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ACADEMIC/INDUSTRY EDUCATIONAL LAB FOR SIMULATION-BASED TEST & EVALUATION OF AUTONOMOUS VEHICLES

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ABSTRACT

An academic/industry alliance can improve the preparedness of students to enter the workforce. When the alliance is centered around a laboratory providing students real world research and development experience, both partners benefit from the intellectual engagement. This paper discusses the benefits of a collaborative laboratory being developed in support of the modeling and simulation engineering program at Old Dominion University. The laboratory focuses on simulation-based test and evaluation (T&E) of autonomous vehicles, an important economic and social problem. Economically, driverless cars and drone delivery systems are the wave of the future. Socially there are issues of public acceptance of these systems as evident by public reaction to the infrequent, but highly public, accidents involving driverless cars. The laboratory allows academia and industry to address these important problems by improving the T&E of these systems while also improving student skills, giving undergraduate and graduate students an opportunity to participate in research.

1 INTRODUCTION

With the advent of a new modeling and simulation engineering undergraduate program, it was necessary to establish strong academic/industry relationships to ensure educational goals. Initially that involved the creation of an industrial advisory board to garner input on curricular issues. However, that has limitations in the impact the industrial partner can have on the educational process. The next step was to create a strong internship opportunity. While creating a strong relationship between industry and the students, it does not directly influence the curriculum. To provide a more direct relationship between industry, the students, and the educational experience, a joint laboratory experience is being created where industry drives the problems of interest and solution approaches while students under faculty supervision drive the solutions themselves. The first such lab focuses on simulation-based approaches to test and evaluations (T&E) of autonomous vehicles as a core industrial partner need.

Autonomous vehicle testing is a major concern to developers. Three recent papers explore the challenges of testing autonomous software. In Koopmann and Wagner (2016), testing and evaluation of autonomous software for unmanned land vehicles is discussed. In Menzies and Pecheur (2005), challenges in verifying and validating artificial intelligence software for use in autonomous vehicles for conducting deep space missions is explored. And in Schumann and Visser (2006), the results of a survey of NASA autonomy experts and software engineers to identify the challenges of verifying and validating autonomy software for applications in unmanned air vehicles are reported. All three papers identify very similar reasons why testing and evaluation of autonomous software is challenging. First, in fully autonomous vehicles, there is no human backup to address faults, malfunctions, and unexpected operating conditions.

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The autonomy system must assume the role of the primary exception handler. Thus, the autonomy software must have significant additional complexity to address all potential contingencies, making testing more difficult. Second, autonomous software often utilizes non-deterministic components and statistical algorithms. The planning component of autonomous software often is based on ranking the performance of randomly generated alternatives. Additionally, common sensing algorithms are based on stochastic models for noise resulting in probabilistic test results. This makes it difficult to evaluate the results of testing because there is no uniquely correct result for a given test scenario and the tests are non-repeatable. Third, autonomy software for unmanned vehicles must meet extremely high standards for safety. A failure of the software could result in the destruction of property and loss of life. Thus, the software system must be tested extensively to demonstrate that failure rates do not exceed an acceptable safety threshold. Such vehicle testing is time consuming and expensive; often it simply is not feasible to conduct enough tests with the physical vehicle to ensure desired safety levels. In Hodicky (2015), it is suggested that modeling and simulation should play a larger role in integrating autonomous systems into the operational field. It is conjectured that testing autonomous software in physical and synthetic domains using modeling and simulation holds the potential to greatly reduce the cost of autonomous system deployment.

In addition to the significance of the problem, autonomous vehicle T&E poses a rich environment for the application of modeling, simulation, virtual reality, and augmented reality. This makes it an ideal problem for students to exercise their breadth of knowledge and skills. A lab addressing this problem presents both graduate student research opportunities and undergraduate development experiences. While the lab is in its initial stages, this paper presents the anticipated benefits to both academia and industry that were the driving force for initiating this effort. The paper presents the concept and structure of the lab in Section 2. Section 3 highlights the academic benefits of the lab, both for undergraduate and graduate students. Section 4 presents the benefits anticipated by the industrial partner. Section 5 discusses future directions of the lab.

2 AUTONOMOUS VEHICLE T&E EDUCATIONAL LABORATORY

The lab is designed to provide an educational experience at both the graduate and undergraduate level. Graduate students perform research in creating an environment to enable testing during the full lifecycle of the development of autonomous vehicles. While not providing a formal lab within the curriculum, the lab provides undergraduate students a chance to participate in research, obtaining scholarships and internships to promote and enable participation. This requires the lab to compartmentalize efforts that can take advantage of undergraduate skillsets as they progress through the curriculum. Participation will provide students further insight into M&S, thus reinforcing their educational experience.

