industry: 240
- Other Government: 103
- Academia: 90
- USA/USAF: 35
- General Public: 24
- International: 23

Over 1100 Members and growing
FY11-FY14 Objectives

- Concept Generation
- Experimentation Program
- Education Venue
- DoD-wide forum for collaboration
Innovation Thread

A two-year event cycle starting in September with a Warfare Innovation Workshop and ending with a research presentation at ONR showcasing the results of the innovation thread.

- **Sept Year 1**: Warfare Innovation Workshop
- **Spring Year 1**: Technical Continuum
- **Spring Year 2**: Field Experiment
- **Summer Year 2**: Research Expo

Teams of academic, govt., and scientific community representatives propose concepts within a scenario.

Review of Technical Papers and proposals for concepts selected from Warfare Innovation Workshop. Includes a Research Fair.

Testing of physical models as a follow-on to the Tech Continuum.

Expo to showcase the results of the Innovation Thread – “Concept to Experimentation”.

Consortium for Robotics and Unmanned Systems Education and Research
Current Innovation Threads

UxS Employment in Naval Operations

- Field Exp (APR 13)
- Expo (JUN 13)

Advancing the Design of Undersea Warfare

- WIW (NPS, SEP 12)
- Tech Continuum (NPS, APR 13)
- Field Exp (APR 14)
- Expo (JUN 14)

Thread #3 – Distributing Future Naval air and Surface Forces

- WIW (SEP 13)
- Tech Continuum (NPS, APR 14)
CRUSER Innovation Thread Three: “Distributing Future Naval Air and Surface Forces”
Concept Generation - Warfare Innovation Workshops

Sept 2010 – Advanced Undersea Warfare Systems (AUWS)


Sept 2011 – UxS Employment in Naval Operations

- Revolutionary Concept Generation from Evolutionary UxS Technology Changes
- Four teams of NPS students, early career engineers from Navy Labs and industry
- Identified over 40 revolutionary concepts
- Five areas identified for presentation at May Tech Continuum:
  - Counter-UAV
  - Info Assurance
  - ISR
  - Non-kinetic Strike
  - Knowledge Management/Data Management

Consortium for Robotics and Unmanned Systems Education and Research
Selected Concepts:

1) **Counter-UAV measures:** UAVs that specifically threat other UAVs – such as an expendable “hunter-killer” UAV for defense of allied forces.

2) **Low possibility of intercept (LPI) comms:** covert and innovative networks – such as the “Digital Semaphore” concept being taken to field experimentation in FY13.

3) **UxS support of ISR missions:** Tagging and tracking operations, innovative surface and subsurface observation platforms.

4) **Bandwidth and data management:** Advanced algorithms for “information triage” or onboard/in situ processing to reduce network loads, and improved data farming of meta-data.

5) **Non-kinetic strike operations:** UxS employed in non-kinetic operations to disable enemy assets – such as fouling agent deployment, jamming or spoofing/decoy operations.
### Technical Continuum

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>SPEAKER</th>
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<tbody>
<tr>
<td><strong>Project MISSION: Maritime In Situ Sensing Inter-Operable Network</strong></td>
<td><strong>Professor Joe Rice, NPS</strong></td>
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<tr>
<td>Wave Powered Unmanned Surface Vehicle Operation in the Open Ocean: a station keeping asset for distributed netted systems</td>
<td><strong>LT Timothy Rochholz, USN</strong></td>
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<td>Mine Burial Expert System for Changing MIW Doctrine</td>
<td><strong>Dr. Peter Chu, NPS</strong></td>
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<tr>
<td>Channel Modeling and Time Delay Estimation for Clock Synchronization Among Seaweb Nodes</td>
<td><strong>LCDR Pascal Gagnon, RCN</strong></td>
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<td>NILUS - An Underwater Acoustic Sensor Network Demonstrator System</td>
<td><strong>Dr. Roald Otnes, FFI</strong></td>
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<td>Underwater Acoustic Network as a Deployable Range</td>
<td><strong>ENS Rebecca King, USN</strong></td>
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<td>Tailorable Remote Unmanned Combat Craft (TRUCC)</td>
<td><strong>LCDR Loren Jacobi, USN</strong></td>
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<td><strong>LT Adam Bush, USN</strong></td>
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<td>Countering Inundation with Innovation: Defeating Swarm UAV Threats with Aerial Combat Swarms</td>
<td><strong>Dr. Timothy Chung, NPS</strong></td>
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<tr>
<td>Autonomous System Support for Maritime Visit, Board, Search and Seizure Operations</td>
<td><strong>Dr. Noel du Toit, NPS</strong></td>
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<td>Emerging Applications of 4K Ultra-high Resolution Full Motion Video for Unmanned Systems and Remote Sensing</td>
<td><strong>Jeff Weekley, NPS</strong></td>
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<tr>
<td>Digital Semaphore</td>
<td><strong>Dr. Don Brutzman, NPS</strong></td>
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- **7-10 May 2012**
  - Held in conjunction with Tenth International Mine Warfare Symposium

