ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans Jazzed about Engineering Education

Paper ID #15147

STRIDER: Semi-Autonomous Tracking Robot with Instrumentation for Data-Acquisition and Environmental Research

Dr. Abhijit Nagchaudhuri, University of Maryland - Eastern Shore

Dr. Abhijit Nagchaudhuri is currently a Professor in the Department of Engineering and Aviation Sciences at University of Maryland Eastern Shore. He is a member American Society for Mechanical Engineers (ASME), American Society for Engineering Education (ASEE) and, American Society for Agricultural and Biological Engineers(ASABE) and is actively involved in teaching and research in the fields of (i) robotics and mechatronics, (ii)remote sensing and precision agriculture, and,(iii) biofuels and renewable energy. He has published more than 70 refereed articles in journals and conference proceedings. Dr. Nagchaudhuri received his baccalaureate degree from Jadavpur University in Kolkata, India with honors in Mechanical Engineering. Thereafter, he worked in a multinational industry for a little over three years before joining Tulane University as a graduate student in the fall of 1987. He received master's degree from Tulane University in 1989 and doctoral degree from Duke University 1992.

Mr. Abbas H. Diab, University of Maryland - Eastern Shore

Abbas Diab, BS in engineering with mechanical specialization, is currently a graduate student at University of Maryland Eastern Shore pursuing MS degree in Food & Agriculture Sciences . During his undergraduate studies, Mr. Diab along with a group of undergraduates, worked on several academic and research projects. He designed and built several ground, air, and water platforms for precision agriculture reasons. Currently he holds the position of chair of the ASME UMES chapter.

Mr. Christopher E. Hartman, University of Maryland - Eastern Shore
Dr. Lei Zhang, University of Maryland - Eastern Shore

Dr. Lei Zhang received his Ph.D. Degree in Electrical Engineering on 2011 from the University of Nevada, Las Vegas. Since 2012 he is working in the Department of Engineering and Aviation Sciences, University of Maryland Eastern Shore. His main research interests include image processing, autonomous system, optical SoC/NoC architecture, and on-chip optoelectronic device design.

Dr. Madhumi Mitra Ph.D., University of Maryland - Eastern Shore

Dr. Madhumi Mitra is currently a professor of environmental sciences in the department of Natural Sciences at the University of Maryland Eastern Shore. She is also the coordinator of Biology and Chemistry Education. Dr. Mitra is actively involved in teaching and research in the areas of biofuels and renewable energy; applications of algae in food and environment; and water quality. She has published several peer-reviewed articles in journals and conference proceedings, and is the recipient of various awards and competitive grants. Dr. Mitra received her baccalaureate degree from Presidence College in Kolkata, India with honors in Plant Biology, Geology, and Physiology. She received her master's degree from University of Calcutta, India, and her doctoral degree from North Carolina State University, Raleigh, NC in 2002.

Dr. Yakov Pachepsky, USDA-ARS
Mr. Rakesh Joshi

STRIDER: Semi-Autonomous Tracking Robot with Instrumentation for Data-acquisition and Environmental Research

Abstract

STRIDER is conceived to be a self-propelled aquatic platform for automated sampling, characterization, and depth profiling to document microbial content and nutrient load of surface waters. It has served as the basis for senior design project for several engineering students at University of Maryland Eastern Shore (UMES) and continues to provide a development platform for a multidisciplinary team of STEM students to meet all of the design requirements with supervision of a team of UMES faculty members and collaborators from United States Department of Agriculture (USDA). The design and data analyses efforts will also serve as the basis of a master's thesis work for a STEM graduate student at UMES.

At present the base platform has been designed and utilized for navigation using remote control to specified locations to collect water quality data and sampling of surface water on a UMES pond. For visualization purposes geo-located measurement data have been embedded on appropriate google earth imagery.   Preliminary trials with PID gain adjustments for autonomous navigation have also been undertaken. Design alternatives are being explored for collecting water samples from various depths along with corresponding in-situ water quality data.

Integration of education, experiential learning, and research encompassing several disciplines that often create artificial walls within academia have provided rich learning outcomes for not only the individuals who have directly participated in design, development, and analysis efforts, but also to those interested students who have participated in group discussions and critical thinking endeavors to explore design alternatives. Informal conversations with students have provided anecdotal evidence of positive learning outcomes. Formal assessments has been undertaken to document assessment of academic, life-skills, and civic responsibility outcomes of the student engagement with the project.

