Underwater Salvage Robot: An Undergraduate Research Experience

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Abstract

Approximately 1 billion golf balls are sold per year in the United States alone. Of these 1 billion, about 100 million of them end up sitting in the bottom of a pond waiting to be retrieved. Golf ball retrieval is currently a 200 million dollar industry and is still growing [3]. Golf balls that are lost in ponds are currently retrieved by professional scuba divers who can make anywhere between 50,000 and 100,000 dollars per year. Although golf ball retrieval is a profitable industry, it is far from safe, and many professional divers have lost their life going after the "white gold". The water is often murky, and divers must crawl through several feet of silt, branches and leaves in order to even find the golf balls [3]. A more efficient and safe system, such as a robot, should be developed to aid in golf ball retrieval in order to save lives and increase the profits of this ever growing industry.

The objective of this research is to design and test an underwater salvaging robot that will eliminate the need for human divers to be put into harm's way in the golf ball retrieval industry. The user of the robot will control the robot on the bank of the pond using a simple controller. Using the visual output of both a depth sensor and an underwater camera, the user will be able to locate and retrieve golf balls within the pond. This paper will include a summary on the research done, the decided course of action, description of the designed robot, and collected testing data.

Introduction

Within the College of Engineering at Ohio Northern University, each senior student is assigned to a team and is required to work on a senior design capstone project. This capstone project is a very important step in the overall education process because it provides students with a comprehensive design experience that encompasses things learned in previous years. Students must ensure their project is ABET compatible and allows them to demonstrate "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health, safety, manufacturability, and sustainability" [1]. Students must also demonstrate their ability to follow a standard problem-solving methodology that includes, defining the problem, gathering information, generating alternative designs, evaluating alternative designs, and communicating the results [2]. The College of Engineering hopes that upon completion of the course, each student will be able to apply previous knowledge to a design project, follow a standard design process, apply project management tools, and effectively communicate their results to others. This paper describes the work of The Underwater Salvage Robot senior design group comprised of four mechanical engineering students and two electrical engineering students. The underwater salvage robot senior design capstone was much different from other capstone groups due to the fact that it is a cross disciplinary group. Most capstone groups are comprised of students within the same major or field of study, but the underwater salvage robot requires expertise in both mechanical and electrical engineering in order to be designed and built. The members of The Underwater Salvage Robot senior design group benefits from this because working cohesively with people from other fields of study is very important in industry.

The first step the group took was to define the problem they were looking to address and narrow down the scope of the project from "underwater salvage" to a less broad topic. It was suggested by one of the faculty advisors of the group to focus on pond salvage because that is something that could be easily tested and implemented in Northwest Ohio, and an acquaintance was looking for a salvaging device. Upon further research, the group decided to emphasize the salvage of used golf balls that rest at the bottom of golf course ponds because it is surprisingly a large industry with very little development. In fact, golf ball retrieval is currently a 200-million-dollar industry and is still growing [3]. Golf balls that are lost in ponds are currently retrieved by professional scuba divers who have to crawl through several feet of silt, battle against animals and cold temperatures, and put themselves at risk of drowning. For these reasons, the group believes that a more efficient and safe system, such as a robot, should be developed to aid in golf ball retrieval in order to save lives and increase the profits of this ever growing industry. With the scope of the project narrowed down to underwater golf ball retrieval and a clearly defined problem statement, the team could then come up with criteria and constraints to govern the project.

Having good criteria and constraints is very important for the overall design process because they essentially lay the framework for the project and highlight the main points of concern. Some of the main constraints are as follows. First, the cost of the project should not exceed $2,000.00 dollars. Second, the system will have a peak current draw of 10 A, a peak power draw of 120 W, an average power draw of 60 W, and will be able to run off of a 12V golf cart battery. Third, the system should be able to operate between 0 and 35 degrees Celsius on days with no adverse weather such as rain or snow. Fourth, the system should give both a video output and depth sensor reading at all times during use. Finally, the robot should be able to dive to a depth of 10 meters without any adverse effects on the motors and microcontrollers. Some of the criteria the robot will be judged on are as follows. First, if the robot can pick up a golf ball and bring it to the surface without difficulty. Second, if the controls are easy to understand and are able to be learned by most golf course grounds keepers. Finally, if the robot is durable and near neutrally buoyant to ensure that the robot will function correctly while submerged. With these criteria and constraints established the team had a good baseline of what is needed, and where to go with the project.

