Conversion Challenges of an Autonomous Maritime Platform: Using Military Technology to Improve Civilian Security

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ABSTRACT

Safe civilian ports are a critical aspect of our infrastructure and our economy. Asymmetric threats against them have grown in both diversity and intensity. Advances in autonomous systems are evolving to counter these threats - and doing so effectively within constraints of shrinking budgets and personnel. This paper describes the Riverscout project - a significant technological advance to improve port security through the use of low cost, commercially available unmanned surface vehicles (USV) for monitoring and reconnaissance. Key benefits described in the paper include optics, to allow remote patrolling operations; onboard sensors, to detect threats; and an M&S-based training suite, to enable training based on the actual platform. A reconnaissance mission typically starts in autonomous mode with the USV following pre-planned waypoints. When any target is detected, the operator switches to manual remote mode to further interrogate. Riverscout's autonomous capability reduces personnel requirements and provides standoff for crew protection.

ABOUT THE AUTHORS

Mr. Jesse Barboza is a Senior Business Systems Analyst at SimIS, Inc. He is responsible for the business/systems analysis of Information Systems development and innovation of upcoming concepts of Modeling and Simulation solutions. Mr. Barboza brings experience to the development of information technologies, software development along with project management to his project teams. Mr. Barboza has a B.S.B.A. from Old Dominion University (ODU) where he majored in Information Systems and Technology with a minor in Business Analytics. Mr. Barboza is currently pursuing a Master's of Information Technology from Virginia Tech.

Mr. Tien Nhan is a Software Engineer with SimIS Inc. He graduated from Old Dominion University with a Bachelor's Degree of Science in Modeling and Simulation. Currently he is also attending ODU for his Masters of Science in Modeling and Simulation. His areas of interest include Transportation Research, Robotics, and software development. Mr. Nhan's focus during this project is on functionality, development, and testing of software.

Mr. Vernon Hayden is an analyst with SimIS Inc. and graduate student studying applied mathematics at ODU. Working primarily with simulation environments, his mathematics background aids in the development and validation of data-driven models to power those applications. In his spare time, he enjoys submitting algorithmic solutions to high computation challenge problems, deriving mathematical models and mechanical solutions for game development, and senselessly working towards a closed-form derivation of Apéry's constant.

Mr. Thomas Langhorne is a 3D Modeler at SimIS, Inc. His talent and eye for art bring a unique perspective for the creation of visual assets, and User Interface design. Mr. Langhorne's education allows him create of art ranging from 2D icons, to fully animated 3D models and scenery. His past experience with coding lends itself well in aiding with software engineering. Mr. Langhorne has Bachelors in Animation from Regent University. In his spare time he enjoys improving his 3D modeling and animation skills through self-study.

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INTRODUCTION

Increased threats to civilian ports and the current fiscal climate call for a low-cost solution for safeguarding our harbors. Autonomous systems present a solution to these maritime security challenges and serve to keep the human operator safe. These autonomous systems and combat technologies present a significant operational advantage in conditions of uncertainty and complexity. Autonomous applications provide maritime security with increased open ocean surveillance and reconnaissance capabilities, the ability to identify vessels not previously known, additional information on crew activity and cargo loading, and the ability to leverage commercial assets that correlate to vessel position information. The notion that autonomous systems are actually "unmanned" is a prevalent misconception. While the robotic platforms themselves are not manned, the systems are, in fact, manned through direct and constant oversight and control by way of Command and Control (C2) systems. Therefore, when developing, configuring, and employing autonomous systems, all system elements must be taken into consideration to support and meet the capability needs of commercial maritime security.

This paper describes the Riverscout project, the US Navy's first unmanned surface vehicle (USV) for river operations, using new technologies to leverage a cost effective solution to reduce the size and weight of controllers while increasing navigation precision. The project can provide support to meet requirements for both military and commercial applications. The Riverscout team developed a virtual testing environment to enhance training and material testing through simulations. The paper will show the benefits of Riverscout, its technological advancements, the virtual testing environment, and the conversion challenges associated with autonomous maritime security. Standard Modeling and Simulation (M&S) techniques can be used to assess the autonomous vehicle's intelligence algorithms, perform trade studies, and exercise algorithms under virtual, yet realistic, conditions far beyond the possibilities of only physical prototypes. Capitalizing on the effectiveness of autonomous systems technologies, the future of manned operations will be revolutionized. M&S is a strong contributor in testing the functionality, controls, and logic of the Tactical Robotic Controller (TRC). The User uses the TRC to control the movement and logic of the USV.

