Design of a low cost Underwater Robotic Research Platform

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***Abstract*— To perform under water robotic research requires specialized equipment. A few pieces of electronics atop a set of wheels is not going to cut it. An underwater research platform must be waterproof, reliable, robust, recoverable and easy to maintain. It must also be able to move in 3 dimensions. Finally it must be able to navigate and avoid obstacles. To purchase such a platform can be very expensive. However, for shallow water, a suitable platform can be built from mostly off the shelf items at little cost. This paper describes the design of one such underwater robot including various sensors and communications systems that allow for swarm robotics.**

***Index Terms*—Robots, Underwater vehicles,**

I. INTRODUCTION

To perform under water robotic research an appropriate platform is required. However, as water and electronics don't mix, the platform must overcome some special environmental conditions. First of all it must be water tight. A single drop of water can stop the whole unit from operating. Even though it must stop water, the eternal electronics must be easily accessible as the research may mean constantly working on the electronics. Next the weight of the platform is important. Too heavy and the platform will sink into the depths, never to be seen again. To light and it will be very hard to sink. Once to chassis is complete it needs a basic sensor suite for navigation and object avoidance. Finally it should be as cost effective as possible.

II. ROBOT TYPES

The research platform, or robot, can be designed in a few different configurations. One possible configuration is having a single thruster unit. Looking like a torpedo it uses a single propeller to provide propulsion, depending on moveable fins to change direction. It is energy efficient but must be continuously moving to maintain steerage.[1-5]

Another configuration adds one or two vertical thrusters to control depth. This system can control depth but still needs forward movement and movable fins for steerage. It maintains a level position by ensuring that the bottom of the robot is heavier than the top.[6]

By adding thrusters more manoeuvrability is obtained. With three or more vertical thrusters the robot can maintain its level with dynamic levelling and with two or more vertical thrusters it can perform both navigation and station keeping.[7]

One interesting configuration is to give the robot flippers rather than thrusters. This robot, with six flippers can achieve 5 degrees of freedom and, using the flippers as legs, can walk along the seabed.[8]

The robot described herein uses the minimum number of thrusters required to control the robot without requiring any momentum for steerage. It has three vertical thrusters, 2 forward and 1 aft, for depth and dynamic levelling and two horizontal thrusters for motion control.

III. CHASSIS

A. Body

The main body consists of 500mm of 90mm diameter DWV PVC pipe. DWV (drain, waste and vent) pipe has a larger wall thickness and will make the robot stronger and able to withstand the pressure at greater depths. On each end of the pipe is glued a grate collar. This will be capped with a clear disc and a 3millimeter thick o ring. The disc can be attached on with stainless steel screws outside the o ring.(Fig. 1)

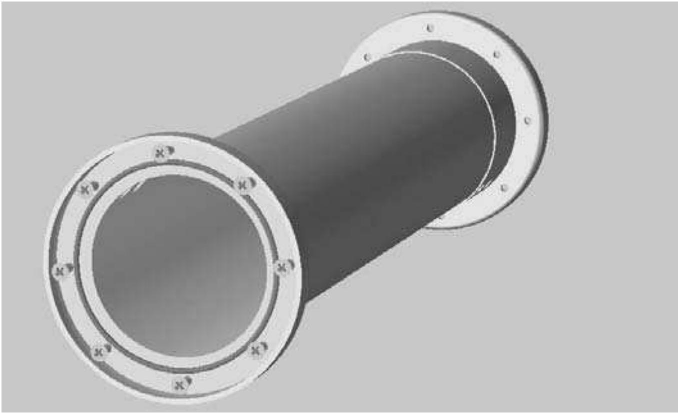

Fig. 1 Robot body with sealed ends

The eight screws are place outside of the o ring so that they

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This work was supported in part by Deakin University and University of Texas, San Antonio, Autonomous Control Engineering.

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978-1-4244-2173-2/08/$25.00 ©2008 IEEE

do not interfere with the watertight seal. Removing them gives easy access to the body from both ends. The grate's wall thickness is thick enough so that it may be tapped to receive the screws. If it is not thick enough nuts can be placed behind the grate collar.

The capping disc, apart from creating a view port for a camera, also allows visual inspection of the o ring to ensure a watertight seal. A one quarter section of the 90mm pipe can be used as a base to slide the electronics into the body.