2.1 Concept: Testing Across the Reality-Virtuality Continuum

The autonomous vehicle T&E lab attempts to promote hardware/software codesign and development. A simulation-based approach is utilized, relying on virtual reality (VR) and augmented reality (AR) to supply external stimuli in the absence of available real stimuli early in the design and development process. To achieve this, there is a parallel development process for a simulation of the physical vehicle and for a virtual environment in which the vehicle can operate. Given initial requirements for the physical vehicle, a behavioral model is developed and simulated, allowing initial testing of the autonomous software. As the vehicle is designed, the details of the vehicle are included in the model, increasing the realism and fidelity of the simulation, until a full functional simulation is available. Likewise, the virtual environment must be developed in parallel, appropriately representing the world with sufficient realism as required for testing. Failure to develop these components in parallel would hinder the autonomous vehicle development as system testing would/should delay future development. The test environment is designed to have as little impact on the ongoing design and development of the physical vehicle and the autonomous software as possible. Testing progresses from a fully simulated system to full physical testing with supporting virtual reality and augmented reality.

In Milgram and Takemura (1994), augmented reality is described as being a member of a larger class of mixed reality displays. Mixed reality displays are described as existing in a *reality-virtuality continuum*. This continuum is bounded on one end by *reality* and on the other end by *virtuality*. In between these end points live a continuum of mixed reality displays that includes *augmented reality* displays and *augmented virtuality* displays. An augmented reality display consists of a display of mostly real objects but augmented by one or more virtual objects. An augmented virtuality display consists of mostly virtual objects but augmented by one or more real objects. The application of this mixed reality perspective to the design, testing, and evaluation of autonomous systems quickly becomes apparent. During initial phases of design, virtual models of autonomy strategies, vehicle components, and vehicle environment can be utilized. As the design continues, a few system components are prototyped in software or hardware and used to augment the virtual system representation. As design and prototyping progress, a majority of system components are realized in software and hardware and are augmented by virtual components whose realization are not yet complete. In the final stages of design and testing, the autonomy software and vehicle hardware are complete and tested in the real environment. An example of using this approach applied to the design and testing of autonomous underwater vehicles is described in Davis and Lane (2010). A virtual reality framework is developed to model the environment and interfaced to physical vehicle hardware and software via an Ethernet-based communication network. This system is used primarily for vehicle testing and evaluation.

The lab presented here covers the full continuum shown in Figure 1, first presented in Leathrum et al. (2018). The process starts on the left with a completely simulated system. As the vehicle's specifications are completed, a behavioral simulation is developed on which basic autonomous control algorithms can be tested. As the design continues, the vehicle simulation progresses to a physics-based simulation to provide more realism for testing the autonomous control. In both cases, the simulation operates in a virtual environment, getting all external stimuli from the environment. As design progresses into development, the continuum moves into the Augmented Virtuality stage where the current state of the autonomous control can be run on the physical computing platform. However, sensor input would still come from the virtual environment and the vehicle motion would still be simulated in the virtual environment. Keeping sensor data virtual, the physical vehicle can be introduced for realistic motion testing. At the same time, sensor input to the autonomous software can be tested in isolation. Moving into Augmented Reality, the actual vehicle can be tested, but in an augmented environment. The vehicles can sense and move in the physical environment, but the environment is augmented with select information from the virtual environment, such as virtual obstacles, by intercepting the physical sensor data and augmenting it with virtual data. Finally the physical system is tested in a fully physical environment.

2.2 Framework for Autonomous Software Development

A primary goal of the testing process is to provide a seamless transition from testing to fielding, covering the complete continuum, to facilitate its use. To this end, the software should be unaware of its current environment, requiring no modifications to allow it to operate in a test environment. The goal is to avoid impeding autonomous software development for the purpose of testing. The process requires information to be inserted/replaced within the autonomous system pipeline to simulate the input of sensor data or sensed objects without the knowledge of the autonomous software. After processing, it is desirable to observe outputs to evaluate the behavior of the autonomous software and the ability for the vehicle to enact the plan. The architecture must support a consistent format between virtual and real data such that the system can readily accept both types.