COMMERCIAL MARITIME CAPABILITIES AND FUTURE DIRECTION

There is much potential for state spaces where autonomous vehicles may be tested within a realistic and operational test scenario. This leads to an increased need to utilize these real world objects/models and their perceived attributes, to simulate conditions and evaluate the responses of the systems to the many specific input conditions. M&S can be used to focus test objectives resulting in reduced field test assets, resources, test iterations, and test duration. This vision combines the inherent strengths of the human factor with robotic assets, sensors, manned/unmanned vehicles to achieve enhanced situational awareness (SA), reduced workloads, improved survivability and sustainment.

The Riverscout project enhances SA, reduces physical, cognitive and temporal workload, improves mission performance, and minimizes overall risk to both civilian and military personnel. Riverscout's onboard optics provides information to a remote operator for detection and interrogation at a safe standoff distance while reducing the personnel needs to a single human operator. The autonomous platform can loiter at a point and continually circle a given radius allowing sensors to detect and identify vessels in order to inform the port for an arriving vessel and its assets. This provides much needed open water surveillance and object recognition capabilities to maritime security.

Additionally, the simulation environment helps expand the Riverscout project into commercial applications such as testing USVs of all sizes. Development of a configuration file allows flexibility to the TRC set up and the feedback displays for the GUI in accordance with the type of USV being tested or operated. Using Global Mapper to input designated maps into FalconView with universal world allows the software to be simulated in Unity3D and then unified with the TRC software and the simulation environment. The autonomous system can then be overlaid onto the maps for SA and object location data. The simulation environment can train users on the TRC and can serve as a test-bed for practicing USV movement and understanding USV behaviors.

The virtual test-bed allows concepts and platform changes of a USV to be rapidly tested. Proposed changes to hardware, weight, the position of cameras, and boat movement dynamics are experimented within a controlled virtual environment to provide feedback on effects to the autonomous system. By this use of M&S can verify the USV as operational and ready for commercial applications such as ocean security, patrols, and surveillance.

SUPPORT THROUGH AUTONOMOUS SOLUTIONS

In order to support and surpass maritime operational goals, the Riverscout platform aims to satisfy three critical commercial theaters through autonomous technologies: cost, modularity, and situational awareness. Through integration of advanced, commercially available technologies, the platform provides its operator with heightened situational awareness through real-time Falconview mapping software, a PTZ camera, two L3 cameras for panoramic observation, and a wireless sensor network for global positioning information and craft health monitoring. With respect to total cost of ownership, Riverscout's training and operational capabilities not only minimize the significance (and potential hazards) of live water training for inexperienced operators, they enhance familiarity between system and operator.

Cost Reduction

Riverscout derives low-cost through components and simulation. Cost effective components, especially those that are commercially available, can be more readily replaced and still retain their reliability. The availability and reduced cost of these materials address the issue of salt water as an insidious concern when it comes to the lifetime of the boat and its components.

The advantage of the simulator allows Riverscout to reduce such a risk such as operational failures, through multiple factors, and thereby reducing cost. With the use of the simulator, training, mission preparation, and even component testing are possible without the risk of environmental deterioration. Even travel costs, and the need to travel for testing, are reduced because concepts can be tested in a controlled lab environment using the simulation.

Modularity

Developed with modularity in mind, the Riverscout is designed for use on multiple platforms. The software can be configured to deal with varying platform types and thresholds for battery life, temperature limits, minimum satellite links, and even operational control radius. The system is even built with engine configuration in mind, is able to return readout, and can function on USV motions through bucket or engine layout.

Modularity also exists through the simulator. The environment is independent, but data packets are continually sent to the TRC. Every function, input and output, from the sensors, to the cameras, even the CANbus itself is modular. Each class in the software performs a specific function or acts as an object. The simulator allows for testing modes in a controlled lab before testing of the physical environment and testing for multiple scenarios inside the simulator.