Background

In 2008, a capstone group at Ohio Northern University designed and built an underwater robot to be entered into a competition specifically for underwater robots. This pre-existing robot provided the interest that sparked this project. Since the 2008 robot was designed to perform specific tasks for the competition many aspects needed to be reevaluated to better suit the new task of the robot: retrieving golf balls. This original robot can be seen below in Figure 1.

Figure 1: 2008 Robot

The arm on the pre-existing robot was fixed at a certain angle and the claw at the end of the arm was specifically made to open and close. This mechanism would not have been able to pick up a golf ball and would also not be able to be modified to perform the desired tasks because of the arm's inability to move up and down. The pre-existing robot also had waterproofing issues, which were attributed to the age of the robot and the poor sealing job that was done. Sealing issues were found in the arm, around the camera and on the black box holding the electronics. The current team decided that the only components of the robot that were salvageable were several of the motors and the frame.

Another inspiration for this project was the methods that are currently being used at golf courses to retrieve golf balls. The golf balls are all picked up by hand or contraptions that do not allow the user to actually get a visual of the balls. An underwater robot would allow the user to avoid the risks of diving for golf balls while allowing them to still have visual of what they are doing. After looking further into the possibility of this, the team then looked at designs of existing underwater robots and the specific components used on these robots.

There are many current designs of underwater salvaging robots. There are also many different ways in which these robots move through the water, communicate with a command station, and perceive their environment. Movement of an underwater robot is accomplished through several different designs; a glider design which uses a ballast tank to propel the robot forward, propellers or thrusters. Communication has been accomplished through two different methods, a tether or an antenna transmitter. Perception is accomplished through many different methods, including a camera, hydrophone and sonar. These three areas will have the greatest impact on the robot's success, so they were investigated thoroughly.

Arm and Body Design

The robot from 2008 did not meet the criteria and constraints of the project, so a major redesign was done to meet the constraints. The body of the robot was not changed drastically, but was rearranged to solve some issues seen during preliminary testing of the original design. The arm from the original design was not able to pick up a golf ball, and was very slow. The arm required the most work to redesign. Also, the sensors on the robot changed and other electronics were added, so the new sensors had to be integrated into the design.

The body was changed based on observations from testing and the new requirements of the design. On the robot from 2008, the electronics box was located near the rear of the robot. This box was moved forward as the new arm added weight to the front of the robot, and moving the buoyant box forward offsets the weight addition as a counterweight was present on the original design under the box. The set of propellers that control depth were moved lower in the body as they were not always submerged on the old robot. Also, the center propeller was moved to the rear to facilitate moving the controls box and to improve the maneuverability of the robot by moving it farther from the center of the robot. This gives the propeller more distance to the center of the robot, and will turn the robot more quickly. The motors used for the propellers will be used in the new design as they are waterproof from the factory, and have held up well since 2008. The front and rear end of the robot were also redesigned as the new sensors could not easily mount to the existing ends. The plates were redesigned to leave more material around the attachment holes in the plate to reduce cracking seen in the original plates. An additional cross member was added near the front of the robot to mount the arm to the robot. Finally, the controls box was replaced as the old box leaked, and redundant sealing will be used to prevent the problems seen in the old robot. The drawing of the new robot frame with the new arm attached can be seen below in Figure 2.

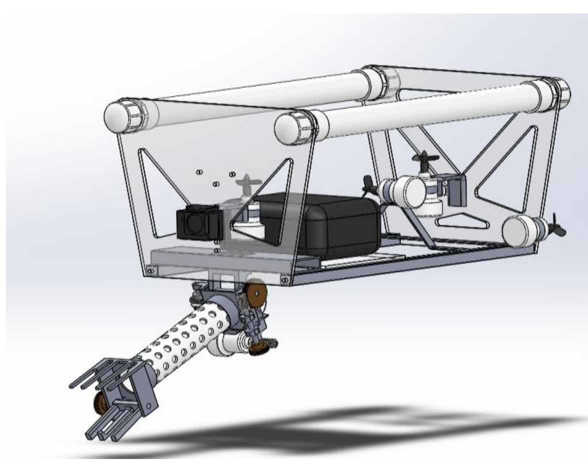

Figure 2: New Frame with Arm

The arm required a new design as the current arm had very limited functionality, and many changes had to be made to meet the constraints of the project. The original arm had a fixed mount, and the whole robot had to be moved to maneuver the claw into position. Also, the claw closed very slowly and only had two opposing points of contact. This design would make it very hard to grab anything off of the bottom of a pond, and only allowed for a single object to be picked up at a time. The new design was given two degrees of freedom, versus the single degree in the original design, to make the arm easier to maneuver. More joints were considered, but this would have added unnecessary weight and complexity to the design. It also would make it harder to control the robot and the arm at the same time with more possible movements. The arm will move up and down from the robot to allow the arm to reach at different angles. Also, the grip was redesigned to better use the movement of the claw to grab objects off of the bottom of a pond. In the new design, a rake will be used. This was decided on as it would give the largest reach when picking up objects, and would reduce the amount of dirt being dragged with the robot. In the original testing, dirt stirred up by the robot made it very hard to see, so a reduction in dirt will aid in the vision of the design. The rake would allow the robot to dig into the dirt and pull out golf balls on the bottom, and small rocks and dirt will filter out of the grip. The new arm can be seen in Figure 3.