A model for an autonomous control system is described to identify key features of the system when developing and testing autonomous software. The software framework is built around this model. Control systems require the ability to utilize various sensors to gain information about the external environment. Control systems must also be able to interface with a physical system's actuators to instruct the system to act. Finally, control systems must be robust enough to adapt to changes in the environment, maintaining consistent feedback and behaving sensibly to a wide variety of possible situations (Brooks 1985). To this

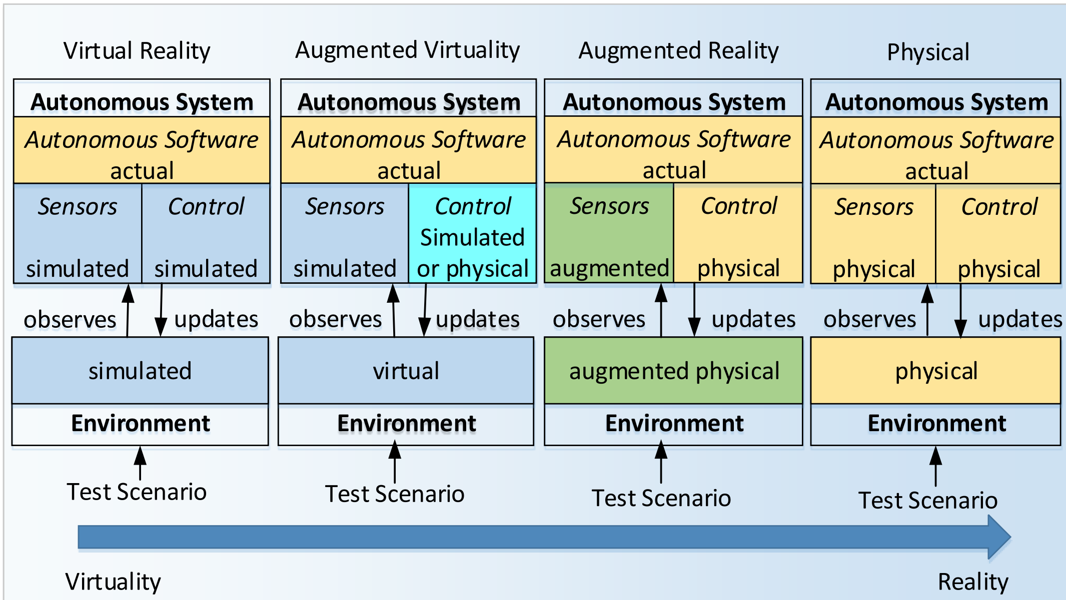

Figure 1: Virtuality to reality continuum.

end, the purpose of the control system is to generate a plan based on knowledge of the external environment and execute the plan based on actions made available by hardware actuators.

The modeling of autonomous control systems for mobile robots has an extensive history of research and development. One approach is to model the control system using a pipeline of functional modules – sense, plan and act (Gat 1998). It is composed, at a high-level, of the autonomous software, the hardware, and the external environment. The hardware can be broken down into sensors, actuators, and vehicle dynamics/state information. The vehicle dynamics and state information include physical attributes of the vehicle such as velocity, orientation, and fuel level. The software can be further decomposed into the functional modules that generate and execute the plan for the system and a world representation, an internal representation of the external environment and internal vehicle state. The world representation could include a panoramic view of distances to boundaries, sets of recognized objects and their computed attributes, or a map of the environment based on past experiences of the robot. The modules are:

- Sense – Computes a perception of the environment based on incoming raw data from the hardware sensors. This involves mapping the raw sensor data to the world representation.
- Plan – Generates a plan composed of actions based on the system's current world representation, operational goals, and past experiences.
- Act – Executes the plan by converting actions to control signals to send to the actuators.

The high-level architecture shown in Figure 2 is the basis for all work in the laboratory. The architecture is composed of the main stages of the autonomous system model, but includes as part of a test harness a software interface between the stages to define locations where information can be injected/replaced without the knowledge of the autonomous software. The software architecture isolates each of the main stages (Sense, Plan, and Act) of the autonomous software from each other and the hardware of the autonomous system (sensors and actuators) for modular testing. At each interface between stages or between a stage and hardware, a model of the information being passed is inserted. Each model operates in one of three modes for each piece of information being passed: it can pass the information through as is, it can augment the information with information from the virtual environment, or it can replace the information with a representation from the virtual environment. This allows each interface to address the continuum. VR and AR are applied for the sensor models and the information model.