B. Ballast

To give to robot some balance and to trim the weight a ballast system is required. A one third section of 90mm pipe with a series of tapped holes affixed to the bottom of the body can be used to attach small weights. The weights can be moved along the body to trim the robot so that it sits level in the water. Adding or removing weight will adjust the weight of the robot. The robot needs to be buoyant enough to barely float. Placing the weights on the bottom helps the robot maintain an upright pose.

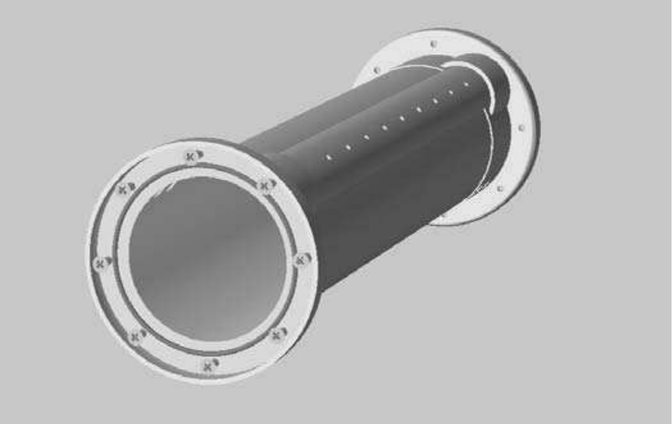

Fig. 2 Ballast strip

C. Floatation

Depending on the weight of the electronics bay, a robot of the size describe above may require some more floatation. Two 40mm diameter pipes along each side of the top of the body will add enough floatation. The pipes must be capped to make them water tight. The caps can be glued on with high pressure PVC glue. The extra floatation at the top further assists in keeping the robot upright.(Fig. 3)

Fig. 3 Robot chassis and thrusters with floatation units

IV. PROPULSION UNITS

A. Thrusters

Thrusters can be very expensive units. Motor shafts, being a moving part, are hard to waterproof. But for shallow water there is a simple solution. Bilge pumps are made to work underwater and can be modified. These motors have an impeller to move the water through hoses. The impeller section can be removed without compromising the unit's water tight integrity. A set of blades from a 90mm computer cooling fan can be attached in place of the impeller. (Fig. 4) A connection piece for 90mm PVC downpipe can be used as a propeller guard. A computer fan grill can be used as a finger guard over the fan blades.(Fig. 5)

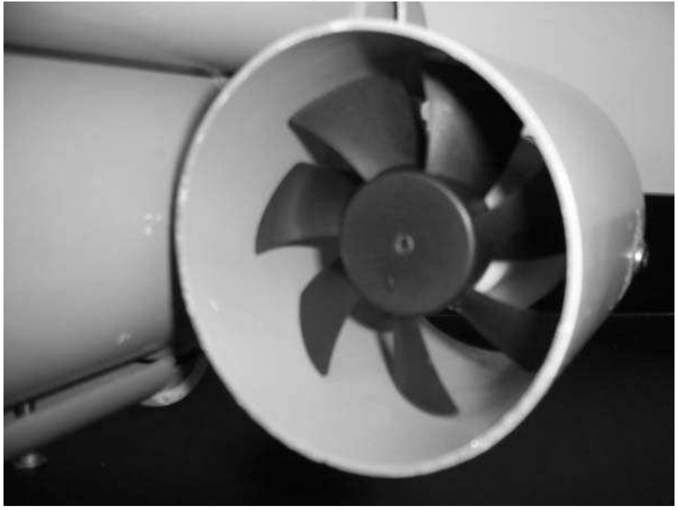

Fig. 4 Thruster showing computer fan

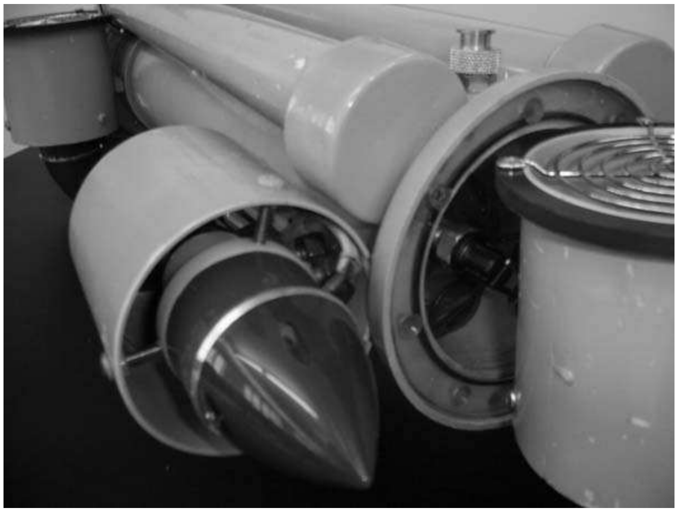

Fig. 5 Thruster showing bilge pump

B. Connection

The hardest part is to connect the thrusters to the body and to get the motor's wires to the electronics bay inside the robot.