- Industry and Navy labs invited to demonstrate technical capabilities related to the selected topic areas

- Two concepts selected for continued development and field experimentation:
  - Aerial Combat Swarms
  - Digital Semaphore

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**Cruser Thread 1**

- **Sept 2011** Warfare Innovation Workshop
- **May 2012** Technical Continuum
- **Apr 2013** Field Experiment
- **June 2013** Research Expo

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Consortium for Robotics and Unmanned Systems Education and Research
Aerial Combat Swarms: Swarm vs. Swarm UAV Competition

A grand challenge where tactics drive the technology

- Develop enabling capabilities for **attacking** the opponent’s aerial bots and their home base while actively **defending** own home base

- Conduct **live-fly, outdoor competition** in tournament-style event

- Seek **innovations** in tactics, concepts of operations, autonomy algorithms, hardware platforms, etc.

- Provide **common standards** and infrastructure for rapid evolution

![Diagram of aerial combat swarms]

**Dates of Events**
- Sept 2011: Warfare Innovation Workshop
- May 2012: Technical Continuum
- Apr 2013: Field Experiment
- June 2013: Research Expo
Initial results: Demonstrated QR codes can be extracted at distances at least 500 times farther than typical (600’ versus 1-1.25’).

Findings: Many controllable factors - QR encoding, QR display, sensor, optics, image processing, data processing can all be adjusted based on conditions. Additionally, Dynamic QR Codes for streaming and moving capture are possible.

Recommendations: Continued Research Warranted - Adaptive Optics to Extend Range past 10K yards, Software for Encode/Decode and Image Processing, Continued Field Testing with Unmanned Systems
Research Fair

- 10 May 2012
- Held in conjunction with the CRUSER Technical Continuum
- Over 20 exhibitors from NPS, DoD, industry and international militaries
- S.T.E.M. event
- Research showcase
Research Expo: Washington DC

- Venue to showcase the results of CRUSER Innovation Thread #1, UxS Employment in Naval Operations

  - Concept Generation:
    - Sept 2011 Warfare Innovation Workshop

  - Field Experimentation:
    - Aerial Combat Swarms
    - Digital Semaphore

- June 2013 at ONR
Warfare Innovation Workshop: Concept Generation

- “Advancing the Design of Undersea Warfare”
- 17 – 20 Sept 2012
- Sponsored by NWDC, NUWC and CRUSER
- Directly supports the NWDC Line of Operation in developing the DUSW
- Focus on employment of the Undersea Warfare Operating Concept in the War at Sea Strategy
- Junior officers from NPS and the fleet, early career engineers from Navy laboratories and NWC SSG Director Fellows
- Innovative Concept Generation for leveraging U.S. strengths in the Undersea Domain to counter A2AD in Phase 0/1
Selected Concepts:

1) **Decoys and military deception (MILDEC):** Designs to obfuscate targeting or cloud the enemy’s operational picture – such as a USV swarm fleet or acoustic deception by unmanned systems.

2) **Vessel tagging:** For domain awareness and tracking – such as remora tag with hydro-fan generator.

3) **Non-lethal kinetic effects:** Generation of non-lethal stopping tactics and mechanisms – such as condenser fouling agents.