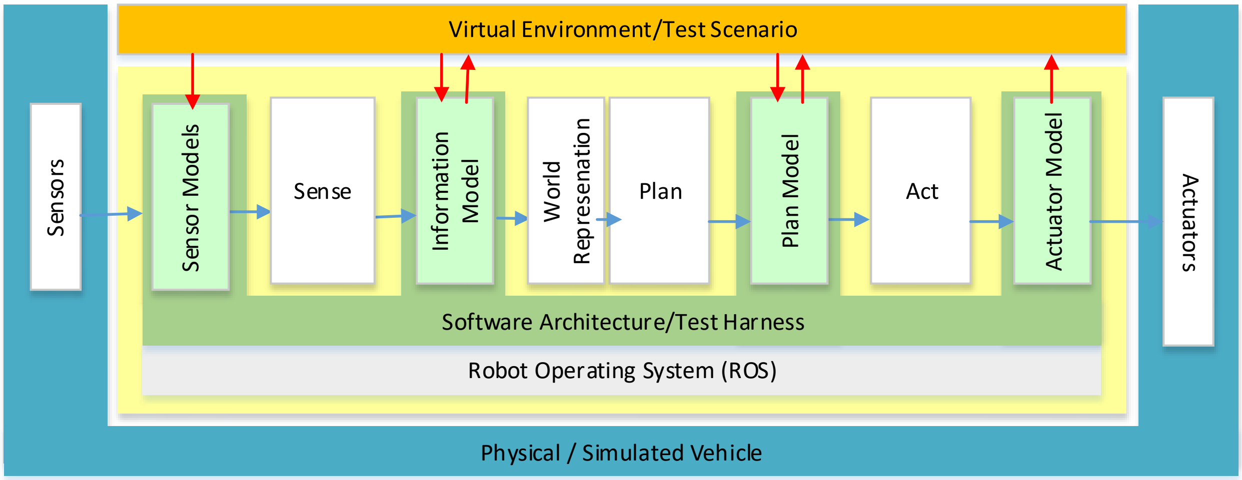

Figure 2: Framework for autonomous system development.

The architecture is being built on the Robot Operating System (ROS 2018) to facilitate use of previously built models and interfaces, especially for sensors and actuators. In addition, it enables testing during the virtual reality phase on a single computing system and then mapping the architecture onto multiple processors as is common on current computing platforms found on autonomous vehicles (Wei et al. 2016). It also allows the virtual environment to be moved off vehicle to support augmented virtuality and augmented reality with wireless communication providing the necessary transfer of information. Finally, the architecture must be lightweight in terms of processor intensive tasks to keep up with real-time communication with a physical vehicle. Building onto ROS allows for simplification of the top layers of the architecture by taking advantage of ROS's existing and efficient infrastructure for data mapping and communication.

2.3 Integration into Autonomous Vehicle Design

A primary concept of the lab approach is to integrate the T&E process into the design and development process as early as possible. To that end, part of the purpose of the lab is to identify when and how to apply the T&E concepts discussed here. Figure 3 illustrates a rudimentary first pass at this process, presented as a waterfall process as a simplification allowing the focus to be on the interaction between concurrent development processes. The idea is to first identify where testing based on different stages within the virtuality continuum can be applied. Given those testing milestones, a parallel development process is defined to ensure the simulation and virtual environment capabilities are complete in time to avoid delaying the design and development. This may require reducing the level of realism in the models, thus rapid prototyping to meet deadlines.

The process begins with defining system requirements for both the hardware and software. At the same time, the environment concept is developed, initially as scripted tests. The requirements can then support development of initial behavioral models which can be tested against the scripted tests from the environment for proper behavior. As the hardware is designed, an associated physics-based model is developed for better functional simulation which prototype autonomous software can interact with. The environment continues to evolve so that the simulation can be observed in the environment. As implementation progresses, the resulting capabilities can initially be tested in a virtual reality, continuing to an augmented reality as capabilities are developed and tested, finally resulting in physical testing.

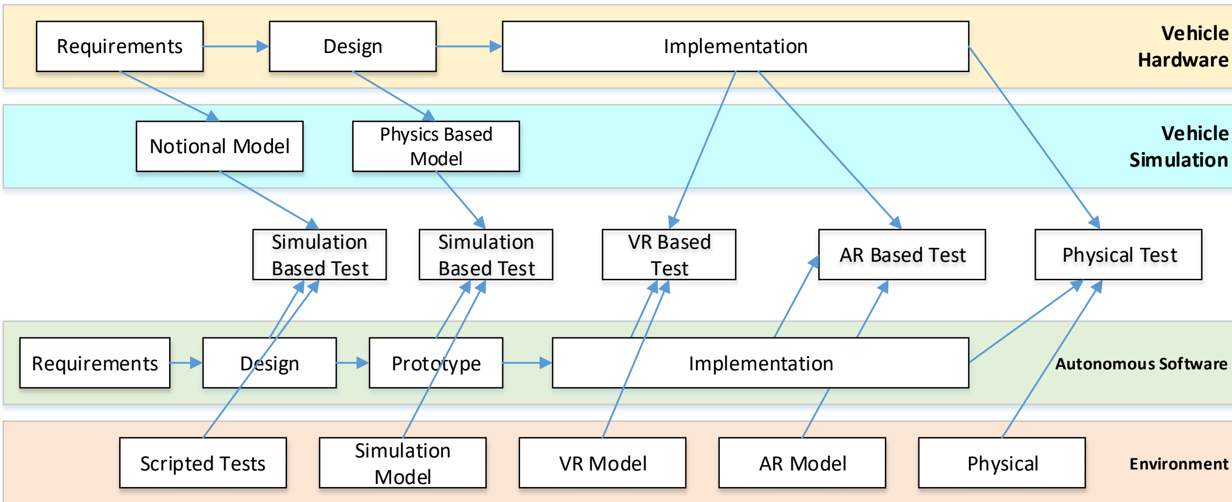

Figure 3: Integrating the virtuality testing spectrum into the lifecycle of autonomous system development.

