

Design of a Roller-Collector Remotely Operated Vehicle

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Abstract- The Roller-Collector Remotely Operated Vehicle (RC-ROV) was designed to compete in the interscholastic Marine Advanced Technology Education Center (MATE) ROV competition. The objective of the competition was to build an ROV which would enter a mock shipwreck and collect as many objects as possible within a time limit.

The most prominent feature of the RC-ROV is the roller collection system. This collection system was chosen because of its simplicity, effectiveness, and ease of use. The system consists of two foam rollers that rotate into each other in order to catch and funnel objects into a collection basket. The vehicle utilizes a fast and easy drive-over collection method which eliminates the need for fine positioning of the vehicle or of the collection mechanism.

The electronic controls of the RC-ROV are also designed for simplicity. Using a "brute-force" approach, all of the motors are wired through a subsurface breakout box directly to a topside controller. Two cameras are wired directly through the tether to topside monitors.

The RC-ROV has two thrusters in each of the vertical, forward, and lateral axes in order to maximize speed and maneuverability. These thrusters can be paired, such that a pair operating in unison provides directional movement along the axis it governs. By operating the motors in opposition, the ROV can be maneuvered to pivot and make directional turns.

The RC-ROV has two cameras, one forward-looking and one back-looking. The forward camera aids in both steering and object collection. The rear camera aids in looking behind to see that no objects have been missed in a sweep over the room.

The RC-ROV design concept could be expanded and improved upon to create an efficient and inexpensive vehicle for underwater use in fields such as mining and deepwater archaeology. The roller concept can be used as a substitute or in conjunction with other collection systems that are commonly used today. The RC-ROV is simple to operate and do not require much pilot training. Roller shape and positioning can be varied to fit specific jobs. The RC-ROV can also operate its rollers in reverse to shuttle cargo to underwater construction sites. Other improvements are likely to be found for the RC-ROV as its low cost, simplicity of design, and ease of use make it very attractive when compared to other, more complicated systems.

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I. INTRODUCTION

The Roller Collector Remotely Operated Vehicle (RC-ROV) (Fig. 1) is a unique vehicle which was designed for competition in the Marine Advanced Technology Education Center (MATE) Remotely Operated Vehicle (ROV) 12-25 class competition. The competition challenges teams to enter a mock "Titanic" shipwreck and collect "sea probes" to be carried to the surface in a given time limit. The competition dictates only three design constraints: ROV's must use no more than 12 volts and 25 amps, and must be able to fit into a 61 square centimeter (2 ft^2) cube.

The wreck is simulated by a structure made of 3.81 centimeter (1.5 in) PVC pipe. The structure is 2.4 meters long x 1.8 meters wide x 1.8 meters high (8 ft x 6 ft x 6 ft) and has two inside decks. Each deck has a corridor and two rooms located side by side each with an entrance coming from the corridor. The structure's bulkheads are fabricated from plastic mesh.

A 61 square centimeter (2 ft^2) entrance to the Titanic is located on the top of the structure and leads to the corridor of the upper deck. Directly below this entrance is an opening which connects the corridors of the upper and lower decks. This opening is identical to the entrance to the upper deck. Each room has a 61 square centimeter (2 ft^2) entrance as well.

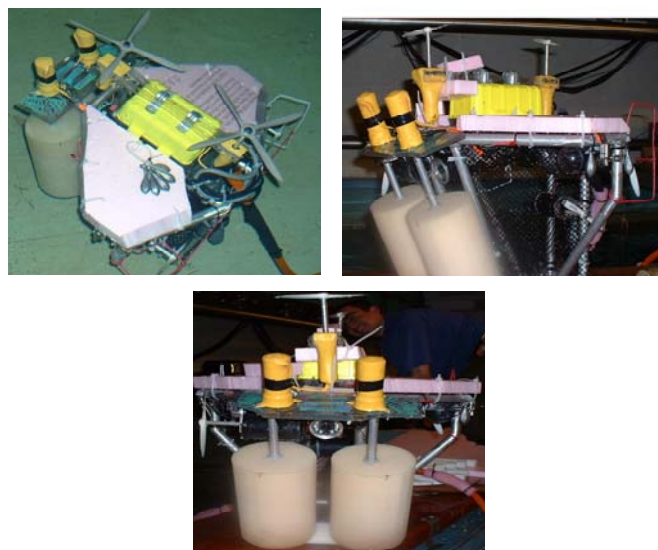


Fig. 1: the Roller-Collector Remotely Operated Vehicle (RC-ROV) top, side, and front views.

