Autonomous Underwater Vehicle Development for RoboSub 2018 McGill Robotics - Clarke

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***Abstract*—For McGill Robotics' fifth year participating in the Robosub competition, we are happy to bring our first C-Class AUV to San Diego. It boasts a number of upgrades over its predecessors, while retaining their advantages and qualities. It was designed with the constraints inherent to the Robosub competition, and thus makes the most of some circumstances, such as the short mission time. It also builds significantly on past years' breakthroughs and research on the software side, while integrating milestones attained this year.**

It also makes use of our brand new custom parts, such as new pressure vessels, as well as new sensor suites, including a DVL.

I. Competition Strategy

The new McGill Robotics Autonomous Underwater Vehicle has been in development since Fall 2017; it is an autonomous platform dedicated to the completion of specific tasks defined by the Robosub competition. As such, the nature of the competition and the aforementioned tasks influence Clarke's design at every level.

From a high-level perspective, Clarke takes advantage of the constrained environment of runtime of the competition relative to other exploration and utility marine robots. Due to the short mission times, a power supply was chosen to optimize size and weight, but not necessarily runtime. A single 16,000 mAh Lithium Polymer battery was chosen for the power density and reliability. In comparison to previous models of our AUV, which employed two separate batteries, this has allowed Clarke to store its power supply in its main hull; however, this also necessitated a more sophisticated power distribution board. One large constraint of the environment is the depth of competition. The pressure vessels, though able to withstand far more pressure at greater depths, the design criteria was to withstand pressure at 10 meters. In a similar fashion, to the power supply, the low depth requirement allows Clarke to use more accessible materials and reduced wall thickness on all of the pressure vessels. Generally, the competition's tasks require a great deal of maneuverability, but the shallow depths and still waters do not demand as much raw torque. For this reason, Clarke is outfitted with BlueRobotics T200 thrusters –which provide well-balanced control and thrust– mounted in an array that provides the AUV with six degrees of freedom.

Clarke is designed to favour certain aspects of the competition that previous models have had relative success with; namely, performing acoustic navigation and performing visual recognition of the inter-task markers to traverse between them. Building on this previous success, these systems have been maintained, but made more robust in order to keep the forward momentum of the design. For instance, though using machine learning principles for complex objects like the dice, classical computer vision (static filtering) is still applied to detect the inter-task markers. These robust and improved systems are mainly related to navigation, which have been further improved by the team's acquisition and integration of a DVL, a sensor that provides accurate measurement of velocity underwater.

Though aiming at maintaining previous success in the realm of navigation, tasks such as "Buy a chip", "Play Roulette", and "Cash In" have induced a complete reimagination of how the AUV performs object manipulation. Where previous models had more traditional arm and gripper assemblies, Clarke is equiped with an underwater vaccuum and release unit. This mechanism takes full advantage of the exemplary maneuverability of the AUV itself, and increases the efficacy of the object collection by having an 'area of effect'. Where previous object manipulation strategies have required extremely precise control of a sub-system, sometimes with its own several degrees of freedom, the new device relies on the control of the AUV itself. Only one axis of complexity was added to the system, to rotate the device, and there is no longer the need to control a gripper. The reason why this simplified system can continue to be competitive is because it has an inherent 'area of effect'. Robosub tasks have typically made it easier to dispense objects with containers that are much larger than the object intended for them. Past models of the AUV have found the most difficulty obtaining task items to begin with. This difficulty is because servoing and maintaining position, while controlling a separate sub-system to retrieve a small object is not trivial. The 'area of effect' essentially moves favour back towards obtaining the task items to begin with, at the cost of a less reliable release, by operating within a radius rather than at a point. This system marks the most radical deviation from previous designs.