2.4 Student Involvement

As the lab's real purpose is student education, identifying student involvement is necessary. Students are divided into two groups within the lab. Graduate students are responsible for research based concepts, in particular design and development of the software framework supporting autonomous software development shown in Figure 2, the development of the process shown in Figure 3, and the design of the VR/AR capabilities necessary to support the testing. Undergraduate students will be focused more on the development of the system. For instance, they will develop sensor and vehicle models and simulations though the spectrum. They will also develop other objects or components in the virtual environments, such as pedestrian model and behavior, weather simulations.

2.5 Future Direction

While the current lab development focuses on the M&S testing of autonomous vehicles, it is intended to include the actual design and development of autonomous vehicles. This will involve including students/faculty from other departments, namely electrical and computer engineering, mechanical engineering, and computer science. Both electrical and computer engineering and mechanical engineering have student organizations competing in autonomous vehicle competitions (land and water respectively). This will allow work to address the ability to integrate into the project lifecycle. In addition, M&S students and computer science students will be engaged for the development of autonomous software to assess the ability to develop in the autonomous software framework under development.

3 IMPACT ON M&S EDUCATION

The decision to develop a laboratory focused on the design and evaluation of autonomous systems was made after carefully considering the impact that the laboratory could have on the department's undergraduate and graduate programs. At the undergraduate level, the laboratory has the potential to enrich virtually every core course and a significant subset of our technical elective courses. At the graduate level, it should provide an important resource for design, development, testing, and evaluation for many of our research activities. The purpose of this section is to describe and explain the impact that we expect this laboratory to have on our educational programs.

3.1 Undergraduate Program Impact

Our undergraduate program leads to the award of the Bachelor of Science Degree in Modeling and Simulation Engineering (M&SE). It is the first modeling and simulation undergraduate program to receive ABET-EAC accreditation. During the first two years, students enroll in the usual engineering fundamentals courses, including mathematics, basic sciences, computer science, and other general education courses. The M&SE program core, taken primarily in the sophomore and junior years, covers three primary areas: basic modeling and simulation, analysis, and software development. (Mielke et al. 2011) In addition, students must select two or more technical elective courses from a list of electives. Students are required to complete a two semester capstone design course sequence where they design and develop a prototype system for a local company or organization. In the short time the program has been in existence, two capstone projects have already been focused on autonomous vehicles, a NASA project simulating air traffic control for airspaces that include autonomous aircraft and a Navy project developing a rapid prototyping environment for creating simulations of boats on which autonomous software can be tested. A display of the M&SE core courses and related elective courses is presented in Table 1.

Table 1: Modeling and Simulation Engineering core program.

Sophomore Year • Introduction to Modeling and Simulation • Discrete Event Simulation & Lab **Junior Year** • Continuous Simulation & Lab • Computer Graphics and Visualization • Simulation Software Design & Lab • Model Engineering • Analysis for Modeling and Simulation	**Senior Year** • Game Physics Modeling and Simulation • Capstone Design I • Capstone Design II **Related Technical Electives** • Distributed Simulation • Game Development • Design/Modeling of Autonomous Systems • Artificial Intelligence

The autonomous systems laboratory potentially can provide support to virtually all of the M&SE core courses and many of the elective courses. Direct course support will occur in the following ways.

- Illustrative Examples and Problem Assignments – The laboratory provides a real-world context for developing classroom examples that illustrate important concepts and applications of course content. Specific examples include: Monte Carlo and discrete event behavioral models and simulations for high-level vehicle representations and for representing strategies for autonomy; physics-based continuous models and simulations for representing higher fidelity vehicle dynamics and sensor/actuator responses; model engineering to represent sensors, actuators, and vehicles, computer graphics and visualization for representing and visualizing the environment and virtual system components, distributed simulation to address time management and interfacing issues, and game physics and game development to address computational and component integration requirements.
- Course Projects – The laboratory presents the opportunity to develop problem assignments around problems and issues that occur frequently in the design and evaluation of autonomous systems, It also provides the facility and resources to prototype and evaluate proposed problem solutions. This adds a degree of realism and real-life engineering experience that is difficult to achieve without access to such a laboratory facility.

The autonomous systems laboratory promises to facilitate a number of other desirable educational objectives and activities. A brief listing is presented in the following.

