AUTONOMOUS SURFACE VEHICLE (ASV)

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ASV University of New Hampshire – TECH 797

TECH 797 Acknowledgment

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Contents

Abstract

Autonomous Surface Vehicles (ASVs) are surface marine vehicles capable of navigating and moving themselves in the water. The 2016-2017 ASV team under Professor May-Win Thein worked on developing autonomy for vehicles already owned and testing the autonomy. The autonomy runs on software called MOOS developed specifically for marine autonomy. The code runs on a processor, which along with power and motor control comprise the enclosed system used modularly as a way to make any aquatic surface vehicle self-aware. The autonomy controls speed and heading through motors for each respective task and makes decisions based on sensors for environment input. Autonomy is defined in our work through 3 stages: point navigation, collision avoidance, and trailing other vehicles. Work this year focused on improving existing vehicles past stage 1 autonomy and also developing communication protocols with a Remotely Operated Vehicle (ROV).

Introduction

Autonomous surface vehicles (ASVs) can be defined as self-driving, and self-aware boats. These vehicles can function independently of human control and make decisions to accomplish specific missions. The goal of the UNH ASV team this year was to develop a low cost, robust, and modular control system, which can enable autonomy on any existing vessel. The team designed this system to be completely modularized meaning any component may be removed from one platform and placed on a similar platform with only minor adjustments. For the UNH ASV team, autonomy can be defined in three stages: the first stage being point-to-point navigation, the second stage being obstacle avoidance or the ability to recognize obstacles in its path and avoid collisions, and finally, the third stage, target recognition, tracking and trailing or the ability to identify a certain object and follow it. In order for a boat to become autonomous it must satisfy all three of these stages. In the future, the ASV team wishes to build a fleet of ASVs and enable communication between those vehicles, and with vehicles both above and below the water's surface. Some of these vehicles will include: Unmanned Underwater Vehicles (UUVs) and Unmanned Aerial Vehicles (UAVs), so that they may all work together to accomplish tasks that they would be unable to complete individually.

ASVs are a rapidly growing industry worth millions of dollars and there are endless applications that they might be used for. By removing the human element from maritime operations, ASVs have unlimited potential for growth and applications. They serve to reduce cost, improve efficiency, and protect human lives from dangerous environments. A few example applications include ocean mapping, swarm defense for the military, aquatic research, search and rescue, and commercial shipping.

This is the fourth year the ASV project has been at UNH. In previous years each team developed their own vessels. The first year of the project, ASV1 was custom built, but unfortunately, many problems arose, which hindered their ability to develop a working vessel. Although ASV1 was never functional, the first ASV team made accomplishments on the autonomy coding and helped pave the way for future ASV teams. The second year's team wanted to avoid the added complications that go along with building their own boat and so purchased a four foot remote control (RC) boat. Similarly, the third ASV team purchased their vessel, which was a seven foot bass boat, and then retrofitted it to be remotely controlled. None of the ASVs in previous years were able to achieve all three stages of autonomy by the end of their respective years. However, ASV3 was able to achieve basic first stage autonomous functions (waypoint navigation).

Since past teams struggled to both retrofit their vessels and achieve autonomy in past years, this year's team decided to use the ASV3 platform, from the previous year, so that they could focus more on achieving all three stages of autonomy. This year's team decided to adopt the larger ASV3 platform in order to easily accommodate all the necessary sensors and increase the functionality and ability to easily work on the vessel. This year's team achieved first stage autonomy on ASV3 and was able to create successful computer simulations for second and third stage autonomy. The team this year also focused on developing multi-vehicle communication and coordination between ASV3 and the UNH remotely operated vehicle (ROV) team. Lastly, the team this year focused on refining the autonomy package on ASV3 to further define and achieve the modules necessary to achieve autonomy.

Design

Autonomy

The autonomy that drives our ASVs is created with a programming language Mission Oriented Operating Suite (MOOS), designed at MIT. The language is specifically built to control autonomous navigation for marine vehicles, and has open source resources and functions available. The function of MOOS on our ASV platform is to make decisions for navigation based on active mapping through various sensors. Each sensor used has an app written in MOOS running asynchronously as well as a central program, MOOS-ivp helm, that processes information from these apps and transmits the data/variables from one place to another. These apps and the helm all run on one processor, which as the project expands has been made a laptop. Once desired heading and thrust are evaluated based on the decision MOOS makes at any given time, they are sent to the motor control to be converted into needed motor signal. All calculation and autonomy is performed in the processor running MOOS. Feedback control, however, is carried out by the motor controller.

