Robotics Club at UCF:
The Gray Goose

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The Robotics Club at UCF, with sponsorship from Army Research Labs (ARL) and the Institute for Simulation and Training (IST), presents a new platform for competing in AUVSI and ONR's 6th international RoboBoat competition for 2013. Leveraging the knowledge from past competitions the goal was to construct a platform that will be competitive in this year's event, and ready to be improved upon by future UCF teams. A lightweight foam pontoon design reinforced with polymer paint and a unique motor configuration allows for seamless movement in forward, reverse, rotation, and lateral directions. The electronics are mounted on modular DIN railing for reliability, ease of configuration and modification. Proven computer vision and mapping libraries from previous designs are extended to fuse multiple sensors including LIDAR, GPS, and compass for robust course navigation. A custom tilting servo mount was designed and fabricated for the LIDAR and heat sensor subsystem to enable 3D imaging of targets. The strategy this year was to give the vehicle the capability of accomplishing the three mandatory tasks (thrust measurement, starting gate, and speed gate) and five additional tasks (Catch the ball, Sneaky Sprinkler, Rock, paper, scissor, lizard, Spock, Capture the flag, and shoot through the hoops).

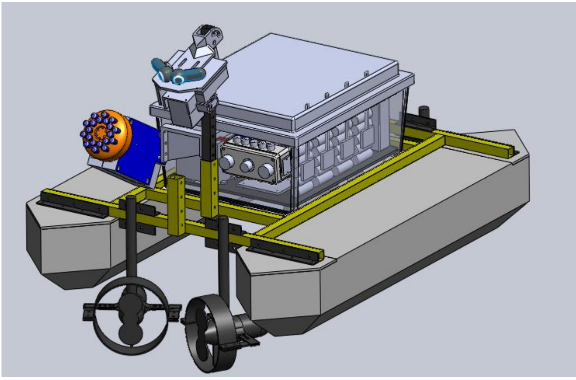

Figure 1 CAD model of Gray Goose

Figure 2 Photo of Gray Goose

1. Introduction

This year's RoboBoat competition presents the team with several difficult challenges. With the input and experience from previous team leaders, the 2013 team decided to reuse the previous year's vehicle. Features that proved successful included the simple and reliable electronics and power regulation system, the versatile motor configuration, and the functional and robust frame construction.

An incremental design approach, lead to development of a sound platform. For example, hardware development stages included: requirements gathering and specification, 3D modeling, rapid prototypes, and final implementation. This process allows the early identification of gaps and design issues before final implementation reducing overall project risk and cost. The Gray Goose team focused on selection of hardware, sensors, and software to accomplish the challenges presented.

Peripheral systems included in the 2013 Gray Goose are the dart gun, the amphibious rover, the tilting Lidar system, the dual webcam array and the wireless radio frequency Ethernet bridge. Having accounted for future development, the boat design leaves room on the frame for additional hardware for future teams to compete in new challenges.

2. Vehicle Mechanical Design

One of the best decisions made when designing this craft was pontoon design and motor configuration. The main design feature was to have reliable lateral control without complexity and points of failure. While lateral control is not strictly necessary for completing any of the challenges on the course, this additional ability improves performance in course correction and all target based challenges.

2.1 Pontoons

A flat bottom pontoon was employed with angular geometry. The points at the front and the back of the pontoons are blunter, decreasing rocking of the boat during rapid changes in direction. Also, the width of each pontoon was chosen so the boat will be more stable during lateral movement, and have less draft. A physics model implemented within Solid Works was used to refine and test these design choices before construction of the final pontoons and frame.

The pontoons were designed as a composite structure, and mostly fabricated in house. The bulk material of each pontoon is white Styrofoam. The basic shape of the pontoon was professionally cut using a CNC hot knife. Polycarbonate plates with tapped holes for structural mounting were fitted and glued into insets cut into the front and back of each pontoon. The whole pontoon structure is covered with Styrospray 1000, a two part polyurethane coating approximately 0.03 inches thick. This adds an aesthetically appealing and rigid protective shell to the Styrofoam while retaining lightweight properties. Total weight of each completed pontoon is less than seven pounds. This design was water tested, and found to safely support a vessel weighing 140 pounds.

