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Vision Based Autonomous Underwater Vehicle for Pipeline Tracking

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ABSTRACT: This paper discusses about the design and fabrication of vision based Autonomous Underwater Cable Tracking (AUCT) system and its working principle based on the propulsion technique. The AUCT system consists of three levels of controllers namely, higher level controller, Middle level controller and the Lower level controller to navigate the Autonomous Underwater Vehicle (AUV). A single CCD camera and an Ultrasonic distance sensor are used to determine the relative position of the underwater cable with respect to the Autonomous Underwater Vehicle (AUV) in a 3 dimensional space. Visual data provides two dimensions and ultrasonic distance sensor data provides the 3rd dimension. An image filtering technique to reduce some undesirable features is underwater images, is used based on the morphological operator. A real-time algorithm is developed to determine the position of the cable in the image plane by cascading an estimator governed by AUV dynamics, with help of Hough transformation technique. The proposed system will perform very well other than in situations where the cable is covered by waterweeds for a long distance. This system can be used as a solution to the problem of underwater positioning especially in pre-determined areas.

KEYWORDS: Autonomous Underwater Vehicle (AUV), Autonomous Underwater Cable Tracking (AUCT), Buoyancy Force, Drag Force, Edge Detection, Centroid

I. INTRODUCTION

Underwater pipelines are usually built for distant transport of communication information and energy resources. The famous North Sea natural gas pipeline system in Europe has a total length over 10,000 km. A cross-country pipeline system in Asia connects a natural gas field in west coast of Indonesia and Singapore. Depending on different working requirements and categories, the deepest depth for underwater pipeline can be up to 600 meters and its maximum diameter can reach 60 inches. For Taiwan, three major types of underwater pipeline can be found.

They are optic fiber cables for communication, pipelines for natural gas, and pipelines for transporting fresh water to outlying islands. For regular inspection and examination of the underwater pipelines, the remotely operated vehicles (ROV) are widely applied due to safe environment for human operators. The underwater vehicle conducts inspection and examination missions relying on cameras installed on the vehicle. However, a long range maneuver always increase mental load on human operators and reduces operational efficiency. Therefore, if an automated pipeline following system can be developed, then human operators are able to focus on actual inspection and examination tasks. The overall operational efficiency apparently will be greatly improved. Although additional sensing device for underwater pipeline may be a direct approach, this method usually faces installation difficulty on the underwater vehicle's body and cost problem. The camera mounted on the vehicle appears to be a readily available sensing tool. Therefore, a visual servo approach becomes an alternative but effective method for underwater pipeline tracking tasks. Pipeline recognition can be achieved by edge information and rectangular shape. The pipeline map can also be incorporated into judgment and estimation for pipeline's location. A neural-network-based hierarchical classification technique was presented for object recognition in underwater environment. This method first decomposes an image into foreground, background, and edges. Then justification of pipeline's location was accomplished by combining angle information and symmetric property. Considering a pipeline following mission conducted by an underwater vehicle, the

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visual tracking needs to be robust enough to adapt to complex and variable underwater environment. This vehicle made up of PVC pipe

II. LEVELS OF CONTROLLER

This system having three levels of controller they are given below

- High level controller
- Middle level controller
- Low level controller

A. *High Level Controller*

The high-level controller for target tracking is divided into different modes of operation. Each mode, as explained below, is triggered depending on the status of the mission reported to the high level controller from the middle level controller.

Wait mode - The entire mission starts and ends at this mode. The UR wait on the water surface until a start trigger is given using an acoustic link.

Orientation mode - It is important to orientate initially at a position so that the target is visible to the UR camera. If the target is not visible after a time t,, then the UR surfaces and get back to the WAIT mode indicating that the target is invisible. Else the TRACKING mode is triggered.

Tracking mode - Once the target is visible the UR starts tracking and navigate according to the target's features appearing in the image. If the target is unrecognizable in the image for a period of t2, then the SEARCH mode is triggered. Once the target is recovered in the SEARCH mode then tracking is activated. Once the target tracking is over, which depends on the time, the ASCEND mode is triggered.

