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SUB-EX: DEVELOPMENT OF AN AUTONOMOUS UNDERWATER VEHICLE (PHASES I and II)

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ABSTRACT

This project focuses on the two development stages of SUB-EX, an Autonomous Underwater Vehicle (AUV): (1) the AUV platform and (2) the visual surveying control software. As an AUV, SUB-EX can move in any horizontal direction, submerge and surface without water leakage and hover underwater. The visual surveying software allows the AUV to operate in manual or automatic mode. In manual operation, movements of the submarine are executed using a remote control. If automatic, the submarine uses color recognition and object tracking. Color recognition aids the submarine to identify a specific color, while object tracking allows it to automatically move towards an object in response to its recognized color. The system was tested in a swimming pool to better observe the AUV's movements.

Keywords: Autonomous Underwater Vehicle, Visual Surveying

1. INTRODUCTION

Technological developments of unmanned submersibles have advanced to a point where such vehicles can now offer great potential for significant improvements in ocean science and engineering applications. These submersibles normally referred to as Autonomous Underwater Vehicle (AUV) can be used independent of existing manned and unmanned systems, or as autonomous assistants to improve the efficiency of existing systems.

AUVs can aid in more comprehensive studies of the behavior of the world's oceans, and conduct ocean bottom exploration, equipped with appropriate functional manipulators to sample the seafloor. The greatest advantage of an AUV is its being unmanned. As an unmanned underwater vehicle, it can independently perform repetitive experiments or monitor environmental parameters such as but not limited to temperature, salinity, and oxygen content. AUVs can also perform underwater surveying that requires long hours of unmonitored and reliable data acquisition of the seafloor.

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Various kinds of robots have been developed parallel to the progress of computers. The operations with robots in extreme environments such as in rescues, space, and ocean explorations are becoming today's most practical solutions. In order to do safe and efficient work, the tasks need to be carried out automatically.

Advanced vehicle control basically applies robotics concept to vehicles. As such, it is slowly gaining importance in relation to intelligent transportation systems. Automation of vehicles helps humans avoid accidents and aids in tasks that may be harmful to them. Different techniques are used in vehicle automation, and vision-based control is one of the more popular ones.

A technique called visual servoing is used for this vision-based robot control. Visual servo control refers to the use of computer vision data to control the motion of a robot. The vision data may be acquired from a camera mounted directly on the robot, or fixed in the workspace so that it can observe the robot's motion from a stationary configuration. Visual servo control relies on techniques from image processing, computer vision, and control theory.

In the field of vehicle automation, underwater exploration is also gaining popularity. But in this field, automation is not as simple as in land vehicles. Underwater vehicles are used to survey the ocean floor and marine species of the depths. Visual data control in this environment greatly differs from the visual control on land surfaces. Lighting condition is a concern because it greatly affects underwater images. As such programmable embedded vision sensor is being considered for providing simple vision capabilities to small embedded systems through an intelligent sensor. Its existence made the development of vision platforms flexible and low cost. Being capable of fast and reliable image processing also made it popular for surveillance in mobile robots.

2. RELATED LITERATURE

2.1 AUV Platform

The most basic feature in an AUV is its size and shape. The AUV's shape determines its application, efficiency and range, and it falls into either the torpedo shaped design or the non-torpedo shaped design independent of the other characteristics.

A typical torpedo shaped or single hull AUV has less drag and can travel much faster than its non-torpedo shaped counterpart. It usually uses an aft thruster and fins to control its motion; thus this design needs some translational speed to keep full control of the vehicle. In general, this classification has a much longer range and can work well in areas with moderate currents. torpedo shaped AUVs are appropriate for low resolution scalar surveys in larger areas, but are not suited for optical surveys or high resolution bathymetric surveys in smaller areas.