On the other hand, there has been a much slower design transition throughout the course of years: migrating from classical to machine learning computer vision. Over the past two years, our robots have attempted to use machine learning to solve the various computer vision-based tasks at Robosub. Until now, the only task to have been executed using machine learning are the buoy-based tasks and with limited success. The repeated difficulty created a strong debate amongst team members regarding its efficacy; however, this year it gained more support. With the increasingly rising interest in AI, both in and out of the academic community, the team has growing knowledge and access to resources for AI development. Leveraging the past experiences of team members and accessibility of high-powered GPU's (applied in the learning phases of AI), and due to the complex visual nature of this year's tasks, Clarke is prepared to attempt most of the complex tasks using machine learning – this includes "Play Craps" and "Play Roulette". However, with consideration to the team's past experiences and the dynamic visual nature of the TRANSDEC pool, last year's classical implementations have been retrofitted as fallbacks for some of the tasks.

II. Design Creativity

Using a team structure similar to past years', the AUV team was once again divided in three Divisions: Mechanical, Electrical and Software. Those divisions then each had a few different sections which focused their efforts on a certain part of the overall system. Division leaders ensured the various Sections' efforts were kept on track while the Systems Team, which includes the Project Manager and Division Leads, oversee the integration of all subsystems into a functional and optimal whole.

Our new C-class AUV, Clarke, is a few years in the making and finally ready to be used at a competition. It's primary purpose as a new class was to integrate new systems into our AUV platform, namely the new main hull, the Doppler Velocity Log, the stereoscopic cameras, as well as support upgraded and improved versions of other components, particularly the new hydrophone and pressurized manifold pressure vessels. The members of the team coordinate using the private social media platform Workplace. This allows us to keep dedicated lines of contact between every member of the team and to schedule events.

The new main hull strives to accomplish a series of objectives. It must first ensure that a similar level of ergonomic design is maintained in terms of access to electronics, whether that be for switching out components, completing repairs, routing wiring or others. As such, an open general structure for the mounting of the electronic components was desired. From our experience with the B-class main hull, we also knew we wanted to improve the accessibility of the volume within the center ring itself, which was made hard to access when electronic components were installed. Finally, we also decided to install the battery within the main hull itself, which has the advantages of removing the need for a bulky, heavy and highly buoyant pressure vessel, of requiring one

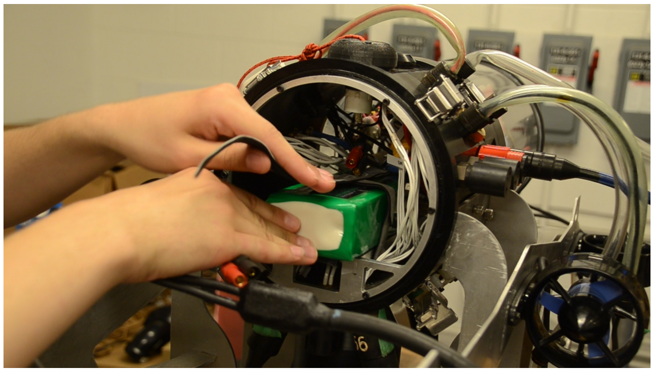

Figure 1: Battery being inserted into the main hull from the back of the center ring.

less external underwater connector and of making the operation of swapping a battery even easier and quicker. See Figure 1 for a picture of this operation.

The new mounting system for our electronics was also designed to be as flexible and future-proof as possible. We also had issues with the racks of the B-class main hull sagging under the load of the PCBs, which made installing the acrylic caps more difficult and put the electronics under more stress and vibrations. To correct this, the racks were attached on two points along their length, on the front and back of the center ring, and the racks are directly fastened to a thread on the support plate itself, rather than an L-bracket. This increases the rigidity of the whole assembly tremendously and virtually eliminates sagging. This setup also has the additional utility of providing an easy mounting point for the batteries.

Creative design was also involved in the creation of the new frame. Our main objectives for this assembly were to preserve the good ergonomic characteristics of the past frame, ease assembly, and be flexible enough to be used for both current and future components. The first two objectives were accomplished by switching from a L-bracket-based assembly method to a T-joint-based one. This reduces significantly the amount of parts involved in the assembly process, increases the rigidity of the structure, and makes assembly easier.