4) **Undersea positioning, navigation and timing:** For navigation accuracy and domain awareness as an alternative to GPS and surrogate for underwater use.

5) **Undersea “garage”:** Autonomous docking, power generation and transfer, deployment and to extend time on station.

6) **Hybrid unmanned vehicles:** Multi-domain vehicles that transition between domains.

7) **Crowd-sourcing:** Leveraging white shipping, regional fishing fleet and other entities to meet mission data collection needs.
Concept Generation: “Undersea Superiority 2050”

• 25 – 28 March 2013 Warfare Innovation Workshop

• Sponsored by Electric Boat and CRUSER

• Goal – advance the Navy’s Design for Undersea Warfare, focusing on relationships between manned submarines and unmanned undersea vehicles (UUVs)

• Junior officers from NPS and the fleet and early career engineers from Navy laboratories and other DoD partners
Technical Continuum/Research Fair

• Showcase selected technologies identified in Sept 2012 and Mar 2013 Warfare Innovation Workshops

• 3rd Annual Robots in the Roses Research Fair
Field Experimentation for technologies selected from the April 2013 Technical Continuum presentations
Research Expo: Washington DC

• Venue to showcase the results of CRUSER Innovation Thread #2, Advancing the Design of Undersea Warfare

• Concept Generation:
  • Sept 2012 Warfare Innovation Workshop
  • Mar 2013 Warfare Innovation Workshop

• Field Experimentation:
  • To be determined at the Apr 2013 Technical Continuum

• Target is June 2014 at ONR
Experimentation

- MIO remote sensor control demonstration in Singapore  
  - (FY11)

- Seaweb experimentation in coordination with Singapore  
  - (FY12-13)

- UxS in Naval Operations Experiment  
  - (FY13)
Education

- CRUSER Robo-Ethics Continuing Education Series (RECES)
  Jan 2012/Sept 2013

- Catalog degree programs, short courses, and certificate programs country wide – FY13

- USNA Summer block internships – FY13

- Create short course programs as identified by community of interest - Continuous

- Align curricula for interdisciplinary autonomous systems education – Continuous

- S.T.E.M Outreach – Continuous
Robo-Ethics Continuation Series (RECES)

January 2012
- Four panels, 2 days
- Over 100 participants from the DC area
- Commands represented included ONR, OSD, NAVAIR, NAVSEA, USNA, NPS, NWC, PEO LCS, NRL, DOS, JGRE, Navy Staff

September 2013
- Enrichment Week event open to entire campus
- In conjunction Warfare Innovation Workshop
- 2-hour panel discussion on UxS ethical issues related to distributing future Naval air and surface forces
STEM Outreach Events

- OR Robotics Day
  - Aug 2010
- First Lego League of Monterey
  - Nov 2010/Apr 2011
- Monterey Academy of Oceanographic Sciences (MAOS)
  - Mar 2011
- “Girl’s Day In”
  - Mar 2011
- Robots in the Roses Research Fair
  - Mar 2011/May 2012/May 2013
- Monterey County Science Fair Judges
  - Mar 2011
- Expanding your Horizons Career Fair
  - Nov 2011
- Brownie Troop 30608 – Mindstorm Robots
  - Jan 2012
- Cub Scout Pack 125 – Mindstorm Robots
  - Apr 2012
- La Mesa Elementary – Mindstorm Robots
  - Apr 2012
- Carmel High Robotics/Engineering Class Tours
  - May 2013
Collaboration

- CRUSER Community of Interest (CoI) data base
- CRUSER newsletter
  - http://CRUSER.nps.edu
- Unclassified Website
  - CoI Listing
  - Calendar of Events
  - https://wiki.nps.edu/display/CRUSER/
- Classified Website
  - https://cruser.nps.navy.smil.mil
- Facebook Page
  - https://www.facebook.com/CRUSER.CoI
Submission of thesis topics for NPS Students via Proposal Form on CRUSER Website available to entire Community of Interest - 48 submitted since Jan 2012