All MOOS applications can be configured by specifying the desired attributes in a configuration block of a (.moos) file. An example of a MOOS configuration block is shown below.

```
ProcessConfig = iMOOSArduino
{
  AppTick = 4
  CommsTick = 4

  CommType = ARDUINO

  SerialPort = /dev/tty.usbmodem1411
  BaudRate = 115200
}
```

The above MOOS configuration block is for the iMOOSArduino application that is responsible for publishing desired heading and speed data to an Arduino via a serial connection. Every MOOS configuration block starts with a header ProcessConfig = <Application Name> followed by a listing of key-value pairs between two braces. Each MOOS application will have the AppTick and CommsTick configuration fields which specify the number of times a second that MOOS application executes its code and communicates with the MOOSDB. Other possible configuration fields for a MOOS application are specified by the developer of that application. Details on how to configure a MOOS application should be given in its documentation. In the above example the SerialPort and BaudRate configuration fields are specific to the iMOOSArduino application and give vital information to the application that allows it to successfully communicate with an Arduino over serial.

The IvP Helm application is special in that configuration of its behavior is not defined in a (.moos) file, but rather in a (.bhv) file. A behavior file contains more detailed configuration information that relates specifically to how IvP should decide how the entire system should behave based on its present state. An example of an IvP behavior configuration block is shown below.

```
initialize   DEPLOY = false
initialize   RETURN = false

Behavior = BHV_Waypoint
{
  name = waypt_survey
  //put = 100
  condition = RETURN = false
  condition = DEPLOY = true
  endflag   = RETURN = false
  wptflag   = WPT_HIT = 10,10
  UPDATES   = WPT_UPDATE
  perpetual = true

  speed          = 4 // in meters per second
  capture_line   = true
  capture_radius = 5.0
  slip_radius    = 15.0
  points         = 233,-12 : 295,-31 : 280,0 : 301,20 : 327,57 : 378,101 : 408,124 :
504,93 : 604,60 : 689,30 : 728,17 : 808,-8 : 837,-16 : 850,-25 : 831,-42 : 805,-55 :
774,-80 : 734,-105 : 680,-131 : 645,-145 : 611,-158 : 567,-164 : 548,-167 : 523,-141 :
539,-136 : 585,-124 : 572,-112 : 533,-124 : 511,-129 : 478,-102 : 467,-95 : 522,-59 :
462,-32 : 436,-31 : 393,-58 : 350,-52 : 315,-41 : 295,-31
  repeat         = 1

  // Waypoint and line coloring configurations for pMarineViewer
  visual_hints = nextpt_color=red, nextpt_lcolor=green
  visual_hints = vertex_color=blue, edge_color=pink
  visual_hints = vertex_size=6, edge_size=3
}
```

Each IvP configuration file will start initialize DEPLOY = [true, false] and initialize RETURN = [true, false] followed by Behavior = BHV_Waypoint before brackets that enclose configuration fields. The above example is of a waypoint behavior type which gives IvP a set of waypoints to navigate, given in the points field of the above block. These waypoints are relative to the vehicle's starting location, imposed on an xy grid system with x+ being North, and y+ being East. Behavior configuration fields such as capture_line, capture_radius, and slip_radius define the maximum allowable margin of error for waypoints.

Electrical

On the ASV the main components that make up the autonomy are all powered by electricity. This decision was made to reduce the complexity of the entire system itself; therefore everything from navigation to thrust is powered strictly by electricity. Other avenues such as hydraulic steering or a gas-powered engine, were discarded as they would have added unnecessary complexity and also could have caused issues due to lack of knowledge of their functionality specifically wiring. Furthermore, these components would have required other support systems such as a gas tank or a compressor, which would have become a deviation from the initial goal of making everything on the ASV a modular unit. Consequently from an early stage in the design process every working component would need to be powered strictly by electricity.

Because of this decision, there were a few minor issues that arise such as processes that require more Voltage and amperage than the average 5 Volt USB could provide to keep their functionality nominal. To handle this issue this, there were two different levels of power sources used to power the many necessary components. For components such as the Motor, Steering, and relay, 12-volt power was used provided by two car batteries. One battery was specifically used to power the engine, while the other car battery powered the steering, and the garage door relay switch, which allowed for remote change from RC to autonomous control. On the other hand, Signal carrying components, such as the Adruino, RC receiver, GPS, IMU, LIDAR, encoder, and the raspberry pi, all functioned off of 5-volt power, which was provided by a small portable phone battery recharger. These components all carried binary signals to other components such as the RC controller, motor, and the steering mechanism. These simple binary signals would tell these components when to turn on or off, which allowed for control of the vehicle. However, for the steering motor and the thrust motor, the 5-volt signals sent out by the Arduino needed to be stepped up (converted to 12-volts) to power these systems. Therefore, H-Bridge motor controllers were used to take the incoming 5-volt signal, and convert it to a 12-volt signal, which would be sent from two dedicated H-Bridges to these two individual systems.