Twenty “sea probes” are located inside the Titanic. These probes are similar to dive sticks and are made of 1.27 centimeter (0.5 in) PVC pipe with caps at each end. They are weighted at the bottom so that they stand upright. At the top of the probes are PVC rings. The goal of the competition is to pick up as many sea probes as possible within a 20 minute time frame. Each probe is assigned a point value so that probes deeper within the “Titanic” or in a difficult to reach position are worth more points than those at an easily accessible location. All probes are located within the structure.

II. DESIGN

A. Global Considerations

The RC-ROV was designed with two key considerations in mind. The first design consideration was that the RC-ROV would accomplish its objective quickly. It was designed to pick up the maximum number of sea probes in a minimal amount of time. Hence, the vehicle needed to be fast and maneuverable and have a probe retrieval system that could be operated easily.

Secondly, the ROV needed a simple, robust design so that it would be less likely to break and easier to fix than a more complicated system. This was accomplished by the use of primarily solid (non-jointed) members and few moving parts. Spinning rollers were found to be a good choice to minimize the number of components (moving or static) used in the collection system. Rollers were also found to be very sturdy and less likely to break than many other possible collection systems.

The vehicle's frame was designed to account for the above considerations (Fig. 2). The frame was designed to be small in comparison to a 61 centimeter cube (2 ft³), sturdy, and light enough to be carried by hand. The small size aids in maneuverability and a low weight makes the vehicle easy to transport and work with when out of the water.

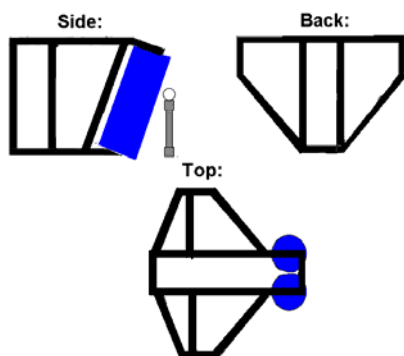


Fig. 2: Frame Diagrams (side, back, top) with rollers displayed in blue and a sea probe displayed in gray.

A frame design was chosen with roller attachment plates on the front of the vehicle. A box built into the frame was to be used as a collection basket. On the top of the vehicle were “wings” to which thrusters, buoyancy, electronics, cameras and anything else that became necessary could be mounted. The frame was made out of 7.62 centimeter ($\frac{3}{4}$ ”) Aluminum tubing welded together into a single solid piece.

The use of several small thrusters aided in maneuverability and also eliminated the need for a movable thruster. Six thrusters were chosen so that each of the x, y, and z axes would have a pair of thrusters for movement. With two thrusters per axis, the thrusters could be made to work either in unison or in opposition to provide thrust or torque along each axis.

B. Rollers

The most distinctive feature of the RC-ROV is the roller system for sea probe collection. The rollers are a unique and innovative solution to the task of gathering sea probes, providing several advantages such as speed and robustness. The roller system has a simple design, consisting of two foam cylinders (“rollers”) mounted onto cylindrical shafts which are rotated by two motors. One cylinder rotates clockwise along its vertical axis and the other rotates counterclockwise such that the two rollers rotate into each other (Fig. 3a).

The rollers are mounted at an angle so that they tilt forward allowing them to grab sea probes from the top (Fig. 3b). The collection technique of grabbing a probe from the top accounts for the presence of a cup in which the probes are placed that would present a problem for purely vertical rollers.

The cylinders are actuated by two 69 RPM 0.91 Newton-meters (8 in-lb_r) torque motors positioned at the top of the shafts that run down the center of each cylinder. The cylinders are mounted on the front of the vehicle and the vehicle is driven directly over a probe that is to be collected while the rollers spin and grab the probe. Once collected, the sea probes are pushed into a mesh collection basket located in the center of the vehicle behind the rollers.

The RC-ROV's roller system has a very simple design and requires minimal attention during operation. The roller collection system allows the pilot to focus primarily on vehicle movement because the rollers can be controlled with an on/off switch. This simplified operation makes probe collection faster and easier than competitive systems because the pilot has few systems to juggle while collecting a probe. The rollers can also operate in reverse and expel the contents of the collection basket in case debris is accidentally collected.