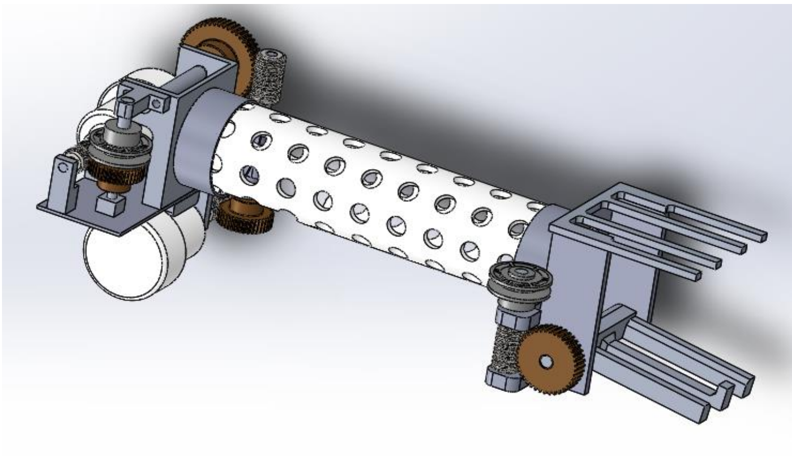

Figure 3: New Arm Design

Storage was also added to the robot to allow multiple golf balls to be carried by the robot during a single trip, improving the efficiency of the design. This will allow more golf balls to be picked up before it has to resurface. It was also decided to use the same type of motors throughout the design because of their reliability of being waterproof.

The design process of the arm and body was one of the critical parts of this project, and many factors have been considered to create the best design. The body is mostly unchanged with parts moved to optimize the old design, and mounting points added for the new electronics and arm. The arm was designed to pick up golf balls with more control than the old robot, and storage was added to improve the efficiency of the design. These improvements should allow the user to explore the bottoms of ponds and retrieve golf balls without ever getting into the water.

Controls and Wiring Design

One of the main components of the old system that needed to be updated to meet our constraints was the motor control system and the wiring of the entire system. The prior motor control system included a bot board II microcontroller and four sabretooth motor controllers. The system was able to control the five propellers and the motor that turned the arm. The user controlled the robot using a Playstation 2 controller. The controls were held in a waterproof box attached to the middle of the robot. The system was then wired back to the user on the shore by 12 gauge power cables. The cameras were also wired back to the shore for the user to receive visual output from which to steer and operate the robot. A wiring diagram for the whole system can be seen below in Figure 4. Red lines indicate wires in the tether connecting the robot to the user on shore.