1.0 Introduction

At University of Maryland Eastern Shore (UMES) efforts to develop autonomous robotic boat platforms have been ongoing for the past few years [1-3]. These efforts were largely funded by Maryland Space Grant Consortium and NASA to promote design and experiential learning endeavors of undergraduate students at UMES in multidisciplinary team settings that parallel similar undertakings in the real-world. Collaboration among engineering and environmental sciences faculty also resulted in providing scientific objectives related to in-situ monitoring of water quality variables related to agricultural run-offs. The STRIDER project was launched more recently under a cooperative agreement with USDA-ARS, Environmental Microbial and Food Safety Laboratory, Beltsville, MD. to include design features for depth profiling and sampling capability to the autonomous boat platform, over and above monitoring water quality variables related to agricultural run-offs

There is a growing consensus in the scientific community and the population at large that unregulated anthropogenic activities have contributed significantly to the degradation of ecosystem health of water bodies [4] . Pharmaceutical industry, aquaculture, as well as, animal and crop farming contribute significantly to the economy of Delmarva Peninsula. Adverse environmental and water quality impacts of these economic drivers in the region need to be properly identified and mitigated before it becomes unmanageable. Moreover, while it has been known for some time that substantial populations of fecal coliforms and E. coli are present in freshwater bottom sediments, bank soils, and beach sands, the importance of sediments as bacterial habitats and as a source of waterborne fecal coliforms and E. coli has not been recognized until recently[5]. Fresh produce consumption, contamination of drinking water, and recreational activities such as swimming has been attributed to an increase in water and food-borne illnesses in the United States [6, 7]. Irrigation water is a potential source for microbial contamination of produce necessitating monitoring of water bodies and periodic collection of water quality data. Data on the levels of nitrogen, phosphorus, dissolved oxygen, temperature, pH, water flux, and bacterial analysis of water samples will help water source managers to identify trends and short term fluctuations in health of water bodies, enabling assessment of environmental health of rivers, lakes, bays, and estuaries as well as providing insight into food safety issues associated with surface waters that may be used for irrigation or contaminate produce during extreme weather events and flooding.

Most of the prevailing monitoring techniques are expensive and time consuming. While in-situ monitoring and assessment of water quality data related to salinity, pH, dissolved oxygen, and levels of nitrates and phosphates from run-offs are possible; for bacterial studies in-situ analysis is difficult and necessitates laboratory evaluation of samples. Appropriate sampling and collection techniques have to take suitable precautions against sample contamination. Water-ways inaccessible to humans and bigger boats are also largely ignored and seldom monitored. The motivation behind developing a relatively inexpensive robotic boat platform such as the STRIDER capable of in-situ geo-located data collection of water quality variables, equipped with an autonomous sampling apparatus for subsequent laboratory analysis of bacterial levels, stems from the needs outlined above. Inaccessible waterways in large water bodies can also be monitored with small devices such as STRIDER as it can be launched from bigger boats. Platforms such as STRIDER lend itself favorably for ground-truthing satellite data when appropriate.

2.0 Design, Navigation, and Control

Figure 1 provides a pictorial overview of different hull designs for boats that are common. Taking into account load capability, speed of operation, stability requirements, and other design constraints, a multi-hull framework was chosen for STRIDER. In multi-hull platforms increased distance between the center of gravity and the center of buoyancy provide higher stability compared to boats with a single hull. This also allows multihulls to have narrower hulls and thus substantially less wave-forming resistance, resulting in greater speed to power ratio.