- Teamwork – The laboratory provides the context and physical resources to conduct team activities related to core courses. Small to medium sized groups of students are able to work cooperatively on problem solving and design/development activities. The laboratory provides the required resources and a persistent environment to conduct these activities that may require several days or weeks to complete.
- Cross Disciplinary and Multi-Disciplinary Activities – The design, development, and evaluation of autonomous vehicles are activities that are of interest to, and even require, participation of individuals having diverse knowledge and skill sets. Thus, the laboratory provides the context for students from different disciplines, electrical engineering, computer engineering, mechanical engineering, computer science, to work cooperatively on different aspects of a common problem. It even has the opportunity to engage the softer disciplines, for instance to develop tests for the ethical behavior of the autonomy. We have attempted to develop such activities many times, mostly with limited success. This facility and problem area will facilitate another attempt to establish cross disciplinary and multidisciplinary activities that we believe will be more successful and longer lasting.
- Student Competitions – A number of programs within our college of engineering participate in regional or national technical competitions that focus on the design and development of various autonomous vehicles. It is difficult to achieve a viable continuous improvement plan for such activities for at least two reasons. First, most often the competition participants reside primarily within the senior class. When they graduate, the knowledge and progress that they achieve is mostly lost; there is a lack of continuity in these projects that limits accumulation of success. Second, teams often are organized within traditional engineering disciplines and thus possess a limited breadth of knowledge. Rarely do they have the knowledge and skills required to test and evaluate at a complete system level from initial design through development completion. The components and subsystems often work well, but fail when integrated and placed in an actual physical environment. The autonomous vehicle laboratory addresses both of these limiting factors. Since the laboratory will be utilized to support numerous core courses, juniors and even sophomores can contribute through projects and assignments in their core courses. Additionally, the laboratory is specifically designed to support complete system testing and evaluation throughout the design and develop life cycle. We are especially enthusiastic over this capability.
- Student Professional Development – We were surprised at the level of interest and enthusiasm that local companies and organizations have shown in this laboratory development project. They view this facility as an opportunity to gain contact with students having knowledge and skills that they have been able to find only in masters or doctoral programs. As a result, companies and organizations have offered to partner with us in the laboratory development by providing hardware, software, class and seminar speakers, student internships, and even the use of facilities that support physical vehicle testing capabilities. These relationships benefit our students during their degree programs and when it comes time to seek employment.

3.2 Graduate Program Impact

The laboratory affords graduate students a rich environment to conduct research in areas that are core to the Department of Modeling, Simulation, and Visualization Engineering and related majors, such as electrical and computer engineering, mechanical engineering, and computer science. In addition to be directly involved in the design and development of the laboratory, graduate students will conduct research in other areas that utilizes the laboratory, and in turn contribute to the further development and expansion of the laboratory. Several directly related research areas are described below and the issues discussed can be used as research topics for theses and dissertations.

- **Software Architecture and Design**. Autonomous vehicles are complex systems that are composed of numerous subsystems and components and as such, autonomous vehicle software and the corresponding test and evaluation software can involve a multitude of software architecture and design techniques and options. Various software design patterns, such as abstract factory, singleton, adapter, composite, and façade, can be utilized for different subsystems or components, or at different levels. To satisfy the real-time performance requirement of autonomous vehicle test and evaluation, emerging parallel computing technologies, such as multi-core programming and computing on graphics processing units (GPU), will be utilized. Cloud computing platforms will be employed to facilitate collaboration and increase the accessibility and impact of the laboratory. Various software development processes such as agile development and spiral development will be exploited for different types of autonomous vehicles, sub-systems or components of the software.
- **Virtual Environment Modeling**. The virtual environments for various types of autonomous vehicles (e.g., aerial vehicles, underwater vehicles, cars) differ vastly in terms of complexity and scale. Virtual environment creation and modeling is a very tedious and time consuming process. Different approaches will be investigated and utilized, such as 3D scanning that uses various types of scanners to generate 3D models of the objects beforehand and procedural modeling that generates or modifies 3D objects through computer code on the fly. One important issue in virtual environment modeling is level of details (or levels of abstraction) that represents the object's attributes at different levels of details, which is critical for different phases of autonomous vehicle design, test, and evaluation, as well as satisfying the real-time requirement of the test and evaluation.
- **Virtual Reality**. Virtual reality requires a high level of coordination between the virtual environment and the autonomous vehicle's computing platform. The communication between the VR testbed and the autonomous system is handled by the software architecture and can be wired or wireless (Wi-Fi, Bluetooth), depending on the type and size of the autonomous system. The software architecture enables the autonomous software to operate oblivious of the source of sensor information, physical or virtual. The VR testbed and the autonomous system must be synchronized in time, e.g., the dynamic objects in the VR testbed should be updated in real time using wall clock, the VR testbed should be paused during communication between the VR testbed and the autonomous vehicle as this time does not exist in real autonomous vehicle operation. Several key issues involved are sensor simulation, vehicle dynamic simulation, communication, and synchronization. All of these are key areas of research.
- **Augmented Reality**. A challenging issue in augmented reality is the fusion of real sensor input and simulated sensor input, e.g., fusion of a RGB image from the real image sensor and a RGB image from the simulated sensor. This will require fusion of different types of sensors with possibly varying resolutions. Another challenge is the accurate registration of the observer (in this case, it is the autonomous vehicle) in the real-world environment so that virtual objects can be added at the correct position. This requires the position and orientation of the autonomous vehicle in the real-world environment be known and passed into the virtual environment to support an avatar representation of the physical vehicle in the virtual environment. Depending on the size and movement range of the autonomous vehicle, different communication methods between the testbed and autonomous vehicle can be utilized. In some situations, if the autonomous vehicle is large and powerful enough to contain the testbed, a wired connection might be preferred (the testbed is placed inside the autonomous vehicle).
- **Transportation**. Autonomous cars are perhaps the most important type of autonomous vehicles because of the impact they will have on human civilization and infrastructure. Before autonomous cars can be widely adopted at a broad scale, some technical issues must be fully addressed, such as sensor accuracy and object recognition. The autonomous vehicle T&E laboratory provides core capacity for new technology development, accident/incident recovery and analysis, and technology dissemination. The laboratory will be used to integrate autonomous vehicles into existing