Increased Situational Awareness

The need for a human operator is a key factor of autonomous systems and their operations. While many command and control (C2) systems are a burden of size, and hard to move, the TRC allows for the same range of control, while minimizing its footprint, and increasing mobility. Command and control interfaces must allow a human commander to stay at the commanding level in order to supervise execution, monitor the progress of the overall mission with the capability to receive detailed information about individual vehicle operation. The TRC is a portable, lightweight system that can easily be carried by a single individual. Though there may be a necessity for other observers, the only personnel needed to operate the TRC, and thus the USV, is a single person. Carried by a backpack, the TRC is equipped with a battery supply, GPS, antenna, and the handheld interface. The size of a tablet, the handheld TRC interface fits in the hands of the user and is comprised of hard button controls and a touch screen. The interface software provides operator control of the USV, observation of the environment through streamed optics, monitoring of the system's current health status, and the ability to dynamically create new mission and route parameters. This feedback along with onboard optics keeps the user updated and aware of the craft's situation and condition.

Technological Advances

As a major part of the execution, the platform must perceive its own world, respond as necessary, and return relevant behavior information back to the human operator. Riverscout has integrated new technologies in the development of the autonomous platform interface that provides capability for the human operator to command rather than drive the USV. Combined with advanced onboard autonomy, the technology allows high-level, complex missions to be executed without human intervention while allowing full tactical command and control.

FalconView
FalconView is mapping software that enables a user to access multiple maps with real-time latitude and longitude coordinates. The TRC uses Falconview to display the map of the designated area that the USV will be using and overlay icons for the boat object and waypoints of the planned mission. The software allows imports of additional raster type maps with geographic information from Global Mapper for viewing on the TRC with varying resolutions.

Optics
The cameras represent the perception of the USV, allowing object identification. The USV uses optics in order to give the operator visibility of the craft through the TRC display. Two types of cameras were implemented on the Riverscout platform and streamed scene mapping and knowledge of the external environment. The PTZ camera has a 180 degree horizontal side to side view and a 90 degree vertical up and down view. The PTZ camera is also an infrared thermal camera. The L3 Cameras include two cameras both with 180 degrees of vision streamed together forming 360 degrees field of view.

Sensors
The sensor devices create a wireless sensor network equipped with a set of low-cost off-the-shelf sensors commonly used in cooperative perception research and applications. Perception is not just limited to optics, but encompasses the whole of the USV and its functions. Through the use of the boat's compass, radio, and GPS, the user remains connected with the craft's direction and position. In the case of failure, the other systems allow the user to be aware of the craft's last known location, and through the use of various sensors placed through the boat's hardware, the user maintains awareness of the boats internal condition.

INCREASED TESTING CAPABILITIES

Simulation allows for increased testing capabilities. M&S allows testing of extreme environments that may be too dangerous, costly, or not possible to observe and allow the collected data to be mapped to the established meta-models of the standardized system. Current testing methods include physical testing of logical concepts, modules, and boat movements in a real physical environment. However, Riverscout introduces simulation hardware-in-the-loop testing. In a hardware-in-the-loop test, testing of the hardware is done in the simulator then tested with real hardware, and this process is repeated. Testing is done using the simulation environment and the TRC software, without need of the real physical environment. This project that initially utilizes a "bottom up approach" to include M&S capabilities that help certify engineering performance of a chassis and sensor packages along with developing techniques that will incorporate high fidelity into the perceived models that are embedded into a virtual test-bed through real world data driven and physics based objects. The government will then be able to proceed with a "top down" approach to certification of the performance that decomposes high level mission requirements into parts of the developed virtual test-bed.

Concepts can be tested in the simulation environment without risk of damage to any hardware. As nearly all logical concepts that utilize movement of the boat can be tested using the simulation, commercial maritime crafts will avoid potential hardware deterioration as the result of unnecessary salt water testing. When concepts are verified in the simulation, then final testing can be done in the physical environment. To avoid unnecessary damage and corresponding maintenance to hardware components, testing is completed in the simulator before being introduced to the real environment.

Perception

Using M&S to provide a testing environment for the autonomous vehicle's perception provides the ability to acquire and use the knowledge about the environment and the USV through taking measurements from various sensor devices as a means of environmental monitoring. Perception requires scenario recognition, which is based on the continuous input of many different types of sensors. In the future, all control systems will have to cope with massive quantities of data that are collected from the environment. A stable system that can reliably perceive situations depends on the diversity and amount of sensor inputs. M&S provides a means to develop perception models to better address gaps among the human operator perceptions and that of the autonomous vehicle, while leading to better algorithms for internal perception and decision making through artificial intelligence (AI).