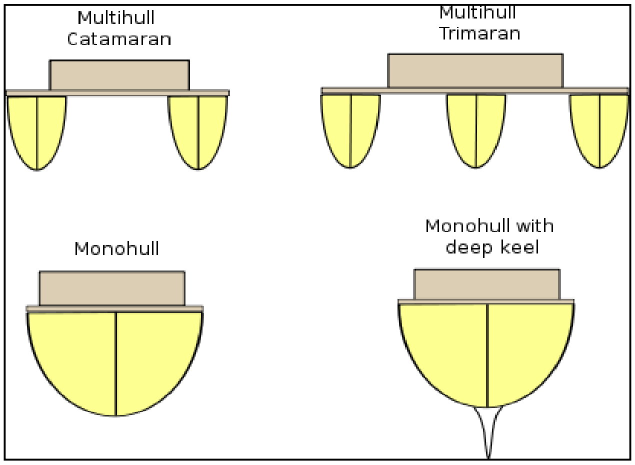


Figure 1: Different Hull Designs

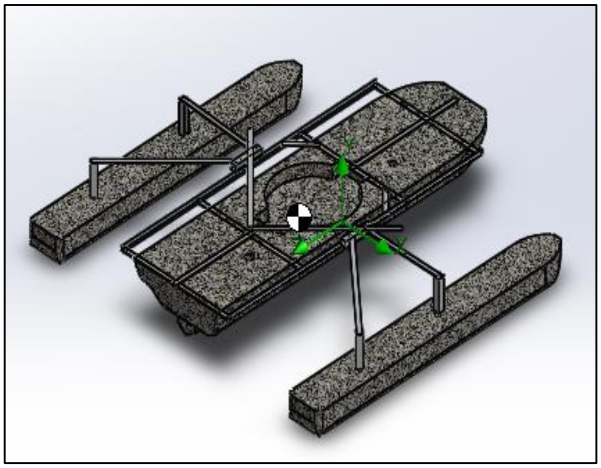


Figure 2: Final Frame Hull Assembly (STRIDER)

After thorough research by participating students and faculty overview, the final design was chosen to be a three hulled boat platform (Figure 2) due its relatively low chances of sinking, shallow draft, and greater load capacity. Moreover level sailing can be achieved with speed and maneuverability with such platforms. While this design is a little more expensive and time-consuming to build, it would provide heavy load carrying capability without significant power usage at low speeds. Higher width to length ratio also allows easy docking.

For stability, all factors such as weight, shape, beam, freeboard, the center of gravity as well as center of buoyancy must be taken into account. A solid model of the hull framework developed in 3-D CAD software (Solidworks) was used to locate the center of gravity for the whole mass (G), as well as the center of buoyancy for the three submerged parts of the boat (B_1, B_2, B_3) as shown in Figure 3. The sections highlighted in red represent 2.5 inch submersion. Stability analysis was performed to ensure that the metacenter remained above the center of gravity for heel angles of upto10 degrees that may be encountered during operation.

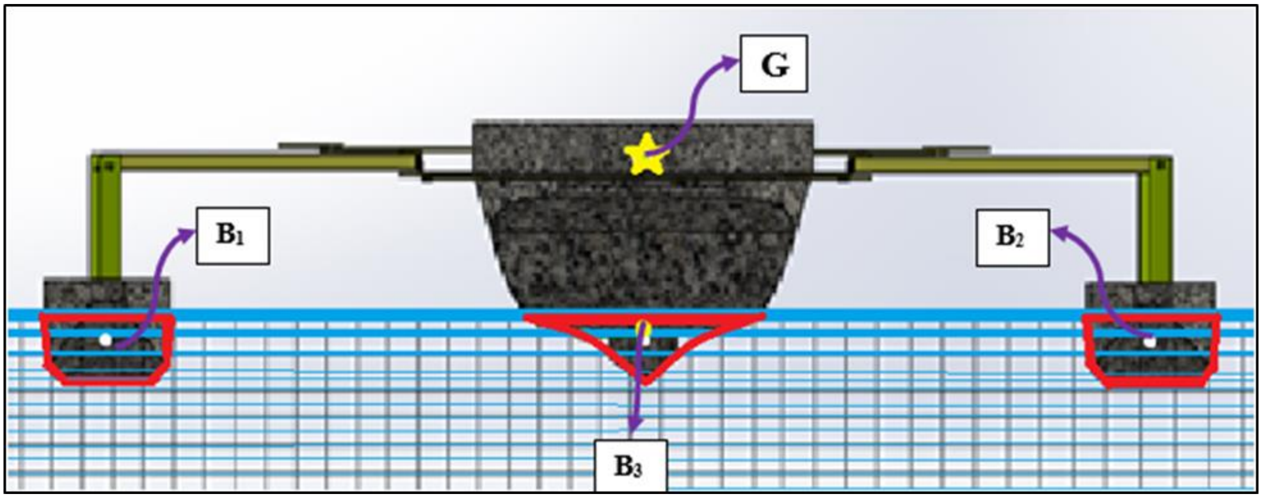


Figure 3: Boat's Center of Gravity and Buoyancy Locations

STRIDER frame has been designed using 1x1x1/8 inches aluminum rods. The main hull and two side pontoons, are constructed of extruded polystyrene topped with ply-wood board. Fiberglass, cloth, and epoxy are used to prevent impact and/or water damage. Air-propeller rather than propulsion using under water propellers was considered initially for avoiding entanglement with submerged vegetation in shallow waters but the design team settled for paddle wheel propulsion for greater maneuvering efficiency. At this time, the directional control (yaw) is achieved using differential speeds of the left and right paddle wheels. In the future, a rudder will also be incorporated for operation in bays or larger water bodies for improved ability to negotiate waves and currents. Brushless DC motors are used to rotate the paddle wheels. The battery power source is chosen based on the endurance and dynamic characteristics desired. For navigation, the system can be remotely controlled with joysticks by an operator or run using a PID (Proportional-Integral-Derivative) algorithm implemented using a Pixhawk microcontroller. The Pixhawk reads and records position and heading from a GPS and digital compass for navigation. The water sampling system is designed using a vacuum pump controlled by an Arduino Mega microcontroller that has been programmed to operate a set of valves. It enables eight small sampling flasks to collect the water samples at pre-specified locations. An additional Arduino Mega microcontroller is used to perform the data-acquisition tasks from the in-situ water quality sensors with associated location information.

