Chapter 17 – US-4: UNMANNED SURFACE VEHICLE CONTROL AND MONITORING HUMAN-COMPUTER INTERFACE FOR AMPHIBIOUS OPERATIONS

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17.1 DATES

The US Navy is investigating the usability of Remotely Piloted small Unmanned Surface Vessels (USVs) to support mine warfare missions. The demonstration focuses on the Human-Computer Interface (HCI) for the Multi-Robot Operator Control Unit (MOCU) software developed at the Space and Naval Warfare Systems Center Pacific in San Diego California USA. Human performance studies are being conducted to investigate alternate design configurations relative to optimum human performance and decision-making. In April 2009, the first technology demonstration illustrated two versions of the HCI, a baseline version and an integrated map-video version. A third version was created following initial end-user review of the map-video version and additional testing was completed in March 2011 to allow comparison of results in a dynamic simulation across the versions. The goal of the technology is to safely and efficiently control simultaneous operations of two USVs and to identify human performance shortcomings that may be mitigated by advanced HCI concepts.

HFM-170 Concept Demonstration 1 was conducted April 22 2009. Concept 2 usability testing was performed August 5 – 12, 2010, and Concept 3 usability testing was performed February 28 – March 10, 2011. Further testing is planned for summer 2011.

17.2 LOCATION

Concept Demonstration 1 was conducted April 22 2009 at the US Naval Submarine Base Point Loma, San Diego California. Concept 2/3 usability testing was conducted in the User Laboratory of SPAWAR Systems Center – Pacific, San Diego CA.

17.3 SCENARIO/TASKS

The USV HCI test scenario consisted of a simple navigation route tracking which simulated both ingress and egress from a “host ship”, e.g., the US Littoral Combat Ship (LCS) to an operational area. The USV scenario picked up after a simulated post-launch from the host ship at a control point where the on-deck launch operator would hand-off the launched USV to the Organic Off-board Vehicle Operator (OOVO). The MOCU HCI allowed the user to shift between automatic waypoint-following control mode to manual control mode. Upon completion of the test scenario the USV would begin a slow search pattern for mine hunting.

The remaining mission phases were deemed to duplicate the first phase for human performance impact and not included in testing. These phases included mission sensor search and transit to a recovery dock for retrieval.

The scenario used to test Concepts 2 and 3 in 2010 and 2011 followed a simulated mission scenario with simulated USVs. Participants in both sessions were USN enlisted personnel, most of whom had previous experience operating USVs. The scenario required them to respond to a series of pre-determined conditions and events as they transited two USVs from the host ship to the mission operations area. The scenario was designed to elicit performance of critical tasks derived during previous task analysis interviews with subject matter experts. In several instances scenario events were purposely scheduled in close time proximity to heighten mental workload and assess attention management capabilities under challenging conditions. Performance measures were developed for each task, which usually specified a window of time for completion. The scenario required the subjects to perform the tasks listed below:

- Take control of USVs;
- Download and execute pre-planned routes;
- Set emergency maneuver actions;
- Activate radar and display contacts;
- Switch between driving modes (manual and auto);
- Start/stop engines, including set to idle;
- Drive USV in manual mode;
- Make waypoint reports at each waypoint;
- Monitor for and report contacts (radar and visual);
- Respond to stationary contacts in path (emergency and non-emergency);
- Respond to moving contacts in path (emergency);
- Respond to vessel in pursuit;
- Use Point, Tilt and Zoom (PTZ) camera to assess contacts; and
- Report/respond to system status alarms.

17.4 TECHNOLOGIES EXPLORED

Demonstration Concept 1 utilized the MOCU HCI with a live robotic USV. Later testing used the HCI with two simulated robotic USVs. In all cases the technology focus was on visualization strategies and dynamic visual and audio feedback during user monitoring and control of missions. In addition to visualization methods, use of hand-held controller technologies was investigated in Concept 3.

The integration of visualization methods within the HCI challenges the end-users visual workload and attention management skills by the use of several sets of cameras with various visual focus domains. These domains include:

1) Pan-tilt-zoom camera;
2) 360 degree camera; and

3) Rear-view focus camera (rear-view available on some USVs).

Other sensory inputs include Digital Nautical Charts (DNC) that display information about known geographic features including algorithms that compare objects on the chart to the depth of the USV keel to determine if a hazard exists. Color coding on the chart display indicates nearby geographic hazards. Radar returns are overlaid with the digital chart information.