Virtual Testing Environment

The inaccessibility of the remote environment combined with the cost of field operations have been the main obstacles to the maturity and evolution of the autonomous technologies. The deterioration of hardware due to natural elements affects the lifetime and budget of the project. This makes real world monitoring and testing a challenge for the developer/operator as they are unable to react quickly or in real-time to the remote platform stimuli. Through concentrated simulation, test methods introduce specific logical or run time operating states that induce an algorithm failure to poor developed logic, create a mechanism for recording and initializing systems to specific states, and act as an interface control description that emulates real world sensor outputs to be provided to the system under test. To simplify cost and testing of associated technologies, the Riverscout team immediately recognized the value of a simulated test-bed. A virtual-environment-based test-bed offers an alternative to difficult, costly, and possibly hazardous real-time testing and evaluation.

Unity Pro

The test-bed is based on high-level mission objectives, priorities, constraints, and rules of engagement. Keeping with Riverscout's modular design goals, every craft component, from individual sensors to non-linear small-scale USV dynamics, needed to be implemented in an appropriately modular fashion. The simulation also needed to interface with and expedite feedback for development theaters whose functionality could not previously be tested without live water tests, but whose development success may be delayed due to lack of such tests. To meet these goals, the simulator is built around the Unity3D environment, a core feature of which is the reuse of Riverscout's onboard software.

The software implemented on Riverscout's on-board microcontroller (the MMC) is designed around the typical 'setup' and 'loop' functions, mirroring the 'Start' and 'Update' functions within Unity. In order to reuse that software, the team built a simulation-specific DLL to drive the Unity simulation using the physical craft's exact onboard code. In addition, having the capability to recognize and correct defects within that onboard code, the simulation's design also allows users to inject systematic failures into the system through the simulation interface and observe the system's response to such a failure.

C++ SimImplementation

The integration of standard tools and interfaces increases usability, allowing an easy extension to new hardware and software components and the reuse of code while decreasing cost of development and allowing for standard simulations to test component changes. The sensor net would enable the Navy to simulate the information passed by the new sensor arrays across physical interfaces and permit system testers to mimic the actual tactical use of the system. This would expose design defects early in the development cycle and could be addressed by a tester within a controlled environment suitable for defect resolution.