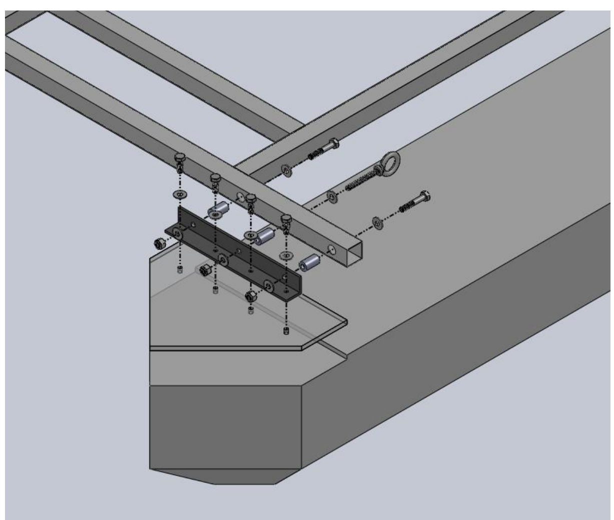

Figure 3 Pontoon with polycarbonate mounting plate configuration

2.2 Frame

A 1-inch square aluminum-tubing frame holds the two pontoons and the electronics box together. An entirely new frame was implemented in this year's boat, maintaining the same lengths, while changing the thickness of the Aluminum tubing from ¼ to ⅛ inch, making the frame 5.5 pounds lighter. The frame was designed with slotted mounting points for the electronics box so it can be shifted to have an equally balanced frame. The lengths of tube were cut on a horizontal miter saw and professionally TIG welded together and anodized to reduce corrosion and extend longevity. The mounting plates for the electronics box and the L-channel were milled in-house using a CNC machine to ensure proper alignment. Aluminum spacers reinforce areas of the frame with through bolts. One eye-bolt is located on each mounting section to the pontoon for easy hoisting during water entry.

2.3 Motors

The motor configuration is set up with a vector thrust design that easily allows the boat to move forward, backward, laterally, and spin in place with static motor mounts. The motors are angled at 30 degrees from forward, giving approximately a 13% overall reduction in forward and reverse thrust when compared to a fully forward facing motor setup. However this configuration allows for half of the motors thrust to be used for lateral motion. In the event that power is lost to the front or rear sets of motors, the vehicle still maintains reliable in the forward, backward and spin aspects of movement.

Figure 4 modified trolling motor

Consumer grade trolling motors were selected for a more reliable product. These motors were mounted using vibration resistant pipe clamps mounted to the frame with angle brackets. The motor's tillers were cut down and connectorised in order to interface with the vehicle's motor controllers. Motor shrouds were not available off the shelf and needed to be custom designed and fabricated.

2.4 3-D Printing

In order to reduce vehicle weight three dimensional printed parts (3-D parts) were used. The parts manufactured from the printer had a significantly lower manufacturing time, and allowed for unique items to easily be mounted to the vehicle's frame. Items that were mounted with 3-D parts include the radio frequency communication link, the tilting scanning laser, the web cameras, the dart launcher, and the launch platform for the rover.


Figure 5 collection of various 3-D printed parts

2.5 Nerf gun

To perform the shoot through the hoops challenge a circuit was introduced to modify the firing rate of an automatic Nerf gun to single-fire mode. The circuit features a reed switch placed near the back of the Nerf gun, which is partially removed to expose the piston responsible for firing the darts. Here, on the end of the piston, a small magnet was attached to trigger the reed switch and allow single-fire control.

2.6 Mast

The vehicle's Aluminum mast was remade this year to reduce vehicle weight. The material was changed from two inch aluminum square tube to one inch aluminum square tube. It hosts the apparatus of the camera, LIDAR, temperature sensor, as well as a newly added dart gun. The mast was designed with ¼ inch holes spaced one inch along the height of the mast. This allows for quick modifications in the mounting position of various sensors and other hardware mounted to the mast. The mast holder welded to the frame consists of ¼ inch holes spaced one and a half inches apart. This allows the entire mast assembly to be moved in increments of one half inch.

At the top of the mast sits the dual camera mount. It is designed to allow for modification to field of view angles of the dual camera system, as well as modifications to the perspective angle. Sitting just below the camera is the tilting scanning laser and infrared temperature sensor mount. It rigidly integrates the servo motor and the scanning laser while bolting to the mast and the camera mounts. Mounted at the bottom of the mast is the dart gun. Its mounting assembly is entirely made of 3-D parts. This allows for a lightweight yet strong mounting solution.