Pixhawk is an advanced autopilot system designed by the PX4 open-hardware project and manufactured by 3D Robotics. It features advanced processor and sensor technology from ST microelectronics and a NuttX real-time operating system, delivering efficient performance, flexibility, and reliability for controlling any autonomous vehicle. It comes with a GPS and compass unit, and a 3DR Radio communication set (Telemetry) for additional live interaction with the autonomous platform on which it is mounted. While Pixhawk system was originally developed for small unmanned aerial vehicles (UAVs/Drones), it can be easily adapted for use with autonomous boats as well as autonomous ground vehicles. The Mission Planner, software available freely over the internet, can be used in concert with the Pixhawk to provide way point entries by point and click over Google Maps of spatial boundaries of relevance. Appropriate tuning of Proportional, Integral and Derivative (PID) gains over a few field trials with insight developed through simulation runs allow the STRIDER platform, integrated with Pixhawk controller, to navigate to pre-selected GPS locations identified using the Mission planner. For the initial configuration of the STRIDER, each mission run is limited to eight way-points to navigate to, record the chosen water quality variables, and collect 100 ml water samples from these locations for subsequent analysis.

3.0 In-situ Data Collection and Sampling

Figure 4: Arduino Mega and In-situ Sensors

While control and navigation functions are performed by the microcontroller embedded in Pixhawk, an independent Arduino MEGA microcontroller is appropriately programmed and interfaced with the microcontroller to measure and record on an SD card several environmental parameters including temperature, dissolved oxygen, oxidation reduction potential (ORP), pH, and nitrate levels (Figure 4). Atlas Scientific is the primary source used by the project team to acquire relatively inexpensive sensors compatible with Arduino microcontroller board. An NiMH Onyx battery is used in conjunction with a BEC (Battery Eliminating Circuit) to regulate the voltage to comply with the power specifications of the microcontroller. As and when the STRIDER platform commanded by the Pixhawk system navigates to the selected waypoints, the Arduino Mega interfaced with the water quality sensors activates the sensors to collect and record data on the SD card including the corresponding GPS locations. Initial efforts for the sensor data collection was attempted using UART protocol but through trial and error the project team learned in discussion with the vendor that the I^2C protocol would be a better choice.

Similar arrangement is used to control the vacuum pump using an additional Arduino Mega as illustrated in Figure 5. The vacuum pump is identified from the vendor “Sparkfun”.