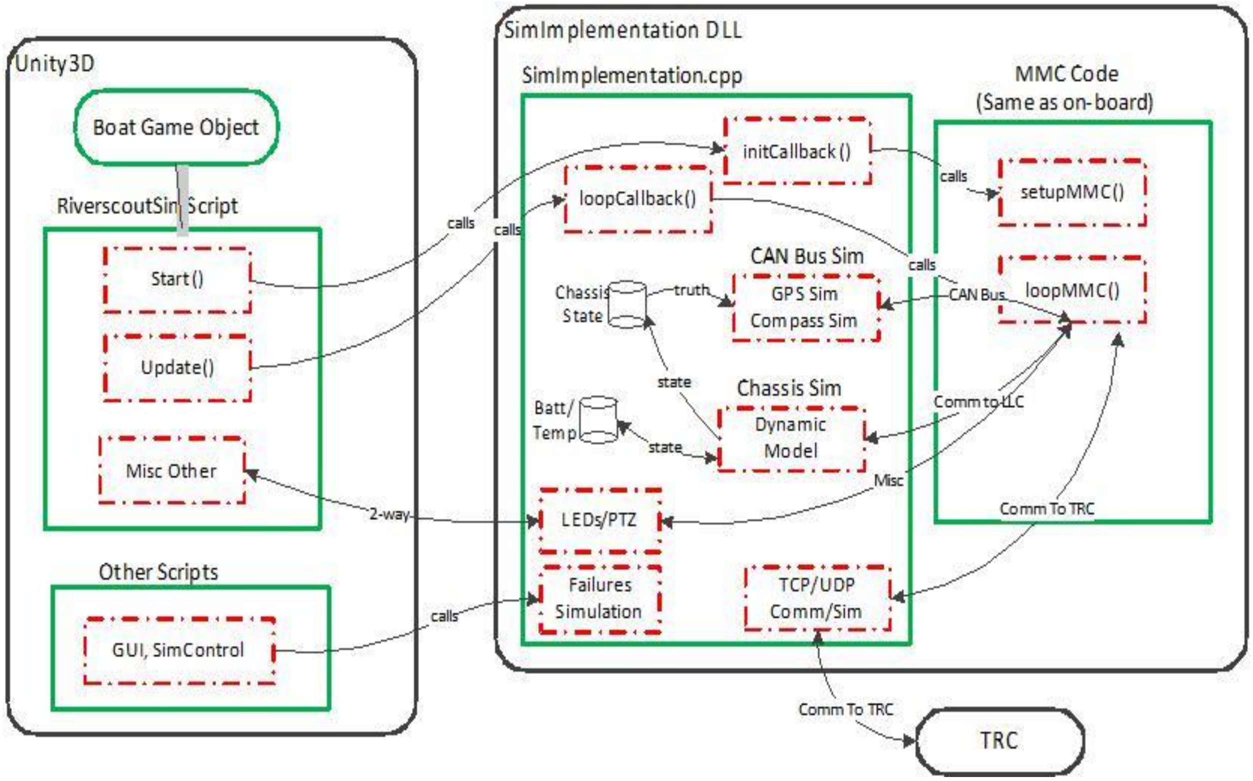

Figure 1: Simulation Architecture

Figure 1 above represents the Riverscout's simulation architecture. The simulation architecture utilizes the actual software routine onboard the physical craft, with Unity playing a deceptively limited role overall. On initialization, Unity triggers the execution of SimImplementation, an external dynamic-link library (DLL) controlled by the TRC software through a user datagram protocol (UDP) network. Once SimImplementation begins its routine, Unity repeatedly calls for updates on craft state and variable information within that DLL, changing the visual environment according to changes within the onboard code and simulated modules. In addition to observing communication between the TRC and a simulated Riverscout craft, the simulation architecture allows users to manipulate actual values and operations within the onboard code during the simulation's operation in real-time, such as observing the residual effects of injected radio delays or outage.

During initial simulation development, analysis of live test data and operational observations revealed hardware-related issues related to craft dynamics. To avoid developing a data-generated model relevant only to outdated hardware, (in the interest of time) the team developed a simple second order linear state-space model within Matlab, operating within the simulator's implementation DLL. This simple model operates under the same modular principles guiding Riverscout's overall development and serving as a placeholder for more advanced future models once hardware updates complete. For model validation and verification (V&V), the simulation utilizes the TRC's data logging capability, exporting simulator-generated data files for comparison with live data.

Networking TRC to Sim

The simulation environment acts as the virtual environment and virtual boat, the information must be sent to the TRC in order to replicate real-time GPS and craft mechanics. A communication protocol is needed to facilitate communication between the TRC and the simulation environment in Unity. The simulation incorporates a User UDP C# winsock application to establish communication. Once a network is established between the TRC and the simulation, packets are continuously sent back and forth representing actual data being sent back and forth from a real craft and the TRC. Due to our own packet protocol structure, a UDP network is chosen over a TCP network; a TCP network has a standard packet order and for the Riverscout purposes, a custom protocol order is preferred. Also, a UDP network is a lightweight, connectionless communication, allowing for fast communications with no need of acknowledgement, instead only an established connection.

CONVERSION CHALLENGES OF IMPLEMENTATION

Given the significance of Riverscout's modular design, the conversion challenges from government to commercial are kept at a minimum. As with any autonomous system, initial design plays a key factor in flexibility and scalability of the USV and it capabilities.

Software Challenges

Software challenges include converting from Department of Defense specific software that may be unusable in the commercial industry such as FalconView. However, the challenge may be mitigated as FalconView also supports an open source version which could be implemented. Additional software challenges include integration of new applications that commercial projects may need that are not yet designed and available for implementation into the current platform. The software architecture should be kept modular, making for a standard design.

Hardware Challenges

Hardware challenges include ensuring that the TRC software has a configuration capability that is generic and dynamic enough to handle the addition of new hardware. Hardware includes new components of USVs or upgrades in the TRC hardware. First, the hardware will have to be thoroughly tested using the simulation, and then the real hardware can be tested as a means to verify and validate the configuration. Functional hardware is critical to operating the boat and reliably transmitting information from USV to TRC.

CONCLUSION

Safeguarding our ports with budget constraints has created a problem domain for which Riverscout can provide a solution. This program provides added capabilities to the ports for security at low cost while increasing safety to the human factors with proven concept to implementation. Riverscout meets requirements for Maritime security to utilize new technology for further development of sensors, optics, and autonomous platforms that increase flexibility along with interrogate and standoff detection capabilities. The use of simulated virtual testing environments allows for low cost ways to address possible hardware and software faults without using the real system. A key function to simulation testing is that software for other larger vessels can be assessed within a controlled environment before launching. Both in simulation and in experiment, our results are showing that this type of networked autonomous system of systems is both appropriate and possible through the integration of video tracking and sensor control across platforms and the network.

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