66 CRUSER thesis or Capstone projects have been completed from March 2011 through March 2013

Monthly CRUSER CoI Meetings – VTC, Elluminate (webinar), and dial-in now available due to increasing call-in demand
Community of Interest

1109 Members and growing
Community of Interest

Examples of CRUSER Member Organizations

- NPS
- NSWC
- NUWC
- ONR
- Northrop Grumman
- NWDC
- USNA
- SSC Pacific
- Raytheon
- Robotic Systems Joint Project Office
- JHU/Applied Physics Laboratory
- Lockheed Martin
- NRL
- OPNAV N2/N6
- Rockwell Collins
- USFFC
- DUSN
- General Dynamics Electric Boat
- Joint Integrated Air and Missile Defense Organization
- TACOM
- Teledyne RDI
- University of New Brunswick
- USFF
- Institute for Religion and Peace

- NAVAIR
- NAVSEA
- NMAWC
- NWC
- OPNAV
- SAIC
- Virginia Tech
- California Peace Officer Association
- Arizona State University
- Avineon, Inc.
- German Air Force
- COMPACFLT
- COMSUBDEVRON TWELVE
- Draper Laboratory
- Georgia Institute of Technology
- Georgia Tech Research Institute
- HQMC
- iRobot
- Jet Propulsion Laboratory
- MIT
- Northwestern University
- NSWC Carderock
- Orca Maritime, Inc.
- Systems Planning & Analysis, Inc
Questions?
REFERENCE SLIDES
Concept Generation Events

- **Advanced Undersea Warfare Systems (AUWS) Warfare Innovation Workshop**
  - Involved Systems Engineering Analysis students as an innovation kick-off to their AUWS Capstone Project

- **Future Unmanned Naval Systems (FUNS) War game Competition**
  - Sponsored by NPS Chair for Undersea Warfare and BATTELLE
  - Concept generation for the deployment of unmanned systems in a future South China Sea scenario
  - All concepts published in a Technical Report
Aerial Combat Swarms: A Grand Challenge Competition

Swarm vs. Swarm Autonomous Systems

Countering the Adversary’s Autonomous Systems
Emerging threats of saturation attacks with unmanned systems

Fact: Proliferation of unmanned systems is rapidly accelerating
Fact: Lowering cost admits new players in asymmetric warfare

Problem: The adversary can potentially exploit many inexpensive unmanned systems to challenge and overwhelm our defensive capabilities

Case Study: Kamikaze UAVs
- Saturation attack profiles
- Persistent threat
- Minimal human-in-the-loop

Harpy UAV engaging radar source

Defeating Inundation with Innovation
Utilize a defensive swarm of UAVs

Future concept: Leverage defensive swarm of autonomous assets to find, fix, and engage the enemy swarm

Aerial Combat Swarm vs. Swarm UAV Competition
Inspire an ambitious grand challenge initiative

Goal: Live fly experiment 50 vs. 50 by 2015!

Aerial Combat Swarms Competition:
- Develop enabling capabilities for attacking the opponent’s aerial bots and their home base while actively defending own home base
- Conduct live-fly, outdoor competition in tournament-style event
- Seek innovations in tactics, concepts of operations, autonomy algorithms, hardware platforms, etc.
- Provide common standards and infrastructure for rapid evolution

Revolutionizing Future Concepts for Swarm vs Swarm UAVs
Challenge and exceed existing frontiers in autonomous systems

Complex systems require holistic approach
- Offensive and defensive tactics
- Autonomy science
- Interoperability
- Human factors
- Manning and logistics
- Networked operations
- Business case analyses
- Platform capabilities
- ...