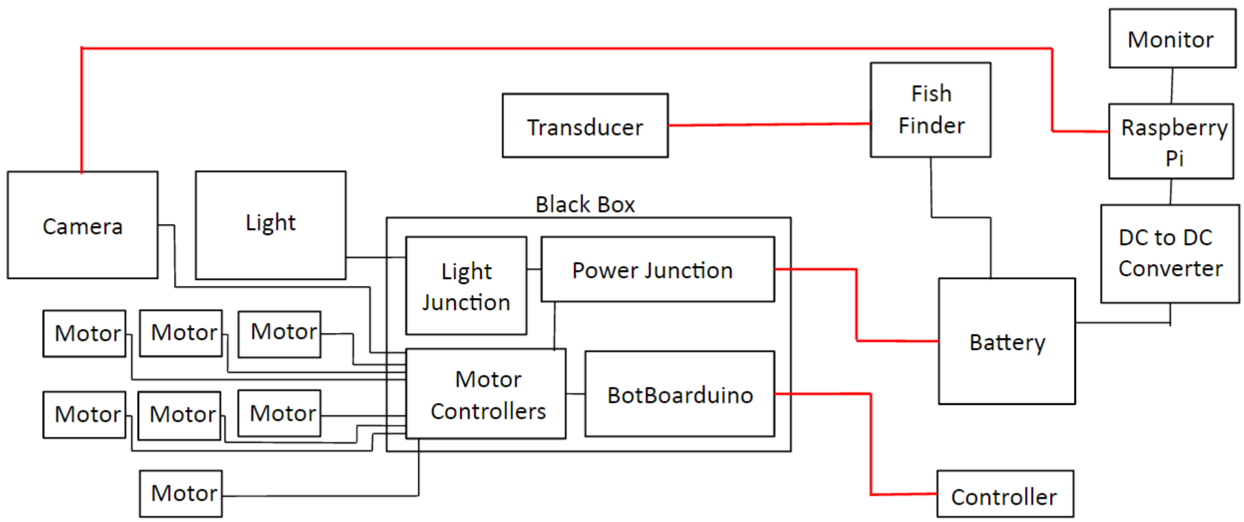

Figure 4: Block Diagram for the Robot

Due to the change in constraints for our project, the following changes had to be made from the prior system; the additional sensor and light placed on the robot must be powered and wired to the power source, the control system and user input controller has to operate all five propellers as well as two motors on the arm, and the power cables must be changed to 10 gauge wire in order to contain the increase amount of current. Along with increasing the capacity of the wires the length of the wire also must be increased. The robot must be able to reach a length of 50 ft. which was established by an approximation on local pond sizes and the deterioration of HDMI video signal over distance. When reconnecting the wires, the connections must be waterproofed and sealed to protect from the underwater pressure.

The Bot Board II microcontroller used for the prior prototype used a program called Basic Atom Pro IV which is no longer licensed for readjustment. Due to this fact, a new microcontroller was purchased from the same company to ensure Playstation 2 controller compatibility and motor controller compatibility. The new microcontroller used is a BotBoarduino which uses the Arduino programming language. The program uses a simple definite logic to control one motor with one button on the controller. The four motor controllers are connected to the five propeller motors and the two arm motors using a water proof power wire. In order to run the motor clockwise and counterclockwise (forwards and backwards) the motor controllers are set to independent mode which allows for the switching of positive and negative terminals. The black box or the waterproof box holds the two motor controllers, the microcontroller, and the power junction.

The power junction is used to send the correct amount of voltage and current to the correct components of the system. The power cable is connected from source on the shore to the power junction block. From the power terminal, both the light and the camera use the full amount of power from the source. Due to the lack of voltage necessary to run the electrical components, resistors are placed to reduce the voltage entering the components.

The final part of the adjustments in the control system and the wiring is the resealing of the black box. The wires coming from the shore and going to the motors are connected using a waterproof connector. Holes on the side and bottom of the black box are then cut to place the waterproof connectors. The holes are then sealed with paste and sealable rubber which protects the electronics on the inside. Making sure the components are all connected together in the correct manner has been a difficult challenge to our project, and making sure all of the connections are waterproofed and safe has increased the difficulty of the project tremendously.

Completion to Date

As mentioned above, this robot design is a much improved design from a previous underwater robot built in 2008. To understand what parts of the old design were still viable, several tests were conducted. A full out of water test was conducted on the old robot to see if the motors and arm worked. Four of the five propeller motors worked and while the arm motor worked, it was slow and was deemed not applicable for this project. The front camera worked, but not well and the bottom camera failed to work. A waterproof test was conducted on the old electrical black box and it was found that it was not sealed properly and let water into the controls. After resealing the black box, a full body underwater test was conducted to test maneuverability and versatility. It was found that the propellers worked well to move the robot around, but the robot was too buoyant and floated to the top of the water when the propellers were not in motion.

A full re-design of the robot was needed. The main body parts would be reused as well as the four propeller motors that worked. The body with new plexiglass front and back ends, new arm mount, and camera mount is shown below in Figure 5.

Figure 5: New Body

The arm was redesigned to pick up golf balls and hold on to them inside the arm section. The completed arm can be seen below in Figure 6 and a detailed picture of the claw can be seen in Figure 7.