transportation/traffic simulation systems, such as macroscopic and microscopic traffic simulations, a core research focus in M&S research at Old Dominion University.

As graduate research should be directly supported by graduate education, the Autonomous Vehicle T&E Laboratory can be used for graduate education as well and it is a rich resource for illustrative examples, problem assignments, and course projects. In particular, the following is an incomplete list of courses that benefit directly from the laboratory: Synthetic Environments, Machine Learning, Artificial Intelligence, Distributed Simulation, Simulation Modeling in Transportation Networks.

4 IMPACT ON INDUSTRY PARTNER

America is worried that its dominance in key technology areas is eroding. Across the government, agencies and organizations are calling on industry and academia to work together to drive advances in science, technology, and innovation. The Academic/Industry Educational Lab for Simulation-Based Test & Evaluation of Autonomous Vehicles provides an exemplar for this type of collaboration.

4.1 Maintaining Prosperity and Security

The key to America's prosperity and National Security involve much more than power and homeland defense. America's 21st Strategy for Science, Technology and Innovation relies on academia and industry working together to drive advances in science, technology, and innovation. The Strategy recognizes that the national security science, technology, and innovation enterprise includes not just the scientists and engineers working in Federal and national laboratories, but also a much larger ecosystem of academic and industry stakeholders. The Defense Intelligence Agency's innovation strategy states the agency cannot survive without its partnerships with industry and academia.

4.2 The Challenge for Industry

The industry challenge with the test and evaluation of autonomous systems is the dynamic nature of the system and the environment. Autonomy refers to a spectrum of automation in which independent decision-making can be tailored for a specific mission, level of risk, and degree of human-machine teaming." Classical methods of test and evaluation are predicated on predictable outputs. A system must also be predictable enough for humans to anticipate its behavior. Test environments must support observed behavior under a wide variety of scenarios. System behavior must be tested for functionality as well as:

- Actions in uncertain situations (decreased visibility, uncertain target recognition)
- Actions in unexpected situations
- Actions in difficult decision situations (ethics, laws of warfare)
- Unwanted actions

Customer's lack trust in autonomous systems and often limit their degree of autonomous operation. This lack of trust is related to the high cost of failure which can be measured in dollars and sometimes lives. Military researchers are asking for industry's help to improve machine autonomy technology sufficiently to enable its use in safety-critical avionics applications such as unmanned autonomous aircraft operating together with passenger planes in controlled airspace. Imagine the cost of failure or unanticipated actions in that scenario.

4.3 The Benefits of Academia/Industry Collaboration

Industry and government researchers are asking for theoretical frameworks for expressing mission goals and limitations as formal system specifications; and using formal specifications to synthesize correct-by-construction protocols, decision-making procedures, or task execution plans. While this capability exists today, generally it is difficult, expensive, and done on a system by system basis. Working with ODU, industry and academia can develop formal methods, mathematical frameworks leading to a library of protocols applicable for test and evaluate autonomous and human-automation systems using multiple mission specifications, environments and scenarios.