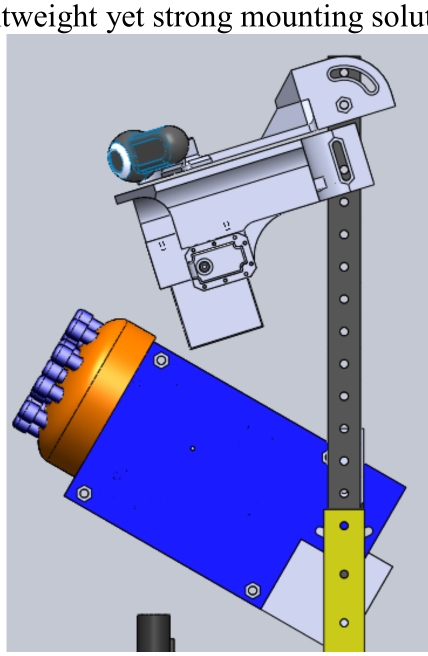

Figure 6 CAD model of mast assembly

3. Vehicle Electrical Design

The gray Goose's electrical design intent was to create a product that was robust and modular. The implementation of the DIN rail as well as the microcontroller not only met functionality requirements for the competition, but allocated resources for future systems to be implemented.

3.1 Propulsion

Four Sevylor SBM 18 motors were used for the propulsion system. 12 volt rated units were selected based on the availability, affordability, and desired specifications on thrust, form factor, and controllability. The vertical tiller of the trolling motor houses the wires and allows for mounting to the vehicle's frame. Once the motors were purchased, a power/thrust test was done. Each motor has up to 13 pounds of thrust in the forward direction at 13 amps, and nearly 11 pounds at 13 amps in reverse. They are controlled using Roboteq motor controllers interfaced to a Cypress PSoC.

3.2 Batteries

A dual power source configuration is incorporated, separating motor and logic power sources. Power isolation has two benefits: preventing interference between systems and allowing for an emergency cut-off of power to actuating devices in off-normal situations. The motors are powered from 4-cell LiFePO4 batteries providing nominal 12.8V, within motor and motor controller requirements. Additional motor batteries are placed in parallel to extend the runtime of the vehicle, with a total capacity of 26.4Ah (approximate runtime of 4 hours). The logic components of the vehicle (e.g. onboard computer) are powered from 6-cell Li-Po batteries providing nominal 22.2V. This higher voltage power rail more efficiently delivers power to all devices. A high-efficiency switching voltage regulator provides a regulated 12V power source required to operate various sensors and devices.

Charging of the batteries is achieved through the use of an external unit consisting of a Hyperion EOS0615IDUO3. Two sets of batteries are used, so that the one set can be charging while the other set is in use on the vehicle

3.3 Printed Circuit Board

A custom printed circuit board (PCB) was designed and fabricated to integrate analog and digital signals for this year's vehicle and provide new student members an opportunity to learn PCB design. The PCB contains an ARM based PSoC3 microcontroller that handles several responsibilities:

- Interprets RC Receiver Signals
- Commands motor controllers
- Monitors vehicle status (Battery voltages, temperature, etc.)
- General Purpose Input Output (GPIO)
- High Current Outputs
- USB-to-Serial Interface to Computer

The high current outputs on the PCB consists of a high power N-channel MOSFET. It is configured in an open drain configuration and allows for switching on devices up to one amp. This is utilized on the vehicle to switch high current components including the autonomous indicator strobe, relays to fire the dart gun and other high power components, and light and low battery audible indicator. Commercial connectors on the board interconnect various components and allow for expandable future uses.

Figure 7 Final Custom Printed Circuit Board

3.4 Wireless Networking

A high power wireless networking solution provides software developers the ability to debug the vehicle's programming remotely. This ability is a key factor in efficient use of testing time on the course, supporting remote configuration and adjustment of parameters on the fly for optimization. Previous designs utilized standard IEEE 802.11b/g/n network wireless routers to maintain a remote connection, which proved to be unreliable at distances achieved across the entirety of the lake. Ubiquiti Networks Rocket M5 wireless base station is a powerful 2x2 MIMO modem that has incredible range, speed and ultimate RF performance in outdoor environments. The network is configured as a point-to-point seamless link, bridging the vehicle and operator command center's network.