Advanced Robotic Systems Engineering Laboratory (ARSENL)

Email: thchung@nps.edu
Web: http://faculty.nps.edu/thchung
Call for Proposals

Selection Criteria
- NPS Student involvement
- Interdisciplinary, interagency, and partnerships with Naval labs
- Partnerships with other sponsors’ funding
- Research related to unmanned systems’ categories:
  - Technical
  - Organization and Employment
  - Social, Cultural, Political, Ethical and Legal
  - Experimentation
  - Defense against threat UxS capabilities
- New research area (Seed money to attract other contributors)
- Related to CRUSER mission thread
- Alignment with SECNAV’s DoN Unmanned Systems

Amount Funded
- FY12 - $400k
- FY13 - $700K
FY 12 Funded Research Proposals

- Passive UxV Navigation using Visual Sensors
- Tropical Cyclone Reconnaissance with the Global Hawk: Operational Requirements, Benefits, and Feasibility
- Joint Optimization of Sensing and Sampling with Unmanned Undersea Vehicles
- Roadmap for Reduction of Total Ownership Cost (TOC) to Support Acquisition Decisions of Unmanned Autonomous Vehicle - Phase I
- Programming the Laws of Armed Conflict (LOAC) for Unmanned Systems
- Autonomous Multi-vehicle Tactical Surveillance and Support for Maritime Visit, Board, Search and Seizure Operations
FY 13 Funded Research Proposals

- The Use of Unmanned Systems for Environmental Sampling and Enhanced Battlespace Awareness in Support of Naval Operations
- Tactical Long Endurance Unmanned Air System (TaLEUAS)
- Networked Unmanned Systems Formation for Rapid Detection, Interdiction, and Expert Reachback in Maritime Interdiction Operations
- Support for NPS Seaglider Operations
- Comparative Analysis of X-47 UCAS & F-18 Squadron Manpower
- A Collaborative Diver Assistant for Underwater Operations
- Corporation of Navy’s Ocean Data into UUV Path Planning with Obstacle Avoidance
- Experimental Unmanned Aircraft System (UAS) Interim Flight Clearances
- UAS Training and Pilot Certification Program
Examples of NPS Student Research

- Autonomy in Lethal UAVs
  - LT Matthew Larkin, USN

- Autonomous Surf Zone Robot
  - LT Steve Halle, USN and LT Jason Hickle, USN

- Multi-Agent Task Negotiation Among UAVs
  - Mr Michael Day

- Search on Optimized Graph Topologies
  - Maj Christian Klaus, German Army

- Future of Marine Unmanned Aircraft Systems (UAS) in Support of a Marine Expeditionary Unit (MEU)
  - Maj Les Payton, USMC

- Business Case Analysis of Cargo UAS Capability in Support of Forward Deployed Logistics in OEF
  - Capt Troy Peterson, USMC
  - LT Jason Staley, USMC

- An Analysis of the Manpower Impact of Unmanned Aerial Vehicles (UAV’s) on Subsurface Platforms
  - LT Thomas Futch, USN
Examples of NPS Student Research (cont)

- Advanced Undersea Warfare Systems
  - Systems Engineering Analysis Cross-Campus Study (SEA 17B)
- Agent-Based Simulation and Analysis of a Defensive UAV Swarm
  - Mauricio M. Munoz-Lieutenant, Chilean Navy
- Derivation of River Bathymetry Using Imagery from Unmanned Aerial Vehicles (UAV)
  - LT Matthew Pawlenko, USN
- Self-propelled semi-submersibles: the next great threat to regional security and stability
  - LT Lance J Watkins, USN
- The Dispersal Of Taggant Agents With Unmanned Aircraft Systems (UAS) In Support Of Tagging, Tracking, Locating, And Identification (TTLI) Operations
  - Capt Dino Cooper, USMC
- Design Requirements For Weaponizing Man-portable UAS In Support Of Counter-sniper Operations
  - Maj Derek Snyder, USMC
- Autonomous Parafoils: Toward a Moving Target Capability
  - CDR Chas Hewgley, USN
- Unmanned Systems Capstone
  - Systems Engineering Analysis Cross-Campus Study (SEA 18B)
Objectives

• Study noisy underwater environments
• Achieve acoustic communications through adverse channels
• Integrate U.S. “Seaweb” and Singapore “UNet” networks

Deliverables

Demonstrate in situ sensor networks in Singapore Strait

Milestones

• MISSION 2012 sea trials
• MISSION 2013 sea trials

Accomplishments to Date

Developed bilateral project plan with National University of Singapore

Payoff to the Navy

Enable distributed wireless architectures for Maritime Domain Awareness and Under-Sea Warfare