The electrical components themselves all had different functionality and use. The main two processing boards, the Arduino, and Raspberry pie used programs, which the team wrote to allow for autonomous control. Specifically the Arduino uses a program that captures a signal from either the RC controller or the Raspberry pi's autonomy program and then sends commands accordingly to the steering and trust. During the autonomous controlled mode, the Arduino also takes data from an encoder, which tells the program what angle the steering motor is currently turning at. The Raspberry Pi on the other hand, takes signals from the IMU, GPS, and the LIDAR, sensors and sends it to the autonomous program MOOSE. MOOSE then takes in the data from these sensors and prioritizes it depending on its relevance to the current route being traveled, and accordingly sends directional and thrust power signals to the Arduino.

The sensors themselves each have a different task in which they perform to allow for higher levels of autonomous control. The LIDAR (Light detection and ranging) sensor scans a 2D plane around it for obstacles in the ASV's path. It does this by sending ultraviolet light out of one lens of the sensor, and recapturing the refracted light with the other lens. This second lens contains a CCD (charge-coupled device), which measures the light intensity received. Depending on the phase change and the amplitude of the refracted light compared to the initial beam, the sensor can tell the distance to an object. The LIDAR does this same process 360 times per rotation of the turret at 1-10 rotations per second. Therefore, if the ASV gets too close to an object, the MOOSE-ivp can give commands to the control systems to move around the object. The IMU (inertial measurement unit) is a sensor that provides the ASV with angular rates and body forces by using an accelerometer. This allows for the MOOSE-ivp to know how fast it's turning relative to the direction it wants to be heading. Although the ASV does know what direction it's trying to turn with the rudders encoder, depending on the vesicle size, the IMU is important to tell the how fast that rudder turn is effecting the direction of the vessel. Lastly, the GPS (Global Positioning System) takes in a signal from a satellite, which allows the MOOSE-ivp to know the specific location of the boat at any given time. This gives the system the ability to stay on course.

Each electrical component from sensors to motors is important to the ASV's functionality and level of autonomy. By making everything electrical, each component in the system is scalable allowing for larger motors or more powerful sensors. Making this ASV truly modular and easily convertible to the needs of the vessel is being used on.

Platform

There are currently two working platforms under our ASV project. They are ASV2 (2014) and ASV3 (2015). ASV1 (2013) had a hull built by the team, but did not float when work began Fall 2016. The decision was made this year to focus on existing and working vehicles (2 and 3) to have more time to test and improve the autonomy rather than build a platform. There is already an ASV4 planned for the summer, but the work this year was primarily electrical and coding-based in nature with some controls work, all of which did not require a new platform.

ASV2 was built Fall 2014 and is an Atomik RC A.R.C. 58" electric racing cat. This boat uses Outrunner Marine Motor (V700 100Kv) for thrust and a rudder controlled by a small motor for turning. All receive input through RC signal, so for our autonomy to be used the RC had to be rewired with the Arduino. The boat currently uses LiDAR, GPS, and IMU as needed for our autonomy. The LiDAR used is the Neato SV16 LiDAR, which was taken from their robotic vacuum unit. The range is 14 feet, which was determined too short for ASV3 but sufficient for ASV2 (the MOOS code does not change significantly). The computing is done through a Raspberry Pi because a laptop is too large for this model. The system is not large enough for future projects so the focus for this boat is testing autonomy.

ASV3 is a 7' bass fishing boat that was built Fall 2015. The hull was purchased online while the motor was purchased separately. The platform uses a 35 lb. thrust motor for movement. It also uses a car window motor to drive two ABS plastic gears. They were made using 3D printing, additive, with an 80% fill. The motor drives one gear which drives the other attached to the mounting shaft of the thrust motor. This vehicle has been the focus for testing and autonomy development with this year's ASV team. Moving forward all ASVs developed by the team will be at least this size.