The HCI concept demonstration was conducted using a PC-based simulation program developed by the Space and Naval Warfare System Center Pacific Unmanned Systems Group. The simulator incorporated video graphics from a customized commercial software nautical gaming simulator integrated with the MOCU-based user interface displays and controls. In Concepts 1 and 2 video graphics simulating forward/aft/starboard and port camera views (as well as PTZ) for each of the two USVs were displayed on the upper console monitor with USV#1 displayed on the left and USV#2 displayed on the right (see Figure 17-1). The lower monitor included an integrated Digital Nautical Chart (DNC) showing landmasses, radar contacts as well as routes and waypoints for both USVs. (See Figure 17-2) Operational information (speed, heading, location) was shown for each USV. In Concept 3, video graphics were displayed in an integrated “windshield” style display (see Figure 17-3) on the lower console and the DNC was displayed on the upper console (see Figure 17-4).

Figure 17-1: Upper Display for Concept 2 Baseline Version of MOCU Multi-USV Video Information.

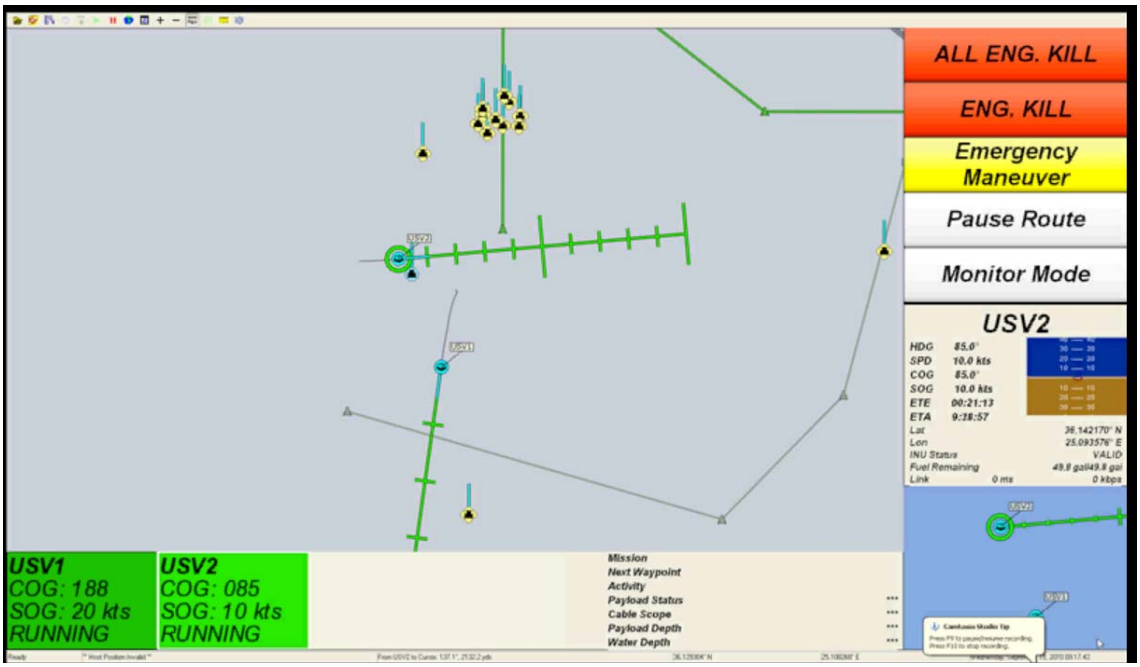

Figure 17-2: Lower Display for Concept 2 Baseline Version of MOCU Multi-USV Chart Information.