3.5 Power Distribution

Power distribution is achieved through the use of an industry standard DIN rail. Chosen for its modularity and standardization of parts, the DIN rail provides a solid mounting point for high current devices. Out of the shore power is delivered through the use of an external power supply fixed to the vehicle's trailer and encased in a NEMA 6P enclosure. The power supply uses 120 volt AC power supply providing 24 volts at 15 amps. A shore power relay, triggered by the AC current itself, switches from battery power to the power supply. This effectively replaces the batteries with the power supply when an AC current is supplied for additional testing and development when not in the water.

3.6 Emergency Stop

Safety is addressed with the implementation of an emergency stop circuit achieved using a 200 amp 12 volt coil contactor triggered by a single pole double throw relay. One of the throws of the trigger relay triggers the contactor and the other is used to control the relay itself. A normally closed emergency stop switch is used to cut off the power to the trigger relay, and a normally open reset switch is used to re-energize the trigger coil. To improve simplicity, a circuit was added to use the reset switch as an initial start switch for the transition into autonomous mode. This circuit uses a diode drop as a reference and a double diode as a trigger. The double diode is initially acknowledged when the switch is open, and set to an equipotential when the reset switch is pressed. The data read from the double diode and the reference diode is passed to a comparator in the microcontroller, and is seen as a 1 when the switch is pressed a 0 when the switch is idle.

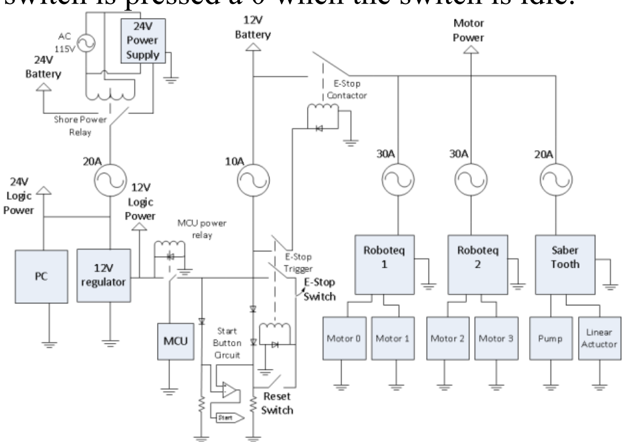

Figure 8 Power distribution diagram

3.7 Temperature Sensor

Completing the 'Rock, Paper, Scissor, Lizard, Spock station requires the addition of an infrared temperature sensor to obtain the temperature values of the four signs. Finding a sensor responsive enough for the range required to complete the task proved difficult, but the team decided on a Raytek MI Series infrared temperature sensor. The sensor has a Fresnel lens with 22:1 distance to spot optics and an eight to fourteen micrometer spectral range which enables the boat to obtain accurate temperature measurements in the infrared light spectrum. This accuracy allows the boat to sit roughly 22 feet away from the signs for the task and still accurately distinguish which suit is hot. The range of input voltages, output configurations, and the IP65 housing of the Raytek sensor fit in perfectly with the electrical designs that were in place and proved to be very reliable in even the worst weather conditions.

3.8 Nerf gun

In order to complete the 'shoot through the hoops' challenge, a 20-dart capacity automatic Nerf gun was introduced. A DC signal triggers a small motor to move a piston, which compresses air as the final catalyst to fire the dart. The darts can easily travel over 30 ft. in range, in rain or shine. The Nerf gun is housed in 3D printed mount designed to neatly fit the Nerf gun in a lightweight package.

4. Vehicle Software

The software this year heavily utilizes the infrastructure built on from previous teams. This software has shown to be proficient in completing the start gate, speed gate, and buoy navigation challenges using color finding. The new boat configuration includes important changes in computer vision (CV), artificial intelligence (AI), and motor control system enabling greater capabilities over past implementations. AI, vision, control and sensor integration are done on a quad core mobile Intel processor with 8GB of RAM.