The distinction for an autonomous system is that the test and design cycles are not linear, but a continuous process spanning the entire system lifecycle. Together academia and industry can develop affordable test and evaluation environments that allows adequate testing and helps customers gain trust in the capability of emerging autonomous systems. Industry can provide the scenarios and test cases used by the customer for their evaluation of system performance. Academia can assist with the expertise need to generate the simulation of and visualization of these scenarios. Using these augmented and virtual realities test and evaluation teams will have a standing environment that can generate multiple scenarios and behaviors that are too difficult or costly to generate in the real world. Since the test and design cycles autonomous systems is envisioned as a continuous process, the ability to observe, measure, and report on these behaviors can result in tremendous savings in time and dollars throughout the development, test, and fielding of the system

4.4 The Way Ahead

Developing new autonomy technologies will allow industry to deliver great value and capability to commercial, government and DoD customers. Billions of dollars in R&D funds are being invested in in unmanned military, systems, self-driving, safety systems and drone delivery systems. The increase in funding has helped accelerate progress and started the public acceptance process. But it has also created a competition for talent. Industry needs to work with academia to develop the technology needed to keep pace in fast moving global defense and commercial markets. We also need to work with academia to mentor and develop the talent needed meet our workforce needs.

5 CONCLUSION

This paper presents the benefits of an academic/industry collaboration to create an undergraduate/graduate laboratory experience. The lab's focus is simulation-based T&E of autonomous vehicles taking advantage of VR and AR technologies. The lab is in its initial stages of development. While the paper presents the anticipated benefits that are the genesis for the lab's creation, the lab has already created several benefits. First it has created a dialogue between the academic and industry partners in identifying the need and strategies moving forward. It has also created significant student interests at both the graduate and undergraduate level, almost half of the current senior class has participated in the early stages of development. Graduate student interest has resulted in design and an initial implementation of the architecture discussed in the paper. This synergy has started to produce conference papers and a project demonstration where students are constructing a basic augmented sensor data representation, allowing physical sensor data to be augmented by virtual data based on vehicle orientation (motion is not part of the initial demo). This demo will be used as a recruiting tool to both recruit students to participate in the lab and to recruit students to the undergraduate program. Thus the early stages of the lab are already showing benefit to M&S engineering education.

REFERENCES

Brooks, R. A. 1985. "A Robust Layered Control System for a Mobile Robot". *IEEE Journal of Robotics and Automation*, RA-2(1):14-23.

Davis, B. and D. Lane. 2010. "Guided Construction of Testing Scenarios for Autonomous Underwater Vehicles Using the Augmented-Reality Framework and JavaBeans". *IMechE: Journal of Engineering for the Maritime Environment*. 224(M):173-191.

Gat, E. 1998. "On Three-Layer Architectures". In *Artificial Intelligence and Mobile Robots*, edited by D. Kortenkamp, R. Bonasso and R. Murphy, 195-210. Meno Park, CA: AAAI Press.
Hodicky, J. 2015. "Modelling and Simulation in the Autonomous Systems' Domain – Current Status and Way Ahead". In *Modelling and Simulation for Autonomous Systems, Lecture Notes in Computer Science*, edited by J. Hodicky, 17-23. Heidelberg, Germany: Springer.
Koopman, P. and M. Wagner. 2016. "Challenges in Autonomous Vehicle Testing and Validation". *SAE Journal on Transportation Safety* 4(1):15-24.
Leathrum, J., Y. Shen, R. Mielke, and N. Gonda. 2018. "Integrating Virtual and Augmented Reality Based Testing into the Development of Autonomous Vehicles". In *Proceedings of ModSim World 2018*, April 24-26, Norfolk, VA.
Menzies, T. and C. Pecheur. 2005. "Verification and Validation and Artificial Intelligence". *Advances in Computers, Volume 65*, edited by M. Zelkowitz, 153-201. Amsterdam, Netherlands: Elsevier.
Mielke, R., J. Leathrum, and F. McKenzie. 2011. "A Model for University-Level Education in Modeling and Simulation." M&S Journal. 6(3): 14-23.2012
Milgram, P., H. Takemura, A. Utsumi, and F. Kishino. 1994. "Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum". In *ProceedingsVolume 2352, Telemanipulator and Telepresence Technologies*, edited by H. Das, 282-292, Bellingham, WA: SPIE.
Robot Operating System (ROS). 2018. http://www.ros.org/, accessed January 31, 2018.
Schumann, J. and W. Visser. 2006. "Autonomy Software: V&V Challenges and Characteristics". https://archive.org/details/nasa.tech.doc_20060015099, accessed January 31, 2018.
Wei, H, Z. Shao, Z. Huang, R. Chen, Y. Guan, J. Tan, and Z. Shao. 2016. "RT-ROS: A Real-time ROS Architecture on Multi-core Processors". *Future Generation Computer Systems* 56:171-178.

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