III. Experimental Results

McGill Robotics is lucky enough to have access to the pool of our sports center. We book two of its lanes every weekend and use this time to test our systems and make attempts at the various challenges. Building the obstacles themselves is one of the tasks our members have to complete. Our standard operating procedure is to start by testing the newest capabilities that have been added to the AUV recently by members, follow up with testing more thoroughly tasks that would benefit from tweaking parameters using experimental results, and finally increase the amount of training data and footage we have at our disposition with the remainder of the pool time.

The new battery Clarke uses provides a longer mission time which is greatly appreciated during our pool tests, reducing how often taking Clarke out of the water to complete a battery swap is necessary. The new center ring configuration also did make this operation quicker in and of itself. Those changes to the main hull can thus be considered to have fulfilled their objectives very satisfactorily.

Where specific tests are concerned, as mentioned before, all of them were conducted in the university's campus swimming pool. This is a specific environment which differs from the competition environment in some ways. They differ firstly in their obvious physical characteristics; the TRANSDEC pool is much deeper and larger than the McGill Pool. This changes the functioning of the DVL which uses bottom-tracking, and will likely require adjustments in some of its parameters. The shape of the pool also affect the acoustic profile of the testing environment. TRANSDEC is designed to replicate an open ocean environment with minimal resonance, while the pool used by the team can create reflections of the sound waves, which can affect the output of our hydrophones. Finally, the McGill pool has very clear, transparent and homogeneous waters. TRANSDEC has slightly more cloudy waters, which adds noise to the images obtained by cameras. This factor must be accounted for in computer vision algorithms.

By being aware of those factors while designing and tweaking our algorithms, we can be better prepared to adapt them to the conditions in the TRANSDEC pool.

IV. Acknowledgements

Once again this year, it was only possible for McGill Robotics to bring an AUV to Robosub thanks to the numerous people who support us in all our efforts. This includes, of course, all the members of McGill Robotics, as well as our supervisor, Professor Nahon Meyer. We are also immensely thankful to the machining specialists who have guided and helped us in the production and design of our parts, namely Don Pavlasek, Sam Minter, Andy Hofmann, Miesam Aghajani, Mathieu Beauschene and Lydia Dyda. Thank you to Jason Boivin and the Lifeguards at the McGill Athletics Center for access to a pool for testing. None of this would be possible without our sponsors either, especially our gold sponsors: Texas Instruments, SBG Systems and Protocase. And of course, huge thanks to the AUVSI team for making Robosub possible! We're very excited to see you again at TRANSDEC this year.

Table I: Technical Specifications of Clarke

Component	Vendor	Model/Type	Specs	Cost
Frame	Protocase	Designed in-house, lasercut with Protocase		340 USD
Waterproof Housings		Designed and machined in-house, anodized with Ultraspec		
Waterproof Connectors	Subconn and Teledyne	MacArtney's Ethernet and Impulse		
Thrusters	BlueRobotics	T-200		1467 CAD
ESCs	HobbyKing	Afro A3		108 CAD
High Level Control	Arduino	Arduino Uno		
Battery	HobbyKing	MultiStar Lipo Pack XT90	16000mAh 4S 10C	60 CAD
Converter	Mini-Box	DCDC-NUC	6-48V input for NUC, 12V or 19V output	
CPU	Intel	NUC6CAYB	Intel Celeron processor	175 CAD
Programming Language 1	C++			
Programming Language 2	Python			
Inertial Measurement Unit	X-IO Technologies	X-IMU		
Doppler Velocity Log	Teledyne	Workhorse Navigator	Bottom-track velocity	5000 CAD
Sonar	Tritech	Micron	Uses RS232	
Cameras	Sony	Chameleon (Sony ICX445)	1296 x 964, 18 FPS, 1.3 MP	
Hydrophones	Teledyne	Reson TC4013		
Algorithms: vision	Darknet			
Algorithms: acoustics	In-House			
Algorithms: localization and mapping	UKF			
Algorithms: autonomy	Smach			
Open Source Software	Sonar and DVL drivers	ROS tools		
Team Size	30 members			
HW/SW expertise ratio	50-60%			
Testing time: in-water	12 hours			

V. Appendix A

VI. Appendix B

A. FALL 2017

1) Robotics Challenge, Oct: The Open Robotics Challenge took place in the robotics workshop where all the attendees got a chance to have a hands-on experience of the Mars Rover arm and drive systems. The students then had the opportunity to attend a presentation coordinated by one of the professors from the Rutherford physics department followed by a demonstration set up by the team. McGill Robotics was offered a Gold sponsorship by the hosts of Open Robotics. What a great way to celebrate Thanksgiving!