There are very few parts involved in the roller system (Fig. 3c) and this simplicity reduces their probability of failure. The weakest and most complex part of the system is the joint between the motor shaft and the roller shaft. This connection was made with a

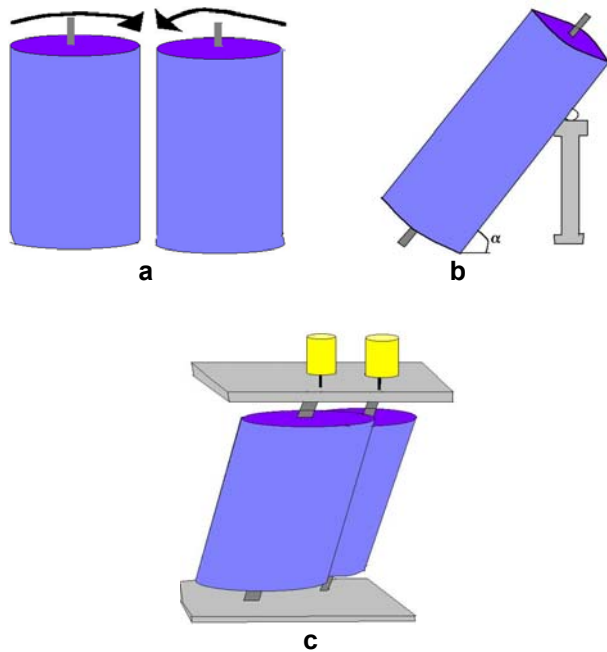


Fig. 3: (a) Roller rotation. (b) Angle of roller tilt and example of grabbing a sea probe from the top. (c) Full roller assembly. Parts include foam cylinders, cylinder shaft, two motors, and mounting plates.

shaft extension coming from the motor shaft. Setscrews and the alignment of the motors with the top roller plate were the most fragile parts of this connection. Other potential problems with the roller system were motor strain due to drag and the glue seal between the rollers and the shaft.

For future applications, a variable angle of tilt on the rollers may be useful. Also, the ability to move the rollers closer together or further apart (laterally) and the ability to move them forward and backwards could be useful. Variable speed motors are also envisioned for future uses. With these improvements, the RC-ROV could be used to collect objects of various sizes and shapes or objects in difficult to reach areas.

None of these improvements were implemented on the RC-ROV because they added more complexity than was necessary for the vehicle's mission. The rollers were mounted in a fixed position and required no operational control (aside from an on/off switch); hence, the pilot could focus more on locomotion than the task of probe collection.

This lack of complexity allowed for the development of the "drive-over" collection method whereby the pilot approaches a probe with the vehicle, turns on the rollers and then drives through the probe—keeping the view of the probe near the center of the camera's view. This collection method is highly efficient and adds considerably to the rate at which sea probes can be collected. It virtually eliminates the need to stop, hover, or execute fine positioning during probe collection as many other systems require.

The drive-over collection method is made possible by several factors. First of all, the rollers can effectively

catch the probe over an approximately 0.1 meter (4 in) span between the lateral midlines of the two rollers. (This span was determined experimentally during a wet run.) As the rollers drive into a probe, a combination of the friction between the roller and probe and the forward motion of the vehicle create this collection span by essentially funneling the probe into the gap between the two rollers. The probe is then pushed into the collection basket. Foam rollers also entrain water; thus, as the rollers rotate, they create a fluid flow which funnels into the gap between the rollers. Hence, probes can be directed toward the intake of the roller system without any physical contact with the rollers.

C. Maneuverability

The RC-ROV's maneuverability comes from six thrusters mounted in vertical, lateral, and forward pairs. The lateral and forward (horizontal plane) pairs are made of 300 rpm, 0.18 Newton-meter (25 oz-in) torque motors combined with a two blade, 0.1 meter (4 in) diameter propeller. The vertical thrusters are made of 600 rpm, 0.06 Newton-meter (9 oz-in) torque motors combined with the same propellers as the horizontal thrusters.

The motors were made waterproof by "potting" with Flexane™, a rubber urethane compound (Fig. 4). The "potting" method of waterproofing was found to be faster, easier, and just as effective as building a waterproof housing for the motors. Mounting plates to attach the motors to the vehicle were bolted onto the face plate of the motor and had a slot for a hose clamp to connect them to the frame of the vehicle. A waterproof seal was made between the mounting plates and the motors by drizzling Flexane between them before they were bolted together. The Flexane filled both the bolt holes and the shaft hole to create a watertight seal. The assembly was then placed into a cylinder partly filled with Flexane and left to dry. While drying, the motors were run periodically in order to minimize friction on the shaft. When dried, the Flexane created a watertight housing around the motor.