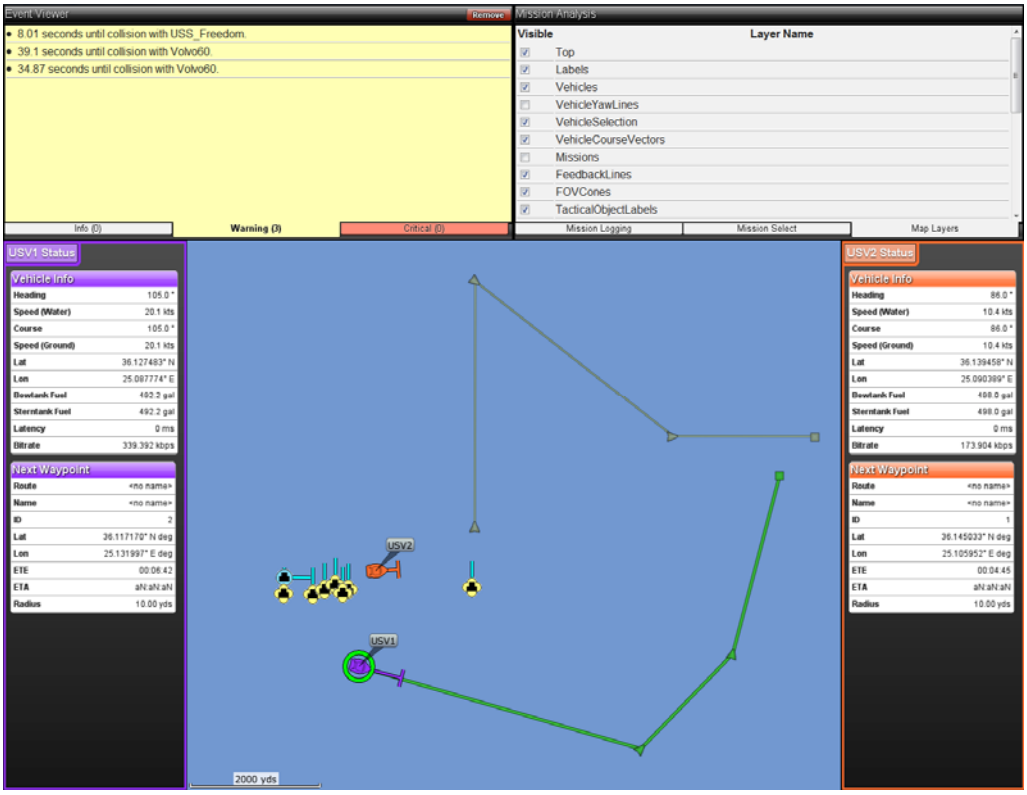

Figure 17-3: Upper Display for Concept 3 Version of MOCU Multi-USV Chart Information.

Figure 17-4: Lower Display for Concept 3 Version of MOCU Multi-USV Video Information.

The modularity and flexibility of the MOCU software architecture allows for relatively quick turnaround in implementing design improvements, therefore the software is well suited to an iterative test and development effort.

17.5 HUMAN FACTORS ISSUES EXPLORED

Human Factors performance issues with two simultaneous semi-autonomous USVs include the following:

1) **Attention Management and Attention Allocation** – Autonomous systems such as USVs that may be in fully auto or fully manual control modes require the user to know where and how long to focus on information pertaining to each USV. Also, the user must shift attention between USVs. The user's strategy must be aligned with the environment (e.g., traffic congestion) and speed of the USV and mission tempo (pace of mission events). Attention management and human vigilance is subject to errors in allocation and fatigue. Initial tests of the baseline 1 model in 2008 indicated the probably of error was high and that visual feedback in terms of type of information coding was not adequate. Also, the point-and-click type of control implementation required full visual attention. Further testing in 2010 indicated significant performance decrement issues if baseline visual cues were used. The Concept 3 version shown in Figure 17-3 and Figure 17-4 included the reconfiguration of displays and use of additional visual cues.

2) **Mental Model of Robot and Mission State** – The user must maintain an awareness of USV mission status and USV equipment status. Situation Awareness includes an accurate mental model of mission

objectives (reaching waypoints, deploying sensors) and safety (approaching danger from fixed or moving objects). The test scenarios for Concepts 2 and 3 included verbal reports for mission waypoints to superior officers. The verbal reporting activity adds to overall user workload. Position awareness and orientation requires understanding of each USV relative to the ship platform, and with two USVs potentially three different course and speeds simultaneously.

3) **Performing Emergency Maneuvers** – The user may need to respond to an unexpected safety issue or threat requiring a shift from automated to manual control and a corresponding course and speed change to avoid collision. If the user cannot quickly orient and respond to an emergency event the mission and USV could be at significant risk of collision and mission failure.

Correlation of real-world stimulus associated with multiple camera views has been a significant design challenge. The camera views distort the perception of approaching and crossing objects (e.g., other vessels). A successful HCI design requires an integration of information that minimizes visual scanning and shift from one display to another. The design problem for afloat USVs differs from both unmanned air and surface (ground robots) in the dimensions, approach and characteristics of obstacles and ability to detect and avoid obstacles. The water operational space is not controlled as air space is and the water surface is constantly moving with waves and floating objects, including submersed objects.

To mitigate human performance risk of errors and improve performance efficiency, several enhanced design attributes were implemented and tested. These attributes include:

1) Attention cues to aid in shifting of attention between USVs.
2) Orientation of map display and camera views to provide synchronized visual feedback to aid in maintaining an ongoing mental model of USV position.
3) Improved visual feedback as mission waypoints approach and are passed.
4) Integration of a hand-held “game” controller to replace point-and-click methods to reduce visual workload associated with manual control. This allows the users visual resources to maintain a camera view focus while a maneuver is made.
5) Overlay and integration of key status information with ongoing dynamic information from cameras and maps to reduce visual search and scanning.
6) USV-specific color coding of video display window borders and vessel status information to reduce confusion between USVs.