Applied Work

Navy Work

The ASV team has worked closely with the Naval Engineering Education Consortium (NEEC) throughout the year to further the interests of both the ASV team and the Navy. NEEC is a program run through the NAVSEA Warfare Center that funds research in order to brings new technology and research to the Navy. The long term goal of the ASV team is to build a modular autonomous system that can be implemented on a variety of platforms and would be able to communicate with each other and complete tasks. The navy has a strong vested interest in autonomous vehicles for a variety of applications from mapping the ocean floor to reconnaissance and engaging a target.

This year the ASV team primarily focused on developing a robust, modular system that could be implemented on a large variety of platforms and achieve our three levels of autonomy. The ASV3 platform was used as the primary test platform throughout the system's development because it can accommodate a wide variety of sensors and equipment. When the system is finished and functional on ASV3, the team will than work to implement the system around the space restrictions of the ASV2 platform. Having both platforms working on the same system is an important step to proof of concept for the NEEC program. Ultimately, having one system that can be used to control multiple platforms is essential for communication between the platforms when running missions autonomously.

While teams at other universities have purchased premade platforms, the ASV team is more interested in developing and understanding the concept of an autonomous vehicle on a more basic level. Understanding how each module of the entire autonomous surface vehicle affects the system performance and capabilities is both a goal of the ASV team and the Navy.

The future goals of the ASV team is to continue to implement and improve the modular system while incorporating multiple platforms into the ASV teams fleet. Having multiple platforms that are able to communicate and run a mission with a variety of tasks is the final goal and proof of concept that the ASV team and Navy are focused on.

ROV Communication

Work has progressed in achieving communication between our ASV platforms and the Remotely Operated Vehicles (ROVs). As of last year the progress was limited to using visible lasers (green wavelengths) to send Morse signals from one vehicle to the other. This application was decided as inefficient and not robust enough for the desired task of coordinated autonomous mapping. Current research is in using sound to communicate data (currently planned to be GPS and IMU data). The WHOI micro modem is being looked at for use, though costs may outweigh our need as the unit costs around $20,000. This year the focus is instead on using wired communication to send data between ROV and ASV. The current task is identifying data necessary to make ROV autonomously move from one point to another based on ASV GPS data. Eventually the WHOI micro modem will be reevaluated for viability, but wireless capability is not a priority until the communication is established.

Holloway

This year, the ASV team entered the Holloway Prize Competition, an idea to market competition within the University System of New Hampshire. The goal of our "company", M.A.S.K. or Modular Automation Supply Kit, was to provide customers with a low cost, and robust kit which would allow any vessel to become autonomous. This control module can be integrated on any existing vessel, from a small fishing boat to a full size ocean liner, and allow it to have fully autonomous capabilities. The difference between our product and existing autonomous boats, that set us apart from other companies, is that our product may be applied to any existing vessel and be altered to fit the needs of our customer.

Our team placed third in the Bud Albin semi final round. Although we did not make it to the final round, many judges expressed interest in our product and encouraged us to continue to working on our business plan.

Testing

To analyze the boats functionality, our initial goal was to test all three levels of autonomy, point to point, obstacle avoidance, and track and trail along with the RC capabilities of the boat as well. To do this the team used three different forms of tests. For the first test we used a simulated program imbedded into the MOOSE-ivp to test the autonomy function of the ASV. This simulation allowed for us to chart courses in which we intended the ASV to follow. This program would then show the expected route compared to the given route in which the autonomous code would send the ASV. We could also use the same program to test track and trail by adding a second ASV to the simulator with the specific task of tracking and trailing the first ASV.

Because we could not test the ASV on the lake during the winter, we decided as a team to attempt to test in the high bay. For this test we specifically wanted to examine the functionality of the ASV's control systems such as the motor thrust and the steering as a unit. For this we tested the system out of the water checking to see if the controls we gave the system were correctly mirrored by the system itself. The system showed to work perfectly, and therefore we decided to continue to develop the ASV and wait for the ice to melt for our open water test.

The third test we preformed was our open water test at Swains Lake, which was about a 15-minute drive from the university. To do this, the team loaded the ASV onto a trailer and launched the ASV along with all off its components into the lake to test the capabilities of the system as a whole. The initial test of the system ended in failure, because the RC control of the boat was not working properly and took away the important ability for the team to maneuver the boat without autonomous control. On the second test however, the RC control of the boat worked perfectly, yet when switching to autonomous control the laptop driving the system was sending data packets to the controls at a faster rate than it could handle, which caused the controls to not respond at all. Although there have been only minor successes in the field, theoretically once all the issues with the system are worked out the boat will function properly. Therefore, we as a team plan on revisiting the lake in the near future to retest the capabilities of the boat before handing the project off to the next team.