In order to maximize the amount of clear water seen by the propellers, a shaft extension was used to attach the propellers to the motor shaft. A hemispherical dome was attached to the opposite end of the horizontal thrusters in order to smooth the flow of water over the thruster. (Fig. 5)

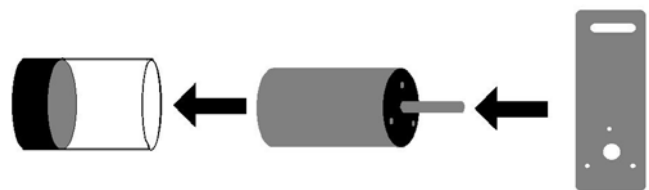


Fig. 4: Potting a motor with Flexane™. A mounting plate was bolted to the motor, and then the assembly was placed into a cylinder filled with Flexane.

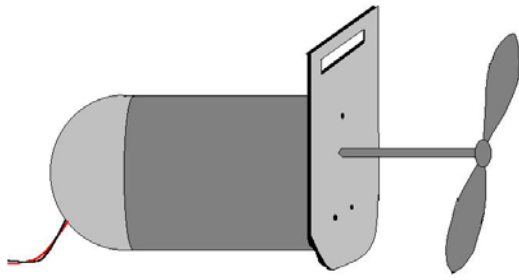


Fig. 5: A fully assembled horizontal thruster.

A similar process was used to pot the vertical and roller motors; however, a paint-on material, similar to Flexane, was used on the motor's body rather than a Flexane-filled cylinder. A shaft extension was attached to the shaft of the vertical motors and the propellers were attached onto the extended shaft.

These six thrusters were placed to maximize maneuverability of the vehicle and so that each thruster would operate in as much clear water as possible to provide for unobstructed flow (Fig. 6). Two vertical thrusters were placed at the top of the vehicle above the electronics box along the axis from the center of the rollers to the back of the vehicle (Fig. 6a). These thrusters can be used to move the vehicle either up or down. The motors for these thrusters were chosen using (1.1) and (1.2) from the Principles of Naval Architecture [1] assuming that approximately 0.57 kilograms (20 oz) of thrust was needed to account for the added weight of the probes and would have approximately a 0.1 meter (4 in) diameter propeller.

$$K_T = T/(\rho n^2 D^4) \quad (1.1)$$

$$K_Q = Q/(\rho n^2 D^5) \quad (1.2)$$

(K_T and K_Q are coefficients of torque and thrust, T and Q are torque and thrust forces, ρ is water density, n is motor RPM, and D is propeller diameter.)

The results of these equations show that in order to avoid the necessity of a variable ballast system, more powerful motors (compared to the horizontal motors) were needed for vertical movement in order to get the necessary thrust. When acting in unison, the vertical thrusters served to provide directional movement along the vertical axis. When operating solo or in opposition they put a torque on the vehicle which serves to tilt the vehicle.

The horizontal thrusters are divided into two pairs, forward and lateral. The forward thrusters are placed at the back of the vehicle directly under the "wings" of the frame. (Fig. 6b) When working in unison, these thrusters serve to propel the vehicle forward. When working in opposition, the forward thrusters serve to drive the vehicle in either a clockwise or a counterclockwise circle.

The other pair of horizontal thrusters is the lateral thrusters. These thrusters are placed primarily to aid in

turning the vehicle; however, they can also be used to move the vehicle laterally to port or starboard. One thruster is placed at the front of the vehicle on the starboard side (Fig. 6c). It is attached to the top mounting plate for the rollers. The other is placed at the back of the vehicle on the port side (Fig. 6d). It is attached to the frame at the back corner of the collection basket at about mid-height of the vehicle. The large distance between the two lateral thrusters provides the greatest amount of yaw-authority possible.

The combination of these six small motors serves to make the vehicle maximally maneuverable with motion in each of the x, y, and z axes as well as turning control and some control over tilting motions. The pairing of the motors (two per axis) also maximizes control of the vehicle, as one motor per axis could cause unintentional motion in the axis it governs. A movable motor would add an unnecessary element of complexity; and, having more than two stationary motors per axis was deemed excessive for a light-weight design.