17.6 UNMANNED SYSTEMS USED

The live demonstration used a laboratory model USV that was comprised of a commercial craft modified for remote control radio with sensors mounted onboard.

Figure 17-5: Unmanned Surface Test Vehicle.

The following components are part of the demonstration:

- Unmanned Surface Test Vehicle is a lightweight Length: 20’ 6” / 6.25 m, weight: 3,250 lbs / 1,474 kg consumer (non-ruggedized) craft containing sensor packages.
- Sensors include: Digitized marine radar, Video (stabilized or non-stabilized), Stereovision (3D range data), Monocular vision for obstacle detection.
- Automatic Identification System (AIS) (receive-only currently, Uncooled thermal imager (in future possible laser range scanner).
- Multi-robot Operator Control Unit (MOCU) baseline version software and HCI package enabling user monitoring and control of one or more USVs.
- Radio transmitter and receiver for video and communications to/from vehicle.
- Obstacle detection and avoidance software and methods were disabled.

For simulated tests in the laboratory, the MOCU simulation used the larger 11-meter “fleet” class USVs designed for operational missions. The simulation also replicated the types of cameras available on the operational model. These USVs weigh approximately 7700 kilograms. The USVs are designed to be remotely operated from the LCS host ship. Although each USV will be equipped with radar, current plans do not include onboard obstacle avoidance capability.

17.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

1) USN received design guidelines from Canada Defence R&D Canada – Toronto on Intelligent Adaptive Systems.

2) Received guidelines on visual display symbology from US Army HFM-170 member.

3) Posted guidelines for command and control mission flow visualization to all members.

4) USN, Canada, Netherlands – discussed generalization of results to Explosive Ordnance Disposal robot applications.

5) USN, USAF – Discuss speech and voice technology applications for robot control.

6) USN, US Army, Discussion of playbook and work process visualization for mission supervision.

	Planning/Design	***Execution***	***Analysis***
Communication	*1) USN and Canada* *2) USN, Canada, NE*		
Coordination	*2) USN and US Army*		
Collaboration	*2) USN and all*	*Potential USN and US Army future collaboration in upcoming cargo air robot project*	

17.8 SUMMARY OF TECHNICAL DEMONSTRATION RESULTS

The operational demonstration was successfully completed in April 2009 [1],[2] using the integrated map and video version of MOCU. The demonstration had several caveats regarding validity of results. First, the users were not end-users (Navy operators) but instead were project engineers. Second, the mission scenario and course was limited to a small range and area due to safety precautions, with a live human operator available on the USV to take over control in case of emergency. Overall the demonstration showed the validity of the initial HCI design concepts and demonstrated a test capability to conduct further testing and analysis.

Subsequent testing sessions in 2010 [3],[4] and 2011 [5] evaluated Concept 2 (baseline) and Concept 3 HCI designs in support of multiple robot operations. Overall, the testing showed that Navy operators had difficulties in attending to two USVs simultaneously, however performance was significantly improved for Concept 3 with the addition of the enhanced design attributes described above. User performance across three task areas is discussed below:

- Responding to contacts in emergency situations – Each scenario included four events requiring the subjects to observe and maneuver around one or more vessels stationed or moving in the direct path of one of the USVs. In Concept 2 testing, all subjects failed to avoid collision in at least one instance and most were involved in multiple collisions, resulting in an overall collision rate of 67%. Subjects typically noticed the contacts too late to take effective evasive action – even though all contacts were visible in at least one video window for at least 30 seconds prior to impact. In three instances, subjects failed to notice the contact at all and took no evasive action whatsoever as they were monitoring other video windows or performing other tasks. In Concept 3 testing, subjects not only showed an improved

capability to detect contacts but also demonstrated improved capability to successfully execute avoidance actions, resulting in a decline in the overall collision rate to 27%. This rate is still significant for operational conditions. Thus, an upgraded Concept 3.1 will be generated and tested.