This is done with stainless steel bolts with a hole drilled through the axis. With an o ring the bolt connects the propeller guard to the body. The electrical wires go through the centre of the bolts with a tube over the bolt and wire to waterproof it. The tube is clamped to the bolt and to the cable. (Fig. 6)

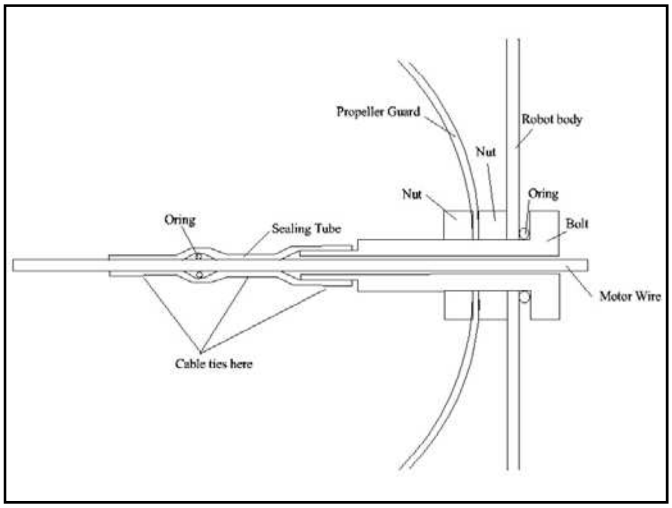

Fig. 6 Cross section of watertight connection of thruster to chassis

V. POWER

A. Battery

In order to make the robot completely autonomous it needs its own power supply. With limited space a battery the battery pack must be as energy efficient as possible. This means either NiH or LiPoly batteries. LiPoly is the more efficient and the lighter of the two. If, however weight needs to be added to the robot then what better way to add it than with the NiH battery.

B. Power Control

The thruster motors used are 12V motors with a maximum current of 2.5A. With 5 thrusters plus the electronics bay the power supply needs to provide a maximum of 15A. The battery pack must then be 12V and able to continuously provide the required current.

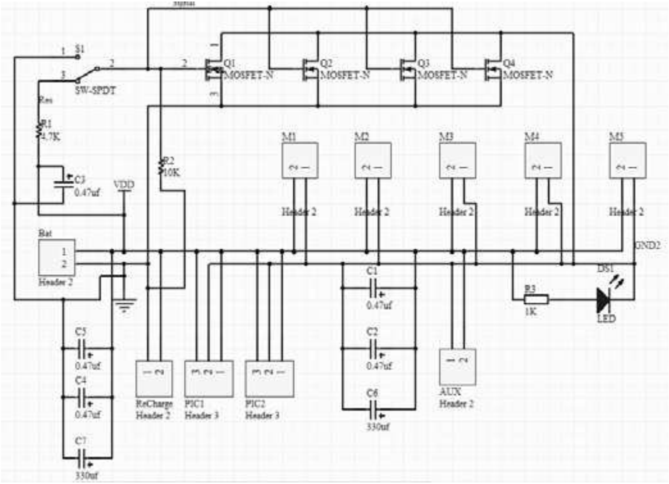

Fig. 7 Power distribution system

The power circuitry must also be able to handle and distribute it. This circuitry needs to split the power to the different motors as soon as possible to reduce the length of the wires and tracks that must handle the full power requirements. Switching the power is also an issue. The small switch is operated by a shaft passing into the body via a watertight gland. That switch uses four MOSFETS in parallel to handle 15A. (Fig. 7) It is then distributed to the motors and the electronics bay. Also included are several capacitors to reduce noise generated by the motors.

VI. CONTROL SYSTEM

A. Microcontrollers

The robot is run by several microcontrollers. Each microcontroller board has one PIC18F4550 microcontroller and an inter board communications system. Each microcontroller is programmed for a different task. One is a master unit that oversees the communications between the other units. Different units control the vertical or horizontal thrusters. Other units can be added and programmed as needed. In the current configuration there are 5 microcontrollers for; Master control and depth, Thruster control, Sonar, Accelerometers and remote control.