Results

The LiDAR used on ASV 2 and 3 in previous years was tested and found that it was not adequate for the goals of the project. The LiDAR was only able to detect objects up to 14 feet and the error at distances over 10 feet was too high. This led to the team researching and finding new potential LiDAR sensors that could be implemented on the ASV platforms. Implementation and testing for the new LiDAR sensors will begin in the final weeks of the spring semester with the majority of the work occurring over the summer of 2017. The LiDAR sensor will be a key factor for the ASV team achieving its long term goal in future years.

The coding for the remote control and the point to point navigation was either corrupted or lost from the previous year’s team. The team was able to recode the remote control functionality and is in the process of testing the point to point navigation code in the field. The simulation for point to point in the lab is fully functional so debugging the system in the field is a crucial next step. Additionally, the team successfully repaired the ASV2 platform. The ASV2 platform had a damaged speed controller and faulty code. We were able to troubleshoot each of the components of ASV2 and restore the remote control functionality of the system.

The tracking and trailing stage of autonomy has successfully been tested in a simulation. The team was able to run a successful simulation using MOOS were ASV3 ran a point to point mission and ASV2 was able to track and trail ASV2 with no knowledge of ASV3’s mission. Implementing the LiDAR system onto both ASV3 and ASV2 will be crucial for the testing of this system in the field. The final step of obstacle avoidance will have to be coded and tested once the point to point navigation and the tracking and trailing are functional in the field. Knowing how the LiDAR system works on the platforms is critical for how the obstacle avoidance behavior is coded.

The system hardware has successfully been relocated into a smaller and more effective case. The reduction of size and increased protection from the elements and dirt or dust is important for a long lasting system when testing in the field. The team has also decided to replace the Raspberry Pi micro processers with a more robust chrome book that is also water resistant. The finalized physical modular design will be altered as the stages of autonomy are implemented and tested.

Conclusion

The ASV team was successful in restoring the functionality of the ASV3 platform. The control systems of ASV 3 have also been optimized and transferred into a more practical housing case. A large focus of the ASV team at the end of the semester will be the transfer of information to future ASV teams. A major obstacle the team had to overcome was lost or corrupted information from previous years. The team has ordered spare parts and components for the systems hardware and will be storing all of the crucial files on an organized external hard drive instead of a cluttered google drive. The improvements to the ASV3 platform will be crucial for the advancement of the project toward the long term goals. The ASV 2 platform has also been repaired and restored to functional capability. A damaged speed controller and faulty code prevented the platform from functioning in any capacity. Restoring ASV 2 to a functional level will allow the implementation of the improved autonomy system developed on ASV3. With the more tactical design of the modular design we are confident ASV2 can be restored to its point to point capability in future work at the end of the spring semester and over the summer. The successful simulations for point to point navigation and track and trail are in the process of being field tested or ready to be field tested. The focus on preparing our work to be transferred to following years is the primary goal of the team right now in order to prevent the obstacles that took large amounts of project time, as well as facilitate the advancement of the project to its long term goals.