Non-torpedo shaped AUVs are typically designed to be completely controllable at much lower speeds. The multiple hull design makes this classification passively stable in pitch and roll. Thus, the other degrees of freedom can be independently controlled using multiple thrusters. A larger form factor for these vehicles means higher drag, making their use difficult in areas with significant currents. The lower speeds and high maneuverability of this class of AUVs means higher navigational accuracy in following very close track lines. They are well suited for high resolution photographic surveys, multi beam mapping, and side scan surveys [1].

2.2 Vision System

Graduate and undergraduate students in the UNC Charlotte Electrical and Computer Engineering department have developed a color tracking system for an autonomous vehicle. This project aimed to test the capabilities of the CMUcam3 (CC3) system for possible future use as a sensor for munitions clearance projects [2]. Figure 1 shows the CMUcam3 hardware used in the study.

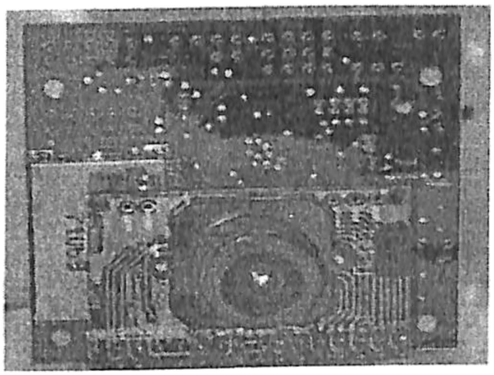

Figure 1 CMUcam3 used in this Research [2]

Capturing an image on the CC3 and outputting the video feed in real-time required setting the camera to view within the Y CrCb color space at high resolution. This is done by computing the mean color of the image using equation (1).

$$mean\_color = \frac{1}{i \times j} \sum_{j=1}^{columns} \sum_{i=1}^{rows} pix(i, j) \qquad (1)$$

This value of mean color is then added to a variable denoted as s pkt. The information from this initial image is used to set maximum and minimum values for each color channel. A threshold range is determined where every pixel in the image is compared iteratively by scanning through the image and finding all the pixels that fall within a given threshold range. The target's centroid values represent the coordinates of its center within the image frame. Cumulative centroids for the x and y dimensions are created from the average number of "good pixels." This accumulation takes place in the API function called "simple_color_scanline." Values for pixel density are then created by dividing the number of "good pixels" by the total number of pixels. This is done by gathering cumulative data and sorting them in the function called "cc3_track_color_scanline_finish." In this function, the true centroid values for x and y are derived from their respective cumulative x and y centroid values computed from the previous function. The true centroid values are determined by dividing each respective cumulative centroid value by the number of pixels in the image [3].

3. METHODOLOGY

3.1 AUV Platform

The mechanical design of the AUV, as shown in Figure 2 below can be divided into two parts: the hull and five motor assemblies.

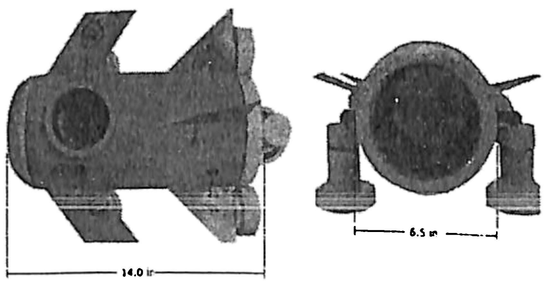

Figure 2 SUB-EX Platform

The hull is made up of PVC with a 16.5 cm (6.5 in) diameter and a span of 35.5 cm (14.0 in), with front glass cover for the camera. The hull contains the electronic circuitry. Waterproofing is achieved by attaching O-rings and gasket into the threaded parts of the AUV, and placing Teflon tapes to prevent water from leaking into the vessel. The PVC used could handle a maximum pressure of 80 MPa and a temperature of 212° Celsius.