B. Internal Communications

The communications between the units uses a one wire star connected system. All units are wired together and each unit has its own address. The master unit will talk to each unit in turn and either ask for information or distribute that information. The microchip's LIN MC201 communications IC used allows serial communications to be use from the microcontroller. The microcontroller used allows 9 bit serial communications. The current protocol uses the 9th bit to indicate the first byte in a packet which is the destination address. The second byte is the size of the remaining data in bytes. The remaining bytes are the data bytes. This is a reliable and robust system used over very short distances so no error checking is needed or used.

C. Tilt System

The unit that controls the vertical thrusters is also given the job of keeping the robot upright. The floatation and ballast systems help with this but with the availability of three vertical thrusters a dynamic balance system is possible. A series of eight tilt switches tells the unit how level the robot is to within 5 degrees. The unit then adjusts the power to the three thrusters individually to maintain the robots balance whilst still responding to vertical movement commands.

D. Motor Control

Each thruster has a motor controller that controls the thruster's power using Pulse Width Modulation (PWM). One unit, as described above, controls the vertical thrusters which, in turn, control the robots depth. This unit also controls the two horizontal thrusters. These thrusters, mounted on each side of the robot, manoeuvre the robot with differential steering much like a tank. They allow the robot to go forward, backward and turn. Sideways movement is not possible.

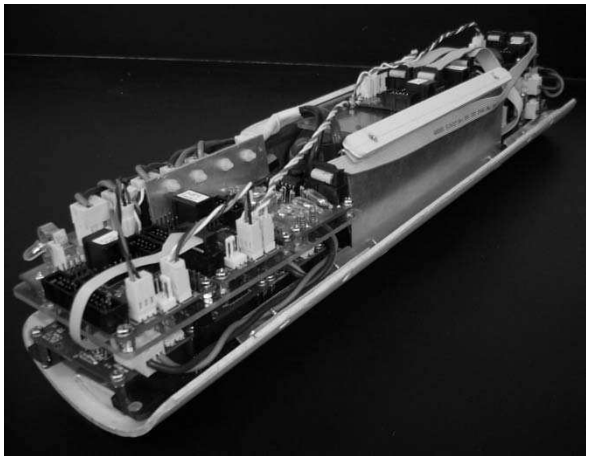

Fig. 8 Electronics bay

E. *Inter Robot Communications*

In order to make the robots as versatile as possible, inter robot communications is required. The main way to obtain this communications is with acoustic modems. The problem with these systems is that they are slow. Therefore for situations where the experiments are performed in a small controlled area, such as a pool, radio communications was considered. It was found that XBee Pro 2.4Hz modules could work underwater to a distance of at least 25 feet in a depth of water of at least 9 feet. Fig. 9 shows the signal strength verses the distance between the antennas (in feet) at various depths. The best signal strength has a value of 0 and the worst viable signal strength is -104. During the radio experiment all packets of information transmitted and received with 100% accuracy.

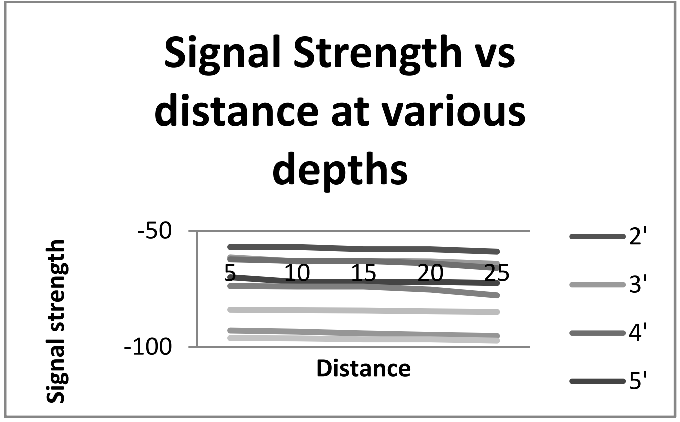

Fig. 9 Xbee Pro module signal strength underwater

Thus, these XBee Pro modules are used to allow the robots to communicate with each other. This in turn, allows the robots to perform operations together and to act as a unified swarm of robots.

VII. EXTERNAL CONTROL

Whilst the robot may be destined to be completely autonomous, there are always times when manual control is desired. There are two possible approaches to this, tether and remote.

A. *Tether control*

A tether connects the robot to the surface using an umbilical cable. Control signals can be sent down the umbilical to manoeuvre the robot. The umbilical can also be used to provide power to the robot allowing the robot to be smaller. The tether, however, can tangle, snare and, if more robots are in the water, become a nasty obstacle. They also limit the robots range and the robot must be strong enough to pull the umbilical.