- Responding to system status alarms – During the scenario a system status alert was turned red and flashed indicating a high engine temperature alarm. Operators responded by making a report to the mission supervisor. In Concept 2 testing, reports were made within the designated response window only 33% of the time. In Concept 3 testing however, the response rate improved to 63% with improvements also noted in the ability of subjects to take appropriate action (i.e., shut down engines) in a timely manner.
- Making verbal waypoint reports to command – Operators were directed to make reports to the mission supervisor as each waypoint was reached along the pre-planned routes. In Concept 2 testing, timely reports were made 90% of the time for the first and last (4th) waypoints on the routes (typically reached during times of low scenario activity when subjects had few distractions), and 77% of the time for waypoints 2 and 3 (which occurred during periods of high scenario activity and heightened mental workload). In Concept 3 Testing, subjects completed waypoint reports successfully 97% of the time for waypoints 1 and 4, and 84% of the time for waypoints 2 and 3.

In addition to the improved performance noted on objective measures for the Concept 3 HCI design, subjective measures collected during an exit survey also showed a strong user preference for the Concept 3 controls and display configuration.

17.9 LESSONS LEARNED

The initial findings of this study demonstrated that the baseline Concept 2 interface would not safely support simultaneous operation of multiple USVs and identified a number of specific opportunities for improving the overall HCI that were incorporated into a Concept 3 design. Although subsequent testing of the enhanced design showed dramatic improvement across all performance measures, operator errors were still observed at an unacceptable level and additional opportunities for design improvements were noted, including:

- Increased collision avoidance aiding tied to attention alerting cues (the need for advanced obstacle cues may require placement of additional sensors onboard USV platforms).
- Prominent urgent alarm messaging, to include the addition of audio alerts.
- Improved color coding to depict route graphics.
- Refinement of hand held controls to reduce joystick sensitivity and prevent inadvertent shifts in driving mode.
- Enhanced indication and control of PTZ camera magnification levels.
- Additional engine status indication and independent start/stop controls.

17.10 STUDY CONSTRAINTS/LIMITATIONS

The primary limitation of this usability testing was the fidelity of the simulator and the realism of the mission scenario. Several aspects of the simulator differ from the actual system including:

- The substitution of digital animation for live video;

- Non-functionality of many secondary screens that operators would normally have access to;
- The actual shipboard hardware with alternate video monitors; and
- Substitution of a mouse for trackball control.

Although every attempt was made to build a realistic mission scenario, it must be recognized that the initiating events and responding actions represented in the scenario would in actuality unfold over several hours as opposed to the 30 minutes it took to simulate the mission. When questioned about the realism of the simulation most subjects (including the most experienced USV operator who was involved in developing the Operational Procedures for the real system) indicated that it was “pretty close” or “not far off” and that fidelity level would be sufficient to serve as a “useful training aid”.

17.11 CONCLUSIONS

The results of the usability studies confirmed the existence of many human factors concerns that had been identified through previous heuristic reviews and HCI design walkthroughs of interface displays. Based on the results of the testing in which even experienced operators demonstrated degraded performance, the researchers concluded that the baseline Concept 2 design interface would not safely support simultaneous operation of two USVs. Design Concept 3 shows great promise but is not yet at a level that would support safe and reliable operation of multiple USVs simultaneously. Concept 3.1 will be generated and tested in 2011.

17.12 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

Further design alternatives will be explored in developing an improved interface that will be tested and compared to previous versions. The goal of the studies will be to measure performance of the current USV sensor package, with the HCI improvements. Another configuration will include obstacle avoidance aids that are technically feasible. These aids will be simulated and tested for comparison with the lower cost, lower fidelity sensor package. A design trade-off between USV cost, risk and user performance can then be accomplished.

17.13 ACKNOWLEDGEMENTS

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17.14 REFERENCES

[1] Kellmeyer, D. and Benhard, R. (2009). Multi-Robot Operational Control Unit (MOCU) Version 1.0 Usability & Heuristic Evaluation Report, SPAWAR Systems Center Pacific San Diego (unreleased tech report) January 2009.

[2] McWilliams, M. (2009). User Review for USV MOCU 3 (v.8) Wireframe Displays and Design Strategies 8/12/2009, unpublished Technical Document, SPAWAR Systems Center Pacific, San Diego CA.

[3] McWilliams, M., Osga, G., Kellmeyer, D. and Viraldo, J. (2010). Usability Test for Baseline Multi-robot Control Unit (MOCU). Unpublished Test Report, SPAWAR Systems Center Pacific, San Diego CA. August.

[4] McWilliams, M., Osga, G. and Kellmeyer, D. (2010). Usability Test Plan for Multi-robot Control Unit (MOCU) December, unpublished report SPAWAR Systems Center Pacific, San Diego CA.

[5] McWilliams, M. (2011). Recommendations from USV MOCU 3 User Testing, unpublished technical report, SPAWAR Systems Center Pacific San Diego CA.