2) John Abbott Outreach Event, Oct 20th: McGill Robotics was kindly invited to host a presentation at the John Abbott College and talk about our robots with future engineering students. Aside from sharing our knowledge and passion for robotics, we were also able to discuss with the attendees about university robotics challenges to come. Many of them were very intrigued by RoboHacks and showed a strong interest in participating to our hackathon which took place in March 2018.

3) McGill Open House with McGill Robotics, Oct 29th: Members of McGill Robotics spent the day meeting students, family and friends from around visiting McGill's Open House. Despite the rainy weather, we were pleased to meet many excited faces, and to present the Mars Rover arm system in action. Tabling alongside other Design Teams fostered a sense of unity, and demonstrated the many opportunities brought upon by student initiatives.

4) National Society of Black Engineers – A Walk for Education, Nov 3rd: At the end of last year, McGill Robotics participated in A Walk for Education hosted by the National Society of Black Engineers. Adrien Sauvestre, Jeslan Rajendram, Clara Chu, and Olu Olabimtan represented the team in the Lionel Groulx community, where the event took place. This impactful exposition encourages children of minority background to explore and develop interest in STEM topics (Science, Technology, Engineering and Mathematics), with the Mars Rover and Arm duo creating excitement in the crowd. Many came up to us with technical questions after interacting with the robots, and are fascinated by its possibilities as much as we are!

5) McWiCS x RoboHacks Present: MLH Local Hack Day! Dec 2: Calling all you hackers out there! Join McWiCS and RoboHacks in kicking off the hackathon season with this MLH Local Hack Day!! You don't want to miss out on this single largest day of student hacking ever! Fellow hackers from all around the world will be simultaneously hosting their own MLH Local Hack Day at their school, and you can participate in this 12-hour global event right here at McGill!

B. WINTER 2018

1) Engineering Involvement Day with McGill Robotics, Jan 23rd: Although it was a busy week day in the McConnell Engineering Building as students traveled between classes, the McGill Robotics table was visited by many at the Engineering Involvement Day. Inquiries varied and ranged from the desire to be recruited to the eventual possibility of being an active participant in international robotic competitions. Furthermore, a couple of upper-year mechanical engineering students showed interest in the specific mechanisms and functions of our Mars Rover Arm, which was displayed at the event. Others were curious about the Marketing Division of our Business Team, the previous events we've participated in, as well as those they could expect us to be joining. Overall, we were pleased to hear about students' eagerness to join the team.

2) Les Filles et Les Sciences with McGill Robotics, Mar 17th: Les Filles et Les Sciences is an initiative that aims at promoting STEM amongst high school girls, and the professions that emerge from this field. McGill Robotics was grateful for the opportunity to have worked with these bright young minds in the last few years, and is happy to announce that we will be once again participating in Les filles et les sciences Montreal-Sherbrooke STEM immersion event at Polytechnique Montreal, held next month on March 17! This year, we wish to organize a workshop accompanied by a demonstration and a presentation, all given in French, to give participants a true feel of what robotics is about.

3) McGill Robotics Robohacks, Mar 30-31st: RoboHacks is a robotics exhibition and hackathon hosted at McGill University, Montreal. Join 250 awesome CEGEP, Undergraduate and Graduate students in powering through 24 hours of thrilling robotics exhibition, caffeine fuelled invention, and engaged learning. We're there to provide the perfect environment to spark learning, innovation and a whole load of fun.

4) My Day @McGill with McGill Robotics, April 5-6th: Over 150 elementary school students will be joining our campus to tour, and participate in workshops and activities for academic engagement. MR tabled our robots in the EUS Commons to show off what we'd been up to lately!