Appendix

Works Cited

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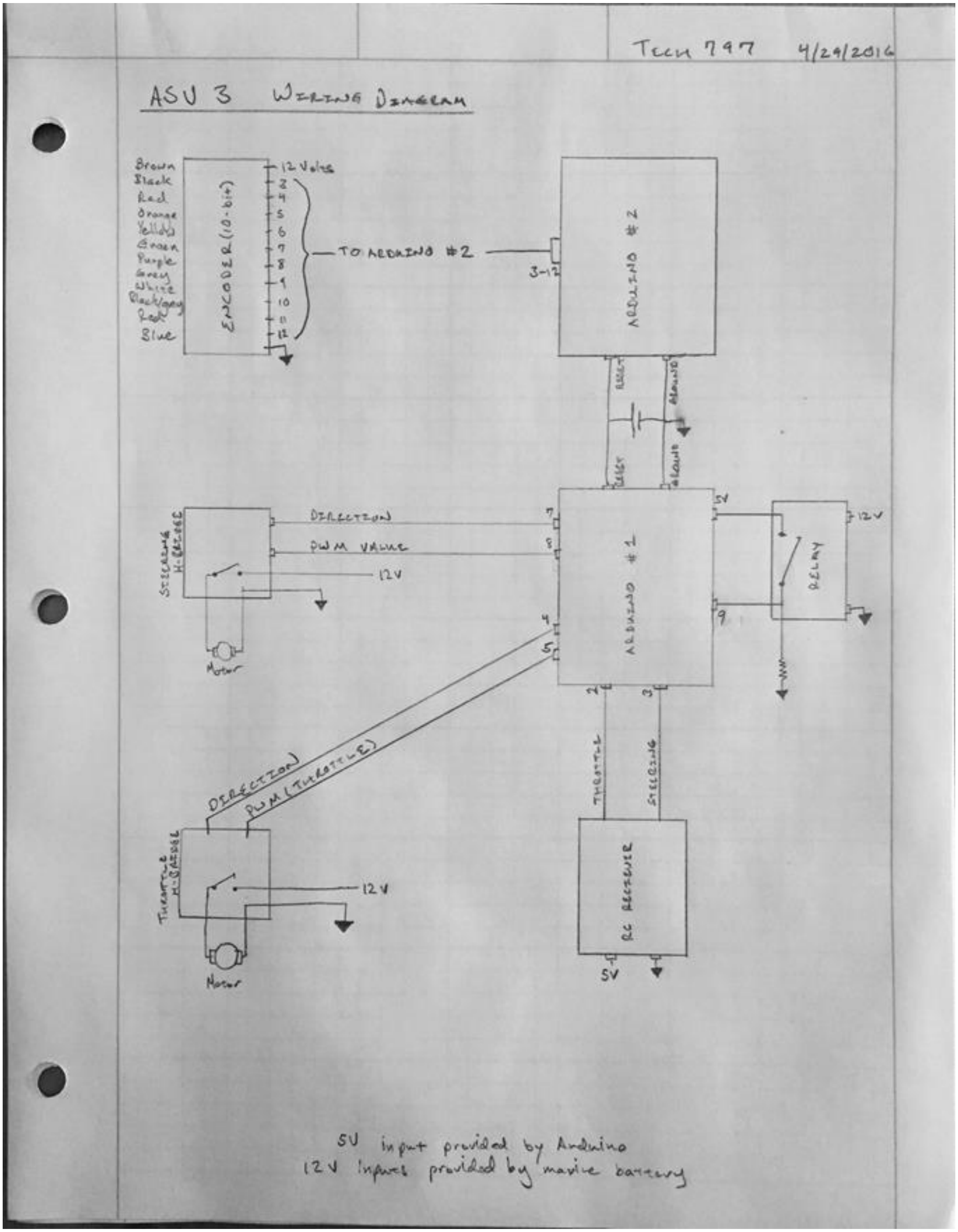
- Loe, O. (2008). *Collision Avoidance for Unmanned Surface Vehicles*. Master's Thesis, Norwegian University of Science and Technology, Trondheim, Norway.

- An Overview of MOOS-IvP and a Users Guide to the IvP Helm - Release 13.5 (2013). http://oceanai.mit.edu/moos-ivp-pdf/moosivp- helm.pdf

Diagrams



Tech 797
4/24/2016
ASU 3 Wiring Diagram
Brown
Black
Red
Orange
Yellow
Green
Purple
Grey
White
Black/grey
Red
Blue
ENCODER (10-bit)
12 Volts
TO ARDUINO #2
3-12
ARDUINO #2
RESET
GROUND
ARDUINO #1
5V
12V
RELAY
9
DIRECTION
PWM VALUE
STEERING H-BRIDGE
12V
Motor
7
8
4
5
2
3
DIRECTION
PWM (THROTTLE)
THROTTLE H-BRIDGE
12V
Motor
THROTTLE
STEERING
RC RECEIVER
5V
5V input provided by Arduino
12V inputs provided by marine battery