4.1 Software Architecture

The robot's underlying software architecture is very similar to last year's boat, and is fairly standard across all Robotics Club at UCF vehicles. Sensor control and communication is routed through the Joint Architecture for Unmanned Systems (JAUS) standard using an open source implementation called JAUS++. Sensor data is packed in JAUS messages and subscribed to by the AI program, which evaluates and acts on the data. This modular approach has several advantages, the biggest being easy reuse across completely different platforms, such as the underwater, ground vehicle, and boat due to the hardware independence of JAUS. On the boat, an always on program maintains connections and communication to all hardware devices, while a separate AI program can be started, stopped, and reconfigured without the need to reconnect to sensors. Using the message passing framework provided by JAUS, software located on other network computers can subscribe to sensor data and take hardware control for fast testing and development. The software architecture implementation also includes logging of all data generated by sensors. This information can be played back within a simulation sandbox or evaluating AI behavior on recorded data. This powerful feature enables fast debugging of robot decision making in addition to development of new AI modules without the need to physically operate the robot.

4.2 Motor Control

The unique motor configuration of Gray Goose allows seamless movement in any direction on the water. This configuration affords power and agility without sacrificing the fine movement needed for achieving this year's tasks. Reliable and smooth lateral control can now be used for advanced maneuvers around targets and through buoy channels. Rotational speed has also been improved thanks to the symmetrical diamond configuration of the motors.

The AI now has access to maneuvers such as face a target while moving around it; align to target angle, and lateral search as opposed to traditional left/right sweeping searches. These new capabilities support lining up to targets without losing them from sensor view. Commands such as move to GPS waypoint, maintain velocity, and heading commands are carried over from last year's robot. High level waypoint commands are translated to velocity commands and then to thrust commands in three channels (linear x, linear y and rotational z). Velocity is estimated by GPS data combined from both the GX3 and Navcom sensors. Thrust output is determined by individually tuned PID controllers for rotation and linear velocities.

Low level motor control requires mixing three channel movement commands to four motors. Symmetrical positioning of motors simplifies the mathematics needed for this process. Each motor can be placed in a quadrant where each quadrant is a unique linear combination of the three channels.

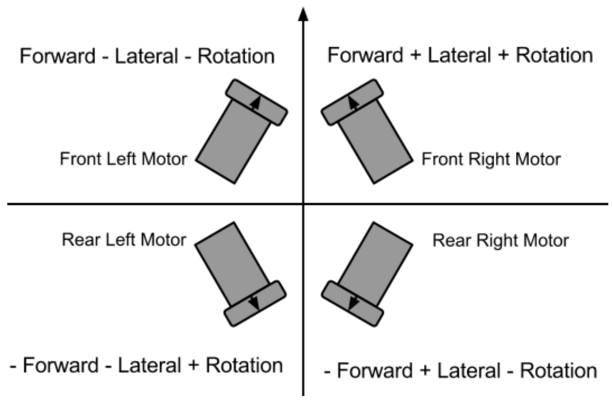

Figure 9 Illustration of motor configuration

4.3 Computer Vision

An array of two Logitech webcams delivers the field of view of a wide angle lens without the cost and the image distortion. The webcams also contain embedded image filtering hardware to allow for more consistent image data in all weather conditions. The two camera's images are fused together through open CV's newly implemented panorama class. All vision processing is done in C++ using the OpenCV library.

Figure 10 Image stitching example

4.4 State Machine

The course is broken down into missions, one for each challenge. Each mission can be broken down further into states and sub-states, in which discrete actions are taken based on fused sensor data. When certain conditions are met, states will transition to new states until an end state is reached and/or the mission is complete. Each mission has a time-out value which ensures the vehicle can "give up" and move on to the next mission maximizing challenges attempted.

Figure 11 computer vision processing

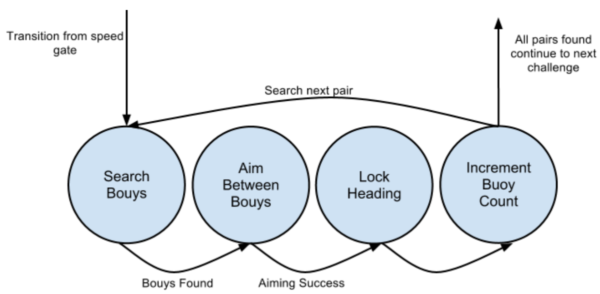

Figure 12 buoy navigation state machine example

4.5 Point cloud

A tilting Hokuyo LIDAR and Dynamixel servo allows laser data to be added to a 3D point cloud used in conjunction with computer vision to better acquire targets of interest. As the LIDAR pivots, angle values are read from the Dynamixel and points are translated and input into the open source Point Cloud Library (PCL). The 3D point cloud is calibrated to camera data to enhance color segmentation and reduce false positive detection.