D. Electronics

The RC-ROV control system is fairly simple, relying on double pull, double throw (DPDT) cross wired switches to apply forward and reverse power to the motors. The main power bus is connected to a 12 volt battery through a 15 amp circuit breaker and distributes power to the control box (Fig. 7) and the two cameras.

Within the control box, power is distributed to several switches that control the thruster and roller motors. The four horizontal thrusters are wired directly through the tether to their controllers, which form a square of rocker switches on the top of the control box.

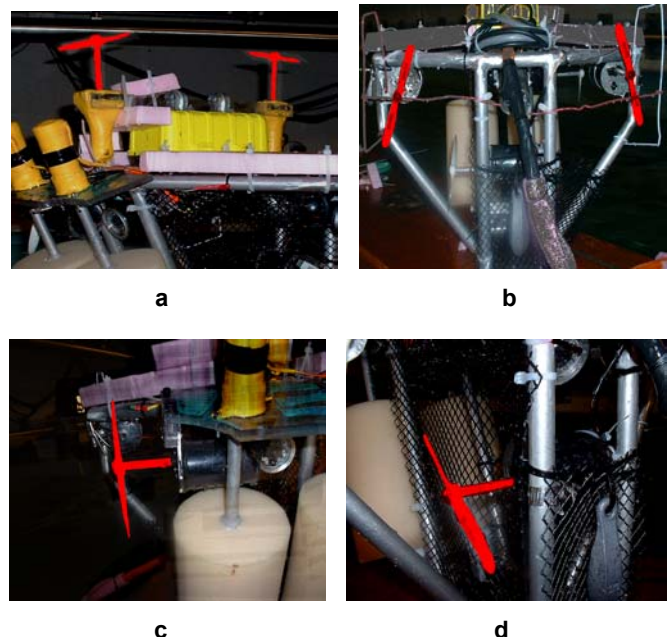


Fig. 6: Propellers highlighted in red. (a) Vertical Thrusters, (b) forward thrusters, (c) forward lateral thrusters, (d) rear lateral thrusters.

The roller motors are controlled in much the same way, except that the switch to activate them is mounted on the side of the control box and the circuit has two LED lights wired into it so that the operator can quickly ascertain the on/off status of the rollers.

The vertical thruster control is also wired to a DPDT switch mounted on the side of the box. However, the vertical thruster circuit has four, 25 watt resistors that can be switched into the circuit in series allowing the pilot to vary the voltage (and thus the power) applied to the vertical thrusters. Three, 2 ohm resistors and a 1 ohm resistor are connected to four single pull, double throw (SPDT) switches mounted on the right side of the control box. Pushing a switch down switches in one resistor, thereby reducing the power delivered to the vertical thrusters. These resistors allow for variable speed vertical thrusters. The variable speed allows for much finer control of vertical movement and compensation for changes in the vehicle weight as probes are gathered. The vertical thrusters also have indicator LED lights wired into the control circuit. These LED's are convenient during recovery because they allow the operator to assure that the vertical thrusters are not running when the ROV is pulled out of the water.

E. Cameras

The RC-ROV has two cameras, one forward-looking and one back-looking. The cameras have infrared LED's around the lens, thus eliminating the need for a secondary light source (Fig. 8). They are directly wired to surface monitors through the tether.

The forward-looking camera is mounted to the bottom of the roller mounting plate and is angled downwards looking over the tops of the rollers (Fig. 9a). This camera serves two purposes. First, it serves as a pair of eyes to navigate around the "Titanic." Secondly, it aids in probe collection as a guide to align the vehicle with a probe that is to be collected. In order for the probe to be caught, it must be sufficiently between the two rollers. Generally, as long as the probe is in the center of the monitor screen as the vehicle approaches, the probe will be collected.



Fig. 7: RC-ROV control box (sitting on its side). Four horizontal thruster motors controlled by square of rocker switches (highlighted in blue). Rollers controlled by pair of two switches on the left of the box. Vertical thrusters controlled by line of switches on the right.

The back-looking camera serves to double check that a probe was collected. When the RC-ROV drives over a sea probe the rear camera can verify that the probe was collected by viewing the empty cap (in which the sea probe sits). The rear camera can also serve as a double check that all probes were collected as the RC-ROV leaves a room.