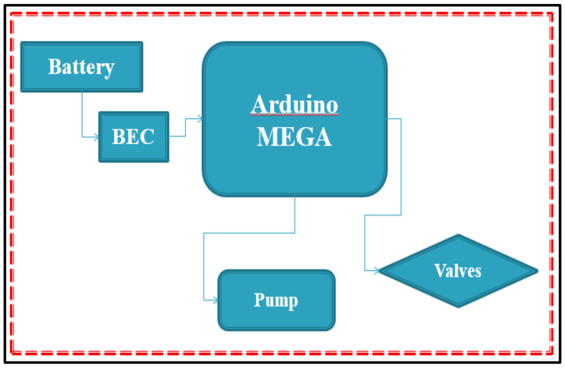


Figure 5: Water Sampling System Schematic

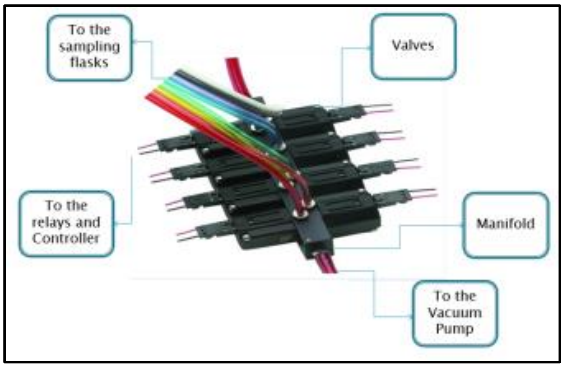
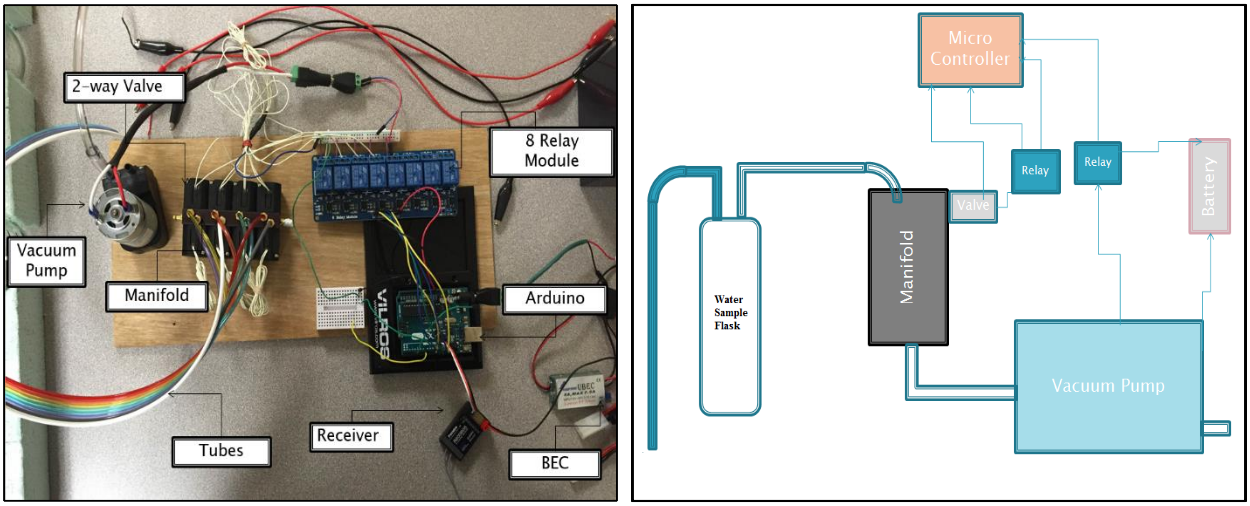


Figure 6: Assembly of Valves-manifold-tubes.

The pump requires 12V DC battery for operation. The vacuum pump is chosen to avoid fluid contamination between different samples. Each sample flask receives the specified vacuum pressure from one inlet, subsequently fluid (water) replaces the air through a different inlet (Figure 6). Clippard Minimatic was the vendor identified to acquire the required relays, valves, manifold, tubes, fittings, and the rest of the needed components to complete the system. Figure 7 (a and b) shows the actual layout and a schematic sketch of the system respectively.



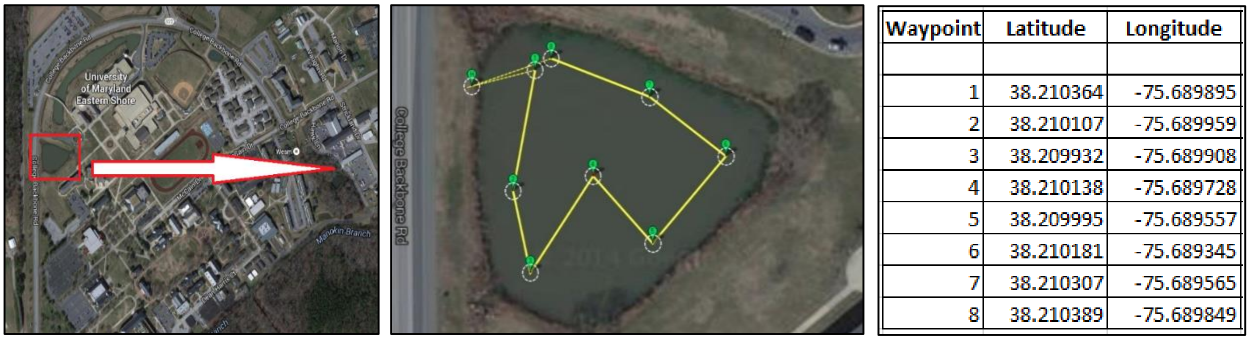
(a) **(b)**

Figure 7: Water Sampling System a) Layout, b) Sketch

The following functional sequence is achieved by appropriately programming the Arduino Mega associated with the sampling system; as each of the waypoint is reached by the STRIDER under Pixhawk navigation, the Arduino Mega interfaced with the sampling system is programmed appropriately to start the vacuum pump, open the desired valve, wait appropriate length of time to create vacuum in the corresponding sampling flask. Pressure difference causes water from another inlet to fill the container approximately 100 ml of water. The valve and the pump are shut off, the counter is increased in the programming loop, waiting for indication that the next way point in sequence is reached in accordance with the mission plan.