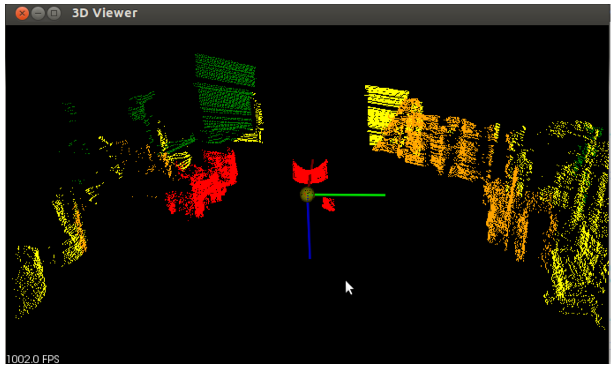

Figure 13 An example of 3D data collected from the tilting LIDAR unit. Distances have been color coded to a heat map.

5 Rover

In order to complete the "Catch the Ball task", a lightweight paddle wheel driven amphibious rover was designed. The rover consists of a Google Nexus 4 (Android device) for its primary computer, communication module and sensor array. An IOIO-OTG board (Android interface) is used to communicate with the Android device, and allow for peripheral interface. A Teensy 2.0 ++ board (motor interface) is used to interface with the motors, encoders, and a remote control receiver unit. It is all housed in a NEMA 4x rated case. Three dimensional printed parts are employed for other mechanical solutions.

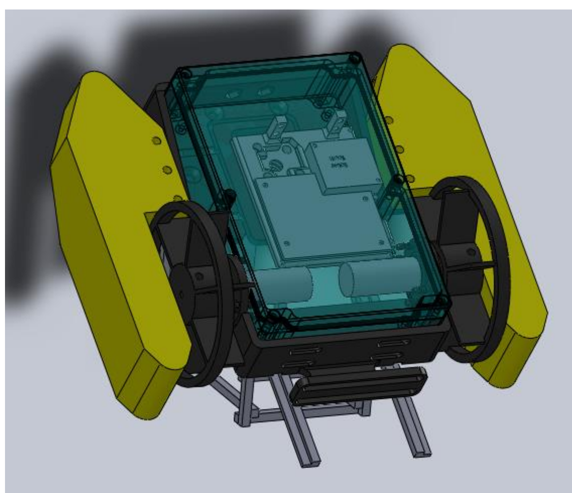

Figure 14 CAD drawing of amphibious vehicle "Rover"

5.1 Rover Mechanical

The propulsion system aboard rover is designed to provide fast, predictable and accurate movement. It is comprised 3-D printed paddle wheel mounted to a waterproof drive shaft via threaded inserts. Because of the innovative paddle wheel design allows the rover to achieve accurate control both in the water and on land without any mechanical changes. The paddle wheel is equipped with large paddles designed to move water and rugged treads designed to provide grip when on dry land.

A major design issue to overcome in the construction of the rover was waterproofing the wheels. A custom machined drive shaft is positioned through the use of high speed oil seals encased inside a 3d printed housing. The oil seals not only keep water from entering the chassis through the drive shaft, but also encase heavy oil between both oil seals which lubricate the drive shaft and adds another layer of waterproofing. Rover is able to maintain full wheel speed in the water while being completely submerged in water.

The three pontoon flotation system is designed to be fine-tuned based on the load that the rover is required to carry. It also corrects the orientation of the vehicle in the event of a fall into water. The pontoons are constructed from 3-D printed material encased in a marine epoxy. The height of all three pontoons can be easily adjusted to compensate for equipment added or shifted during the design process, without having to fabricate new pontoons. The forward facing pontoon is designed with a large flat face, and functions as a deflector when entering water from a drop, causing rover to always return to right side up when driven off a platform into water.