The motor thruster assembly, shown in Figure 3 below includes three motors and three propellers for vertical movement encased in a Teflon body, 8.79 cm (3.46 in) in height and 9.5 cm in diameter. Furthermore, two motors and two propellers for horizontal movement are encased in their respective Teflon container, 7 cm (2.76 in) in height and 4.5 cm (1.77 in) in diameter, and joined to the hull with a threaded tube. The Teflon used can handle a maximum pressure of 500 kPa and a temperature of 327 degrees centigrade.

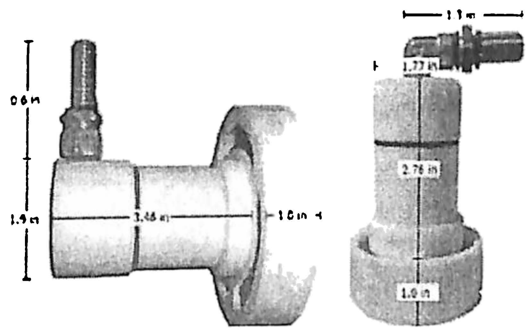

Figure 3 Motor Thrusters Assembly (left) for vertical movement and (right) for horizontal movement

3.2 Visual Surveying Control

The overall functionality of the project was implemented using a Z8F6401 microcontroller, a CMUcam3 and a remote control. The CMUcam3 was mounted in front of the submarine, in bird's eye view, to provide a wide range of vision. CMUcam3 is an ARM7TDMI-based fully programmable embedded computer vision sensor. The main processor is the NXP LPC2106 connected to an Omni vision CMOS camera sensor module. CMUcam3 was used for its reliable and real-time image processing. An additional RJ11 was provided for the camera input and output pins.

SUB-EX has three switches for its controller used to alternate from manual to automatic mode, from color recognition to object tracking mode, and for red or black color selection. Two L298 motor driver boards are added on the motor control. One motor driver is provided each for the left and right horizontal actuators. The two other drivers are for the vertical actuators, one for the single motor at the rear of SUB-EX and the other for the two vertical motors in front.

A CPU power source was used to supply voltage, 12V 16A, to the motor drivers, and a 9V DC adapter for the other circuitry. This includes regulated 5V for CMUcam3 supply and motor driver enable, regulated 3.3V for input buttons, switches and MCU supply. Power is supplied to the AUV through umbilical cords.

4. RESULTS AND DISCUSSIONS

SUB-EX can maneuver in six directions i.e. forward, reverse, dive, and rise, left and right. Table 1 shows the average speed of SUB-EX in each direction.

Table 1 Average Speed of SUB-EX

Test Parameter (Distance Travelled)	Average Speed
Forward (4m)	0.15 m/s
Reverse (4m)	0.13 m/s
Dive (1.37m)	0.05 m/s
Rise(1.37m)	0.08 m/s
Turn Left (90 degrees)	≈11 deg/s
Turn Right (90 degrees)	≈8 deg/s

Hovering is achieved by applying a specific PWM duty cycle and exploiting the property of the AUV's partial buoyancy, i.e, without power, it will automatically rise. Figure 4 shows the approximate hovering depth of SUB-EX. At 50% duty cycle, having supply voltage of 12V, the hovering depth is about 1m, while at 70% duty cycle, the hovering depth is 1.50m.