4.0 Results and Discussion

For preliminary testing a pond in the UMES__ campus (Figure 8a) is chosen to assess the designed capabilities of the STRIDER platform. Eight locations are chosen from the Google Earth map of the pond and entered in the mission planner and downloaded to the Pixhawk (Figures 8b and 8c).

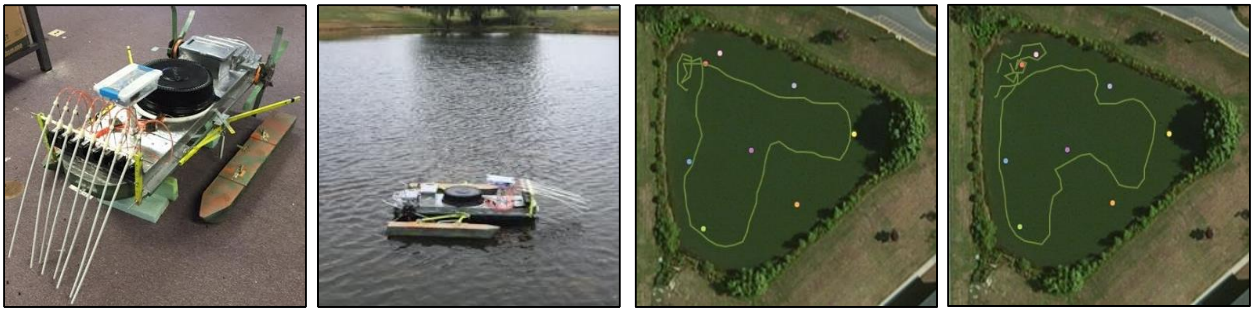


Waypoint	Latitude	Longitude
1	38.210364	-75.689895
2	38.210107	-75.689959
3	38.209932	-75.689908
4	38.210138	-75.689728
5	38.209995	-75.689557
6	38.210181	-75.689345
7	38.210307	-75.689565
8	38.210389	-75.689849

(a) **(b)** **(c)**

Figure 8: a) Google Earth Image of Campus, UMES pond, b) Mission plan c)Waypoints for Preliminary Trial

Figure 9 shows images of the completed STRIDER system as envisioned for the phase-I (Figure 9a) STRIDER system deployed in the UMES pond (Figure 9b), and the results from two preliminary trials as the navigation system PID gains are tuned so as to follow the mission plan and reach the desired locations to collect water quality data and water samples (Figure 9c). No attempt is made to reach the exact location but rather a region encircling the desired location, prior to activating the data collection and sampling system. Subsequently, the platform navigates to the next way point until the entire mission is completed. STRIDER system has also got provision for remote control besides autonomous PID control to navigate to pre-selected data collection locations. The table (Table 1) below show results from the first successful data collection and sampling trial run. The table shows the in-situ data as recorded in the SD card for each pre-selected GPS location for nitrates, salinity, dissolved oxygen, pH and temperature. The RHS table shows the results of bacterial analysis of the water samples collected from each location performed using membrane filtration technique in the laboratory. The count is reported in CFU (colony forming units/100ml).



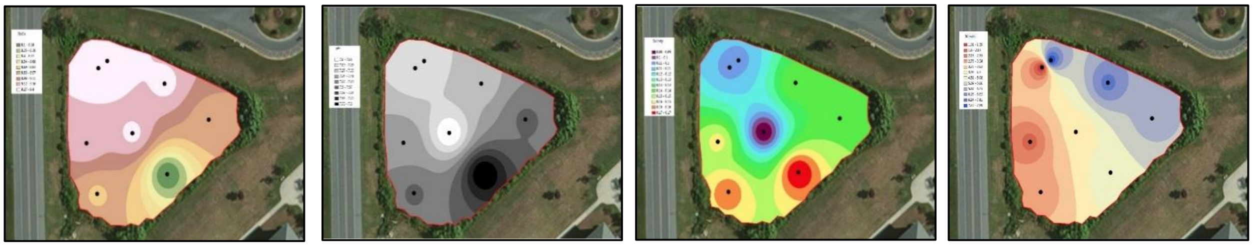
(a) (b) (c)

Figure 9: a) Phase-I STRIDER Platform, b) STRIDER deployed in UMES pond, c) Preliminary PID tuning trials