A custom built launch platform was fabricated using welded ¼ inch aluminum rod, creating a structure which houses a launch solenoid and provides a ramp used for deployment of the Rover subsystem. The launch solenoid is triggered when Grey Goose enters the “catch the ball” state.

The puck retrieval system consists of a passive and active component. The passive component consists of four screws mounted to the bottom of the rover. They are positioned in a way that directs the puck into the field of view of an infrared proximity sensor when the vehicle passes over the puck. Once the infrared proximity sensor detects the puck, the active portion of the system is activated.

The active component of the puck retrieval system consists of a servo driven piston mounted inside the chassis attached to a Velcro surface outside the chassis. The motion of the piston is able to maintain rover’s water resistant qualities using a triple O-ring shaft-sealing system. The shaft seal system is made possible using 3d printed material, the design is impossible to make using classical manufacturing techniques.

5.2 Rover Electrical

The electrical portion of the rover consists of a Teensy++ 2.0, an IOIO-OTG board, a Futaba FASST receiver, and a Sabertooth 2x5 motor controller. A custom built circuit board connects all the components into a tightly knit package that allows for easy mounting and power regulation and distribution.

A Teensy++ 2.0 is used to process information used in the control of the hardware on the Rover. The Teensy processes input from quadrature motor encoders, the Futaba RC receiver and the IOIO board. These inputs are interpreted and translated to a Sabertooth 2X5 motor controller via the simplified serial protocol.

The Teensy receives heading and throttle commands from the IOIO board or the RC receiver. A motor mixing function, written in the Arduino environment processes the data and relays the information over a serial communication port to the Sabertooth’s RX port.

The IOIO provides connectivity to an Android phone via Bluetooth. It also has basic microcontroller functionality, allowing it to interface with peripheral devices such as an Infrared distance sensor and a servo motor. During autonomous use, the IOIO takes over as the hub of the rover. Digital Input/Output, PWM, Analog Input, I2C, SPI, and UART control can all be used with the IOIO.

5.3 Rover Software

An android smartphone was chosen as the platform device to control the rover because of the already robust frameworks available to build from. The hardware is headed by a Nexus 4, it provides a compact all in one package to gather, analyze and transmit data

5.4 Nexus 4 Specs

The Google Nexus 4 is equipped with a 1.5 GHz quad core processor and 2 GB of RAM. Also included is a 720p Camera used for computer vision, an 802.11 a/b/g/n Wi-Fi module for communication to the mother ship, and a Bluetooth module. The Bluetooth module allows for transmission of data to the embedded components of the rover without a physical cable. This solves the problem of electrical connectors in the rover. Other sensors include a Gyro, GPS module, Accelerometer and a magnetic compass. These sensors allow the rover to preform heading control and basic GPS localization.

5.5 Android Operating System

Android allows the rover to leverage the powerful, already written code found in OpenCV, the Android SDK, and Java libraries. Rover was built around a framework that takes modularity and reusability into account. This framework will allow Rover to adapt to different situations with minimal changes in the code base.

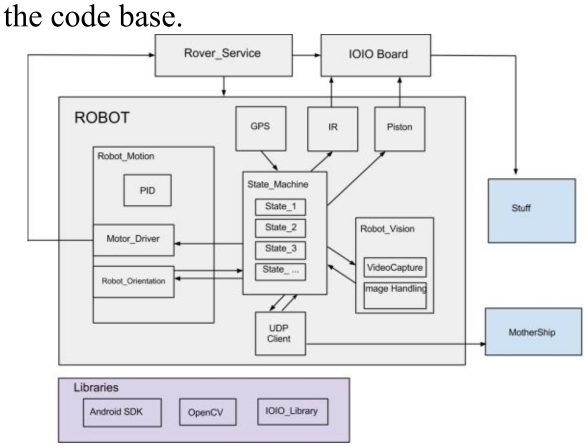

Figure 15 Rover's software diagram

6. Conclusion

The Robotics Club at UCF has been hard at work on a completely new Autonomous Surface Vehicle (ASV) called the Gray Goose. Innovative new features such as a vector thrust control for three degrees of movement on water, wider, more stable and lightweight pontoons, point cloud generation with a tilting Hokuyo LIDAR and improved power regulation will allow the vehicle to go far in this year’s competition.

7. Acknowledgements

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