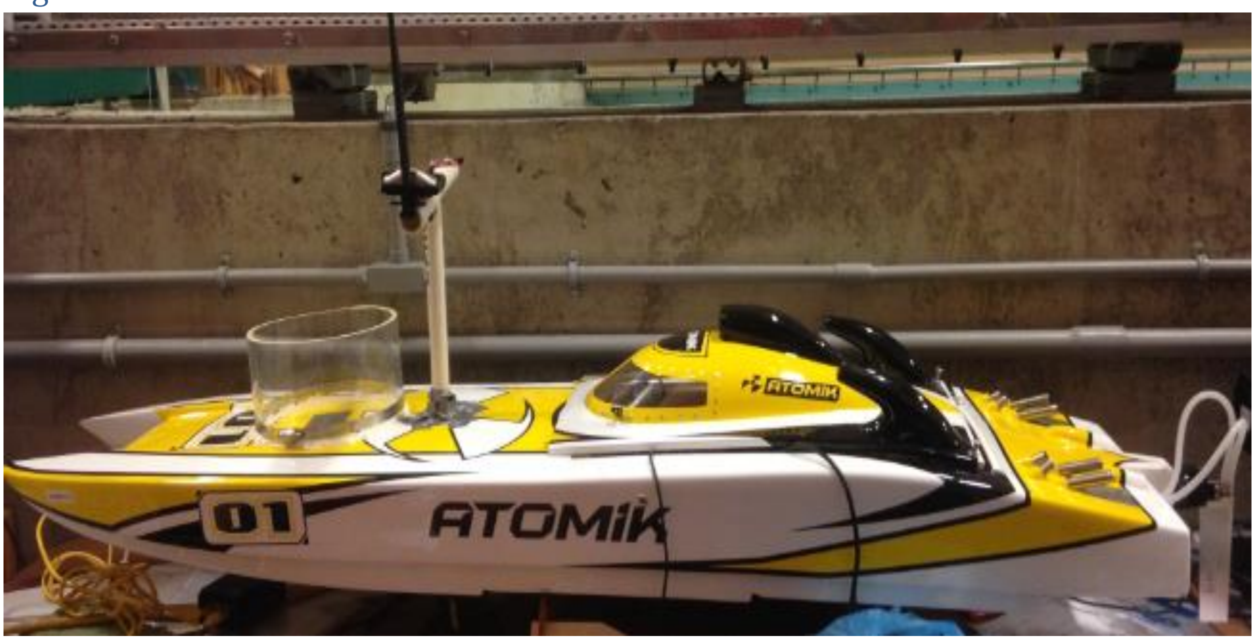
Budget

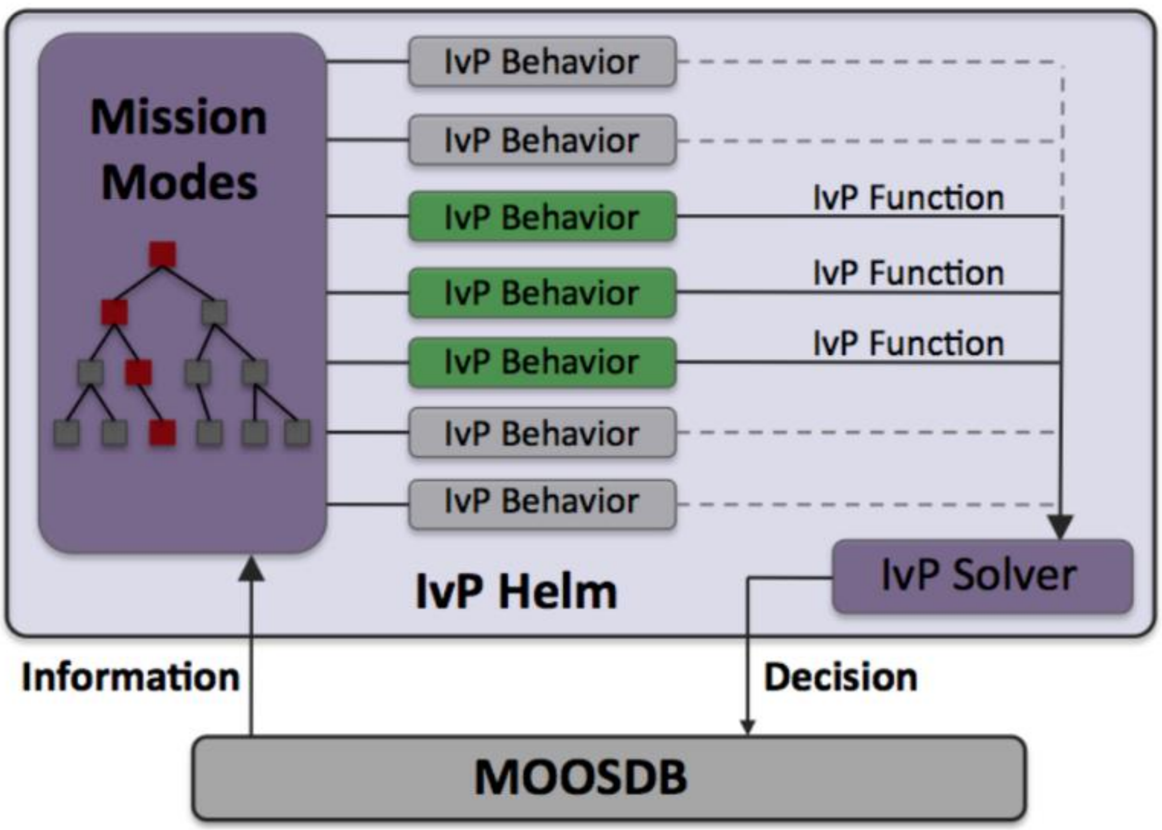
Budget	3520.19					
Item	**Cost per Item**	**Number of Item**	**Total Item Cost**	**Shipping cost**	**Total Cost**	
Ras Pis X5	38.27	5	191.35		191.35	
Arduinos X5	17.99	5	89.95		89.95	
H-Bridges X5	40.08	5	200.4		200.4	
Water tight box budget	100	2	200		200	
Tubing, Fittings, Sealant Budge	50	2	100		100	
External HD	49.99	2	99.98		99.98	
Car Battery Charger	57.75	1	57.75		57.75	
Chrome Book	199	1	199		199	NOTE: MAY WANT TO LOOK INTO ACCIDENT PLAN 3 Year (40$) 2 Year (30$)
Extra Wiring/connectors Budge	$50	1	50		50	
			0		0	
			0		0	
			0		0	
Tentative Shipping Cost			0	125	125	
			0		0	
Total			1188.43	125	1313.43	