Waypoint	Latitude	Longitude	Nitrate (mg/L)	Salinity (mg/L)	D_Oxygen (mg/L)	pH	Temperature (F)	Total Coliform: Pink + Blue colonies (CFU/100ml)
1	38.210364	-75.689895	6	0.1	9.4	7.2	68	1.4 x 10^2
2	38.210107	-75.689959	7	0.15	9.2	7.4	67	2.6 x 10^2
3	38.209932	-75.689908	8.5	0.16	8.8	7.5	68	3.1 x 10^2
4	38.210138	-75.689728	6.5	0.08	9.3	7.1	65	4.8 x 10^2
5	38.209995	-75.689557	8.7	0.17	8.1	7.8	69	2.4 x 10^2
6	38.210181	-75.689345	8.8	0.14	8.9	7.5	70	3.4 x 10^2
7	38.210307	-75.689565	7.2	0.14	9.3	7.3	68	1.9 x 10^2
8	38.210389	-75.689849	6.1	0.1	9.4	7.2	68	4.1 x 10^2

Table 1: Data collection and bacterial analyses results of a preliminary trial with STRIDER

Participating undergraduate and graduate students are encouraged to take the GIS course offered in the department of Agriculture, Food and Resource Sciences at UMES to develop skills for visualizing geo-located data. Figures 10 a-thru-d shows the spatially interpolated data from the left to right for (a) dissolved oxygen, (b) pH, (c) salinity and (d) nitrate. The data is inputted to ArcMap (ArcGIS- Geographic Information System (GIS) software- http://www.esri.com/software/arcgis) and interpolated using inverse distance weighting technique. Vector data in GIS is often spatially interpolated to develop raster maps to simulate likely data values for intermediate locations.



(a) **(b)** **(c)** **(d)**

Figure 10: Data Visualization in ArcMap for selected water quality data using spatial interpolation a) Dissolved Oxygen, b) pH, c) Salinity, d) Nitrate

5.0 Experiential Learning in Vertically Integrated Multidisciplinary Teams

UMES engineering program is relatively new. In 2006 UMES initiated an independent engineering program after severing ties with the collaborative and 2 plus 2 feeder program with Clark School of Engineering at College Park. Subsequent to graduating first set of engineering students from its General Engineering Program with specialization options in mechanical, aerospace, electrical and computer engineering the program was accredited by ABET in 2012. At this time UMES does not have a graduate program in engineering which presents a unique set of challenges and opportunities for undertaking intensive experiential learning and research endeavors. The UMES faculty lead for the STRIDER project have worked to develop a vertically integrated multidisciplinary team of undergraduate and graduate students from engineering, environmental sciences, agriculture and food sciences, aviation sciences and computer sciences programs at UMES to undertake challenging engineering design efforts, integrated with agricultural and environmental research problems that address global sustainability concerns related to food, energy, and water for a growing world population(http://www.asabe.org/media/195967/globalinitiative.pdf). The efforts of the project team, not only support the UMES land grant mission, but also challenges related to managing nitrogen cycle, reducing carbon footprint, clean water, and engineering tools for scientific discovery, consistent with the twenty-first century grand challenges as outlined by the National Academy of Engineering(NAE)(http://www.engineeringchallenges.org/challenges.aspx). Traditional disciplinary boundaries in academia and engineering curricula that often creates artificial boundaries, will need to be diffused to sensitize young minds to effectively address these challenges that are at the interfaces of traditional disciplinary boundaries in academia. Faculty members in engineering with expertise in mechanical and computer engineering with teaching and research interests in robotics, engineering mechanics, embedded systems, basic circuits and instrumentation, and control systems work alongside faculty members in aviation, agriculture, and environmental sciences to advise the student teams. Integration of education and research following the Kolb's experiential learning framework [8, 9] forms the hallmark of the endeavors undertaken by the project teams. Along with academic outcomes, life-skills and civic responsibility outcomes are integrated and assessed at the end of each semester by surveying participating students (Figure 11). Assessment surveys and anecdotal evidence from discussions with participating students confirm that the students realize the project setting and framework provides a rich learning experience for them.