Remote Control

A radio remote control system can also be used to control the robot. This frees the robot from being tethered and allows the robot to range free. It also means that the robot must carry its own power supply and all intelligence must be on board. Radio also can only be used down to a maximum depth of 3m limiting its use to a pool or shallow lake. One microprocessor unit converts the remote signals to commands that are then distributed through the robots control systems. The robot can be set up to use both systems by designing for remote control and then giving it a tether point.

The current system uses a 4 channel remote control. One channel is used to control the depth. Two more channels are used to control the forward, reverse and the yaw. The final channel is used to switch the robot from remote control to autonomous control and back again. This way the operator can take control if the robot cannot cope with a certain environmental condition and then let the robot control itself when it is safe to do so.

VIII. SENSOR SUITE

In order for the robot to operate on its own it requires a series of sensors to learn about its environment and its location in it. First and foremost it must be able avoid any possible chance of a collision. Next, if it is to operate on its own, it must know it position and orientation in its environment. These two requirements form its basic sensor suite.

Once the basic sensor suite is in place, the experimenter is free to place many different types of sensors into the robot to gather the information required or to interact with its environment.

A. *Basic Sensor Suite*

This set of sensors is described in greater detail in Serna, et al. .[8]

1) *Collision avoidance*

To perform object detection, and hence, collision avoidance, sonar can be use. Sonar is currently quite costly. A simple echo sonar unit alone can be from USD$2000 upwards. There is however a commercial unit used by fishermen to find fish that retails at under USD$30. This unit, the SmartCast made by Humminbird, can be modified to create an echo sonar unit with a range of 30m.

These units can be tapped to obtain a signal that provides a synchronisation pulse, that indicates an acoustic ping, and then a few pulses that indicate the returning pings. The widest pulse indicated the seabed and the smaller pulses are fish or possibly other robots or divers.

This signal can be feed into one of the microcontrollers used by the robot and the sonar sensor can be placed on the inside of the robots chassis pointing in the required direction. Better still, four sonar units can be multiplexed onto one microcontroller, with the sonar units pointing in different direction as was done with this robot.

The sonar units point down to determine the height above the sea, and left, right and forward to perform object detection. It is important here to be able to power down the sonar units so that only one unit operates at a time. This avoids an acoustic ping from one sonar unit triggering a different unit and so creating a false signal.

The sonar units were tested by driving the robot down in a 9 foot pool and recording the sonar record to the bottom and the depth from a pressure sensor. The results are shown in Fig. 10. (the depth is in feet from the water's surface).

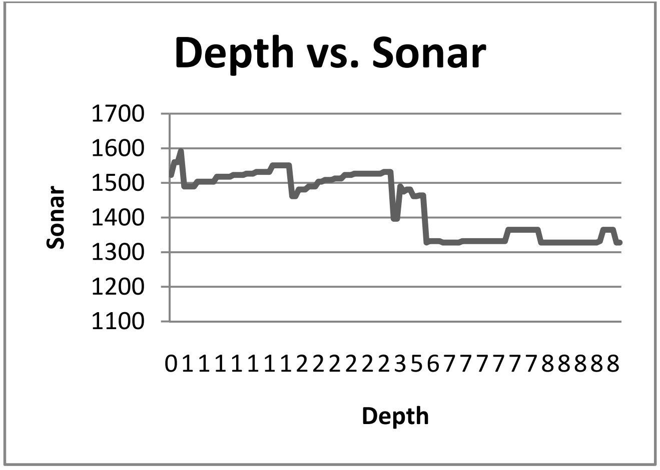

Fig. 10 Measurements to bottom by sonar at various depths

The depth reading was a number between 44 and 53 which has been converted into feet. The sonar reading is a count of the time it takes an acoustic pulse to travel to the bottom and back. Hence the larger the number the greater the distance to the bottom.

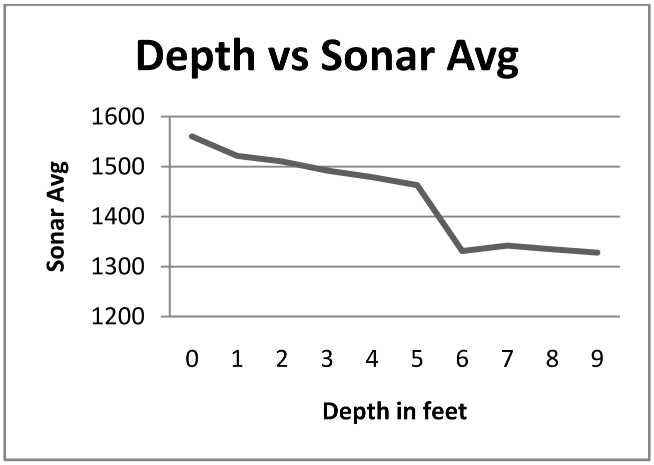

Fig. 11 Average measurements from Fig. 10

As can be seen there is still a lot of noise in the reading from the sonar unit. It can also be seen that the readings don't make sense under 6 feet. At this point the robot is getting close to the bottom and the sonar is not reliable when the distance is this small.