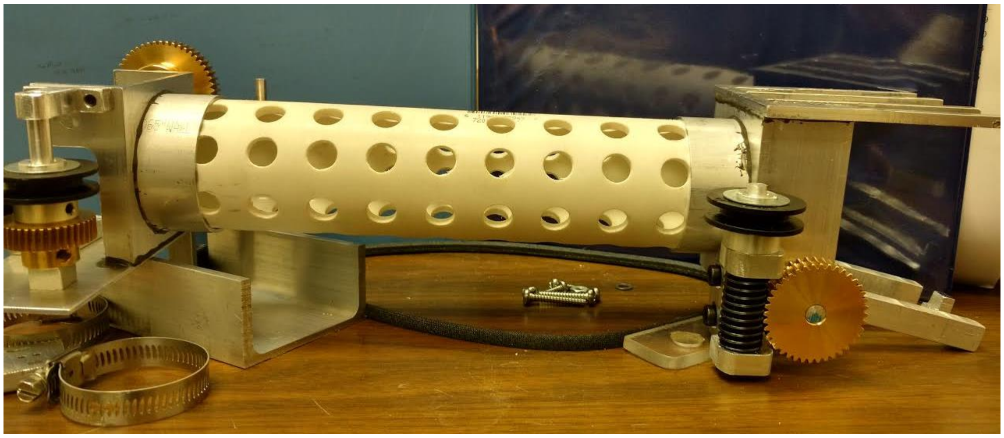

Figure 6: Completed Arm

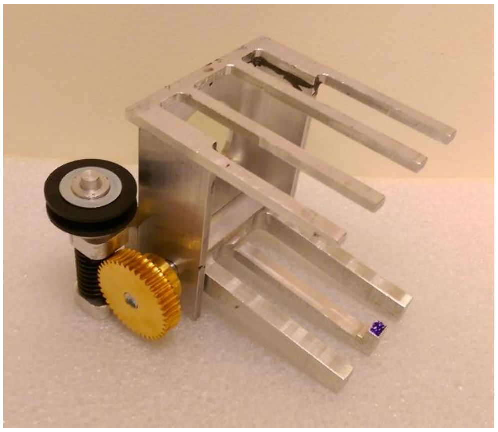

Figure 7: Completed Claw

A new box was necessary to hold the electronics and keep them waterproofed. A new camera was needed for the front of the robot and a fish finder was needed for the bottom of the robot. The new camera can be seen below in Figure 8 and the fish finder can be seen in Figure 9.

Figure 8: SJ5000x Waterproof Camera

This is a SJ5000x sport camera. It is waterproof inside its case up to 30 ft. (the underwater salvage robot will only dive to 10 ft.). It will utilize the HDMI output feature to display the video feed on an HDMI for pi screen powered by raspberry pi image processing. It is replacing a security camera that was encased in a dome, which can be seen in Figure 1 on the front end of the robot. The security camera utilized an analog video connector which displayed video on a TV screen. Since, the new robot needed to be battery powered for golf course use, the SJ500x and HDMI for pi screen better suited the new requirements.

Figure 9: Garmin Echo 101 Fish Finder

The Fish Finder will display a basic image of the bottom of the pond terrain and a depth of how far the transducer (mounted on the bottom of the robot) is to the bottom of the pond. Prior to the Fish Finder transducer, there was a second security camera mounted on the bottom. The Underwater Salvage Robot team did not think that this would be beneficial to tell the depth in the pond, because it would mostly just be mud. The depth sensor gives the user a better idea of the robot's positioning.

After full design of the arm, body, controls and wiring, the underwater robot was physically built. All parts were custom built to specification and design. The arm was put together and attached to the bottom of the robot. The camera and light were mounted to the front body panel and the fish finder was mounted to the bottom of the body. All propellers were attached in the specified orientation. The electronics were wired into the black box and a tethered connection was made with 50 feet of cords to the controller, power source, and viewing screens at the shore of the pool.

In testing, the camera was found to work very well and with the addition of the LED light, it worked even better. The fish finder was able to read the depth of a pool at various heights. The propellers all work.

Conclusion

The Underwater Salvage Robot team is invested in creating a more efficient and safe system to aid in golf ball retrieval to save lives and increase the profits of this ever growing industry. In order to do this, the team has taken the previous design of a competition underwater robot, tested its components, and decided to repurpose it to aid in golf ball retrieval. After extensive research done to decide the best approach to each section of the robot the team decided on the following: redesigning the robotic arm to function as a scoop leading to a retrieval basket, replacing the vision system with a new camera aided by a light and a depth sensor, and redesigning several of the main body components of the robot due to age and inefficiency.

The team has tested the individual components of the robot as it has been being assembled. While each component has passed tests individually, the team is now in the process of executing an extensive testing plan for the whole robot now that construction is complete. In addition to testing, the team will make the robot as close to neutrally buoyant as possible. Once these main objectives are complete the group can continue to make improvements on the robot as seen necessary. More details on the results of these tests can be expected in the final presentation as the group should have completed testing by the conference. Having made strong progress thus far, The Underwater Salvage Robot team looks forward to continue to delve deeper into the creation of a device for the golf ball retrieval industry.

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