Figure 11: Assessment Survey Results (2014- 2015: Student Participants)

Project teams meet on a weekly basis to provide progress updates and make plans for the following week, collaborators from NASA Wallops Island and USDA ARS Beltsville Laboratory are invited to join these meetings when convenient. Besides teamwork in multidisciplinary teams, the participating students are encouraged to interact with the vendors identified for supplies and parts. These interactions provide valuable learning experiences that are lacking in traditional classroom settings. Exposure to research scientists and engineers from collaborating federal agencies also provide a rich learning experience for the students and opens up avenues for professional development. Participating students are encouraged to integrate aspects of these efforts for project work that are integrated in some of the courses they take as well as in their senior design project requirement. In fact, a large portion of the phase-I efforts were completed as a senior design project of a team of four engineering students. The lead student has now joined the graduate program in the department Agriculture, Food and Resource Sciences at UMES and is supported under a cooperative agreement with USDA-ARS Beltsville Laboratory. He will integrate natural resource management, food safety, and engineering design in his master's thesis work with the broader scope of the STRIDER project. Since participants from all funded projects undertaken by the PI are present at the team meetings, they can witness the synergistic and complementary nature of the endeavors which provides an opportunity for them to broaden their outlook. Incidentally, one of the project participants from the aviation science program recently got hired by Lockheed Martin. The student attributes his interview success largely due to his participation in one of the project teams. Although he did not pursue an engineering degree at UMES the interviewers were impressed with his broad exposure and hired him as a systems engineer.

6.0 Conclusion and Future Work

Phase-I efforts of the STRIDER project has been completed. It has successfully integrated education and research efforts and promoted learning and discovery in vertically integrated multidisciplinary teams. Design refinements are underway. Additional trial runs are being planned to collect in-situ water quality data and water samples from other water bodies and ponds readily accessible within campus. Trial runs will also be conducted in chosen locations in nearby rivers, lakes and estuaries in the near future. In discussion with USDA collaborators, the lead graduate student and the project team are now exploring design alternatives for Phase-II that will involve capability of monitoring, depth profiling, and visualization of in-situ water quality data at various depths and bacterial analyses of water samples collected at these depths. In addition, the project team is investigating integration of an underwater camera system with STRIDER to image submerged aquatic vegetation (SAV).

7.0 Acknowledgment

Authors would like to acknowledge USDA-ARS Beltsville Laboratory and Maryland Space Grant Consortium for their support. Besides the student co-authors, several others participated in the group meetings and provided inputs. Their involvement is also gratefully acknowledged. Mr. Zoe Johnson in the Toxicology graduate program at UMES assisted with the bacterial analysis of the samples.

Bibliography

1. Diab,M., Uche,E., Dyab,M., Nagchaudhuri,A., Mitra, M., “SAMPLE : Small Autonomous Monitoring Platform for Lakes and Estuaries”, *Proceedings of the 2014 Annual Conference of American Society for Engineering Education*, Indianapolis, IN June 15-18, 2014
2. Villalobos, D., Nagchaudhuri, A., Mitra, M., Diab. A., Henry, X., “CAUTION – An Innovative Aquatic Platform to gather Water Quality Data for Environmental Studies” *Proceedings of 2015 Annual Conference and Exposition of American Society for Engineering Education*, June 14-17, Seattle, Washington
3. Nagchaudhuri, A., Mitra, M., and Zhang, Lei, “AIRSPACES: Air-propelled Instrumented Robotic Sensory Platform(s) for Assateague Coastline Environmental Studies- A Multidisciplinary Experiential Learning and Research Project at Minority Serving Land Grant Institution”, *Proceedings of 2013 IEEE Frontiers in Education Conference*, pp. 1623-1625, October 23-26, 2013, Oklahoma City, OK.
4. Constanza, R., R. d’Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limberg, S. Naeem, R.V. O’Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt. 1997. "The value of the world’s ecosystem services and natural capital." *Nature* 387:253-260.
5. Pachepsky, Y., Shelton, D., Dorner, S., and Whelan, G. (2014). Can E. coli or thermotolerant coliform concentrations predict pathogen presence or prevalence in irrigation waters? Critical Reviews in Microbiology, DOI: 10.3109/1040841X.2014.954524
6. Pachepsky, Y.A., and Shelton, D.R. (2011) '*Escherichia Coli* and Fecal Coliforms in Freshwater and Estuarine Sediments', Critical Reviews in Environmental Science and Technology, 41:12, 1067-1110. (DOI: 10.1080/10643380903392718)
7. Pachepsky, Y.A., Shelton, D.R., McLain, J.E.T., Patel, J., and Mandrell, R.E. 2011. Irrigation Waters as a Source of Pathogenic Microorganisms in Produce: A Review. In: Advances in Agronomy, Vol. 113, pp. 73-138, D. Sparks, editor. Academic Press, Burlington.
8. Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development* (Vol. 1). Englewood Cliffs, NJ: Prentice-Hall.
9. Kolb, D. A., & Wolfe, D. (1981). Professional education and career development: A cross-sectional study of adaptive competencies in experiential learning. Final report NIE G-77-0053, ERIC no. ED 209 493 CE 030 519.