Fig. 11 shows the averages of the sonar reading. This hides the noise but shows that the readings are not reliable within 4 feet of the bottom. By taking the averages over at least 10 samples gives a result that is good enough to use, especially for sensors that cost so little.

2) Localisation

The simplest way to determine one's position is with a GPS unit or a differential GPS if accuracy is required. Unfortunately, GPS does not work underwater, so a different approach is required.

The approach chosen was a dead reckoning system using accelerometers. A three axis accelerometer will give the acceleration along the x, y and z axis. A rotational accelerometer will give the yaw or the robot. As the robot is designed to remain level there is no pitch or roll. The robots location on the x and y plane can be calculated by multiplying the accelerations by the change in time squared to get the distances and angle and then using simple trigonometry. The depth along the z axis can be determined separately by getting a distance from the z acceleration and adding it to the current depth.

This system is cost effective but does have a couple of flaws. It needs a known initial location so that it may determine its subsequent locations. It is also prone to accumulative errors.

When working in a pool or another well defined location, a pool corner may be used as the starting point. Thus the robot can always be first placed in the one location to be initialised.

When accumulative errors get to large the robot could use the sonar to find the same pool corner to reinitialise itself.

If the robot is being operated outdoors then the robot could be allowed to rise to the surface at any time to get a GPS fix and then submerge again to continue its mission.

A simple absolute pressure gauge can also be used to determine the robots depth be backup the depth found with one of the accelerometer. Every 10m the robot descends adds one more atmosphere of pressure on the robot. Measuring this pressure provides a simple way to determine the robot's depth.

These sonar, accelerometer and pressure sensors, along with the microcontrollers interfaced with them form the basic sensor suite.

B. Advanced Sensors

The robot is now almost ready to be used in different experiments and missions. What it now needs are the tools with which to operate. The choice of tool or sensor depends on the mission's profile. The possible include, but are not limited to the following:

1) Camera

The first and obvious senor to be added to the robot is a still or video camera. The clear front plate of the robot allows for a camera to be mounted just behind it on the electronics bay. This can be used by on board systems to analyse the environment or, when tethered, can send images or video to a surface operator or computer.

2) *Water Quality*

Sensor packages are available that will measure water temperature, saltiness and pH.

3) *Compass*

Electronic compasses are available that will aid in yaw correction and navigation.

4) *Magnetic Anomaly Detector (MAD)*

MAD devices, also called metal detectors, can be used to detect ship wreck, downed planes, divers, some ore deposits and, hopefully, sunken treasure!

5) *Passive Sonar*

Passive sonar listens to sounds in the environment without introducing any sound of its own.

6) *Active Sonar*

Although the robot already has active sonar it is the simplest type. Other type of sonar, including sidescan sonar and multiarray sonar can be use to create an accurate 3D map of the surrounding seabed.

C. Sensor Physical Interface

Many of the sensors can be installed inside the robot chassis. The PVC chassis is easy to work with and modify. Some sensors need exposure to the water. In most cases this is through a threaded shaft and an o-ring. The PVC is soft enough to easily drill and tap but strong enough to hold the senor without stripping the thread.

If there is not enough room in the robot chassis then an external waterproof container can be designed in a similar fashion to the robot chassis. The container can then be fastened to the robot in the same way that the thrusters were fastened using the hollow bolts.

IX. CONCLUSIONS

The final research platform has a central body with five thrusters, three for depth and balance control and two for manoeuvring. It can be controlled with a remote or via a tether. The electronics bay is easily accessible and is easily upgraded by adding sensors with more microcontroller units. The construction technique allows simple attachment of external units if require. The inter robot communications allows the robots to act as a unified robot swarm.

ACKNOWLEDGMENT

M. A. Joordens would like to thank Jared Serna, Scott Songer, Casey Friday, Julie Hoy, Ralph Seiger and Walter Madalinski for their assistance in the experimental work for this paper.

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