III. IMPROVEMENTS AND APPLICATIONS

A. Troubleshooting

During the competition it was discovered that a combination of drag on the rollers and long running time caused the motors to overheat. When the motors overheated, the roller system seized and could not even be turned by hand. However, after each motor was allowed time to cool, the roller driven by the affected motor resumed normal operation.

Several hypotheses were developed and tested as the cause of the motor failure. Upon retrieving the vehicle from the water when the rollers had stopped working, the breakout box was found to have a wire caught in the seal. Thus, the first possible explanation for the rollers' failure was an electrical short. This explanation was proven false by running the RC-ROV system wet—with the breakout box opened up to the water. The vehicle ran normally and it was found that 12 volts DC was not sufficient to cause short term problems (on the order of a minute or two). Furthermore, most other teams had similar motors and wiring with no waterproofing in their systems.



Fig. 8: Cameras, displaying LED lights surrounding the lens.

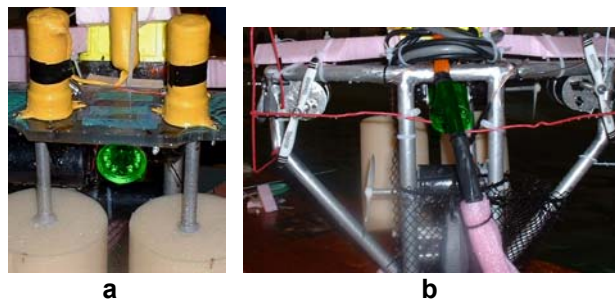


Fig. 9: Camera positions, camera highlighted in green. (a) front camera, (b) rear camera somewhat obscured by tether.

The next potential explanation was that there was a problem with the motors themselves. Upon inspection one of the gear boxes was found to be mildly wet, but the inside of both motors was completely dry. Hence, a waterproofing problem did not cause the failure either.

The possibility of debris caught in the motors was also proven false upon opening the motors for inspection. Furthermore, most debris that could get into the motors would not stop the rollers from being turned by hand. Another possibility, misalignment, did not seem to be the problem either. Upon inspection, no misalignment or deformation could be found in either the connection between the motors and roller shafts or within the motors themselves.

Motor fatigue, may have partially contributed to the roller failure, however was most likely not the primary cause. The vehicle had been in operation for somewhat extended periods of time both during testing and earlier during the day of the competition. However, under normal operating conditions the motors should have been able to run with no problems for the amount of time that they were in use.

It was found that the roller motors could be experimentally overheated by adding drag. This drag was created by pressing a hand against the rollers while they were in operation. During the experiment, the motors' temperature began to increase which caused the motors to stop working. Once the motors stopped working on the bench, the effects were similar to those that occurred during the competition. The rollers seemed to seize such that they could not be turned electrically or by hand. Once the motors cooled down the rollers resumed normal operation.

Based on the results of this experiment, it appears that drag on the rollers caused resistance to the turning motor shaft. This resistance caused the motors to work harder and draw more current, hence increasing resistive heating inside the motor. This heat most likely caused the metal parts (gears and bearings) in the motor to expand enough to prevent movement of the shaft. This failure could potentially have been avoided by using a higher torque motor or rollers with less drag.

The rollers were made of open-cell foam pigs (generally used to clean oil pipelines) and worked extremely well for collecting objects in both dry and wet environments due to their compressibility. This compressibility made the rollers able to grab a sea probe more effectively than a solid surface would be able to. (Experimental results showed that solid surfaces tended to push away sea probes whereas compressible foam molded to the shape being collected.) Unfortunately, these waterlogged rollers required a lot of torque to turn effectively.

For this competition, a less compressible roller material would have been sufficient for probe collection, and would have reduced drag. Drag could also be reduced by a different size of roller. The rollers used in the competition were bigger than was necessary for the task in both length and width dimensions. Since the

sea probes were being picked up from the top, it was not necessary for the rollers to extend to the bottom of the vehicle. Also, at approximately 10 centimeters (4 in) in diameter, the rollers were wider than necessary for the purposes of the competition. A smaller diameter roller would have sufficed, and would have allowed for a further reduction in drag on the rollers and the power required to drive them.