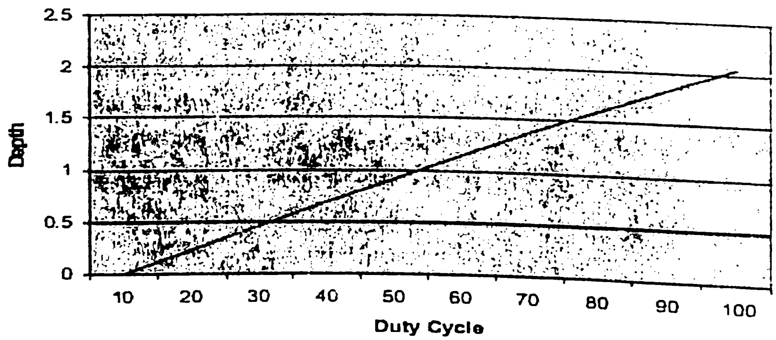

Figure 4 Approximate Hovering Depth vs. Duty Cycle

SUB-EX was also tested for water leakage. After 12 hours of submersion, there was approximately 15cc of water inside the hull. However, this is not enough to endanger the circuitry. The remote control was used for manual directions while the visual surveying software governed SUB-EX's automatic functions. Figure 5 shows SUB-EX moving towards a specific direction depending on which input button is pressed in the remote control.

Figure 5 SUB-EX Manual Control

Figure 6 shows SUB-EX automatically following the target object through color recognition. Black is set as the tracking color to identify the target object.

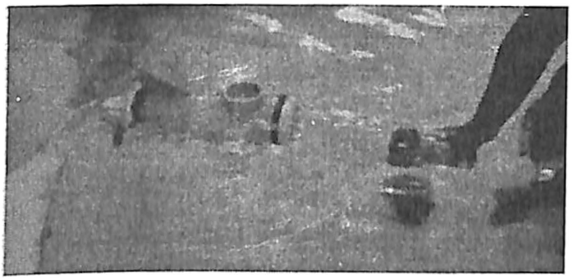

Figure 6 SUB-EX Automatic Control

Table 2 shows the RGB channel parameter values used to find the black object on the image. These settings allow SUB-EX to detect black object during daytime or nighttime.

Table 2 RGB parameter for color BLACK

Lower Bound Channel	Red	0
Upper Bound Channel	Red	40
Lower Bound Channel	Green	0
Upper Bound Channel	Green	50
Lower Bound Channel	Blue	0
Upper Bound Channel	Blue	60

Figure 7 A shows the first image captured by CMUcam3, superimposed with centroid and bounding box parameters. Relating the centroid to the white bounding box produced an output that would cause SUB-EX to move left. Figure 7B shows the next image captured while moving to the left. Relating its centroid to the white bounding box caused SUB-EX to continuously move to its left. Figure 7C shows the captured image with its centroid inside the white reference, causing SUB-EX to move forward to track the object.

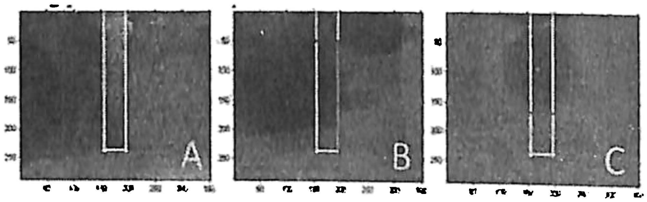

Figure 7 Underwater Actual Images

The data from the underwater actual image are shown in Table 3 below.

Table 3 Underwater Actual Image Data

Figure	A	B	C
Centroid (x,y)	(28, 155)	(99, 154)	(169,94)
Bounding Box)	(0,45) (80,250)	(0, 45) (198,266)	(106, 0) (230,168)
Target	Object 1	Object 1	Object 1
SUB-EX Movement	Left	Left	Forward

5. CONCLUSION

This research proved that the development of SUB-EX, an autonomous underwater vehicle, is possible through the use of inexpensive, everyday, off-the-shelf materials. SUB-EX is waterproofed and is capable of moving in six different directions: forward, reverse, rotate or turn left, rotate or turn right, dive and surface while hovering underwater. SUB-EX can be placed in manual or automatic control. When in automatic mode, visual surveying takes control. SUB-EX can recognize a color specified on the tracking parameters (RGB pixel value) of the code and can automatically navigate to track an object.

Future experiments will incorporate the power supply inside SUB-EX's hull, while testing it in an actual lake, Taal Lake in particular. During the test, it will provide research outputs such as water content monitoring and other beneficial results according to the host barangay's needs.

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