Remaining Budget	2206.76

Maybe		
SONAR	130-290	for nicer models High end 290$ model has many great features
Small Boat	500-723	for bass boat
LiDARs		
WHOI Micro-Modem (ROV)	5000	

Figures




Mission
Modes
IvP Behavior
IvP Behavior
IvP Behavior
IvP Behavior
IvP Behavior
IvP Behavior
IvP Behavior
IvP Function
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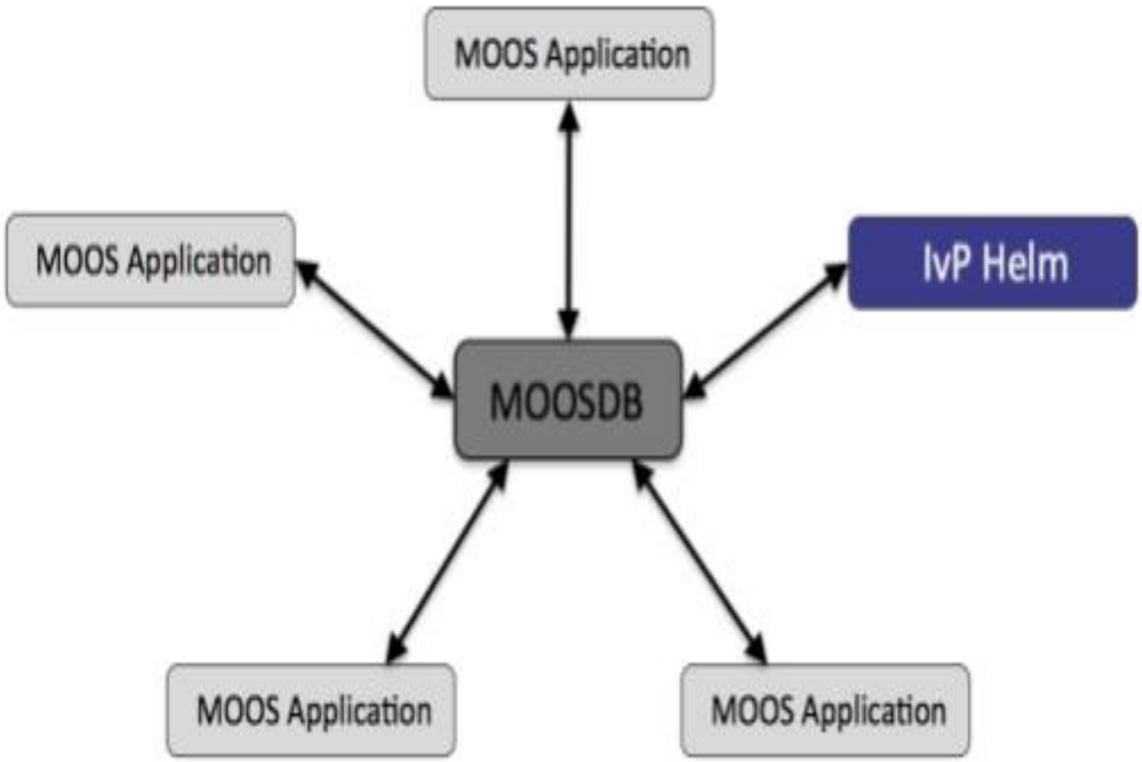
IvP Solver
IvP Helm
Information
Decision
MOOSDB


MOOS Application
MOOS Application
IvP Helm
MOOSDB
MOOS Application
MOOS Application