Although the RC-ROV is small compared to the 61 cubic centimeter (2 ft^3) size constraint, it could have been made smaller. A smaller size would have improved both speed and maneuverability. A vehicle not much larger than the volume of the twenty sea probes to be collected would have been an optimal size. The frame of the vehicle was taller than necessary by approximately 10 centimeters (4 in). Also, the wings were wider than necessary. The vehicle was long; and a wider, shorter collection basket would have been more effective than the long, rectangular basket. Less bulky rollers would shorten the vehicle as well, although the rollers would not reduce the length by more than about 5 centimeters.

The material selection of the frame had both advantages and disadvantages. A welded aluminum frame was stronger than an alternative PVC frame would have been; however, it had to be built early in the design process so that the welding could be finished in time. The electronics, camera, and motor placement had not been selected at the time the frame was designed. As a result, the frame was larger than necessary and not optimally designed for placement of the final vehicle components.

A PVC frame would have allowed more time in the design process to work with and optimize individual components and systems of the vehicle. It would have also allowed for the components to be better placed at a later design step. A PVC frame would have also been lighter, and consequently faster and more maneuverable. However, a PVC frame would have reduced both strength and flexibility of angle design (as PVC elbows can only be found in a few specific angles).

Another difficulty with the vehicle was that it was underpowered. More powerful motors would have fallen within the 25 amp design constraints and would have provided considerably better speed and maneuverability. More powerful roller motors would have been particularly useful in fighting against drag. Also, faster roller motors would have enhanced the suction effect, making probe collection faster and easier.

B. Future Applications

There are several potential future applications for the RC-ROV design. The roller concept could be used as a substitute for or in conjunction with other competitive systems to collect underwater samples or aid in construction of underwater projects. First of all, rollers are easy to operate. Rollers require less fine vehicle positioning and collector/manipulator precision

than arm systems. Rollers can collect objects with ease, and are particularly useful in the presence of a current or in choppy water near the surface. Therefore, rollers minimize the time it takes to gather or deposit samples underwater. This speed helps to reduce bottom time and allows for more work to be done per mission.

RC-ROV's are considerably less likely to malfunction than competitive systems, which tend to be very complex. In the event of a malfunction, roller systems are also easier to repair than comparable systems because they have fewer and less complicated components.

Interchangeable rollers would be easy to implement, making the RC-ROV a highly-adaptable multi-mission vehicle. On the other hand, RC-ROV's are effectively "disposable" due to their low cost of production and maintenance. However, since cargo is generally not disposable, the relative placement of the rollers and the collection basket is useful for delicate operations. Although the ROV itself may sustain damage, a collection basket located inside the vehicle (as opposed to a more exposed collection tray) allows for greater protection of samples. This protection would be useful in rough water conditions or tight operating quarters.

The RC-ROV could be used in archaeological or mining applications to collect many kinds of objects by the method of roller operation used in the competition. Irregular or sharp objects could present problems to perfectly cylindrical rollers or rollers made of soft material; however, roller material, shape, position, and speed could be varied to fit specific jobs. Soft rollers could be used in order to protect delicate samples whereas textured rollers could have improved grip on difficult to hold objects. Large rollers with inset chambers could be used without a collection basket for one-object missions or to collect objects that are extremely irregular. Variable roller positioning could allow the rollers to reach or tilt to pick up objects in difficult to reach places. For example, the combination of a solid roller material and spring-loaded rollers (in the lateral plane) could be used to collect sharp objects which are likely to pierce or cut a collection system. A high speed roller would create a fluid flow into the collection chamber, thus sucking lightweight objects into the rollers. Low speed rollers would likewise prevent unwanted objects from being collected. For missions that require it, a conveyor belt system (or something similar) could be implemented to keep samples in separate compartments within the ROV's collection

basket. The RC-ROV could also be useful when operating in reverse. Samples could be taken down to an underwater construction site and rolled out from the ROV into the water.

IV. SUMMARY

The RC-ROV is designed to be a simple and effective vehicle. The roller system of collection has several advantages over comparable systems in that it is robust, simple, and can be easily modified for specific jobs. Its drive-over collection system is faster than many other systems. It is easy to use and can be operated with the flip of a switch; hence, it allows the pilot to focus on maneuvering the vehicle itself without the added concern of operating a separate collection system. It is also composed of simple, solid parts and consequently easy to repair or modify. The RC-ROV can accomplish its task of underwater object retrieval quickly and easily. Several uses are likely to be found for the RC-ROV as its simplicity of design make it easy to operate and less likely to malfunction than more complicated systems commonly used today.

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