Search mode - When the target is lost from the image scene, the SEARCH mode is activated. The searching is initiated from the position at which the target was last seen. Once the target is recovered and is visible in the scene for more than time t,, then the TRACKING mode is activated. If the target is not recovered after time t, then ASCEND mode is activated to surface the UR indicating that the target is lost and recovery is not possible.

Ascend mode - This mode is activated when the tracking mission is over, target search is unsuccessful, or when initial orientation is unsuccessful. In this mode the *UR* is surfaced and transfers to the WAIT mode.

B. *Middle Level Controller*

This is the most important level in which the control references, depending on the mode of operation, state of the UR and environment, are derived and commands the low level controller to activate the propellers of UR. The parameters defining the state of the UR and the environment are derived using the onboard sensors. The proposed system uses these parameters to generate the navigational command.

C. *Low Level Controller*

From this level find the yawing target angle and swaying target distance from the image using image processing algorithm.

III. HARDWARE SETUP

A. *Principle of Working*

In the vehicle for linear displacement two propellers are used. For vertical displacement another two propellers are used. The propellers are driven by brushless DC motors. The microcontroller should be programmed such that it can vary the speed of the motor by PWM technique and can provide the variable speed to the motors by the way the vehicle direction is controlled. This vehicle having one CMOS camera captures the image continuously. Various image

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processing technique are applied to that images using MATLAB software. From that image find the location and symmetry axis of the pipe line. Based on the direction of the pipe in image the command is send to the controller by serial communication. The controller sends the signal to the motor drivers based on the controller inputs. The motors are driven by the way the vehicle follow the pipeline. The vertical distance between vehicle and pipeline should maintain constant to get the feedback signal from the ultrasonic distance sensor.

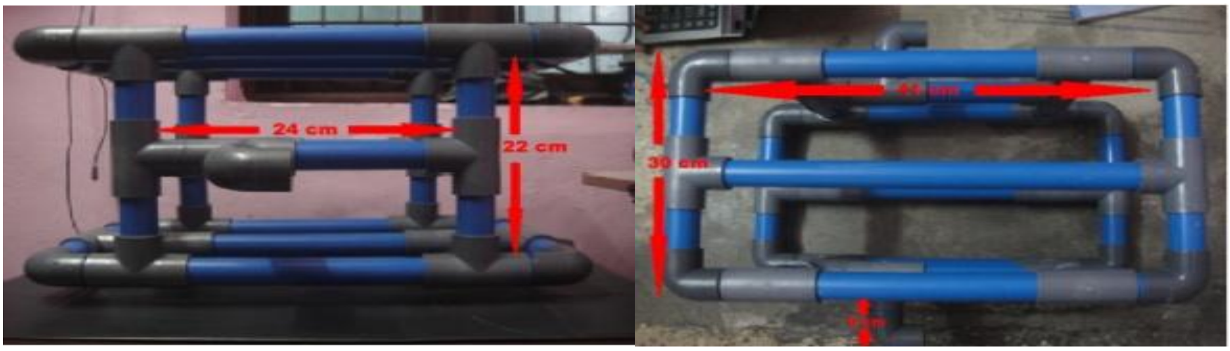

Fig. 1 (a) Side View (b) Top View

The frame made by PVC pipe size of 2.54 cm (1 inch) diameter. The structure created by T and L joints. This frame contain rectangle cubic it carry the electronic circuit boards and battery. The propellers are placed for the movement of vertical and horizontal displacement. The horizontal displacement propeller placed in the sides of the vehicle and vertical displacement propeller placed in the bottom of the vehicle.

Initially the robot is neutrally buoyant (Weight of the vehicle is equal to the buoyancy force) and centre of Gravity of the robot is exactly on the bottom centre of the vehicle. The centre of buoyancy is maintained in top of the vehicle so the vehicle balanced under the water.

By activating bottom propeller to achieve the pitch motion of the vehicle and activating the horizontal propeller to achieve the yaw motion of the vehicle by the way the various direction of the vehicle is achieved.

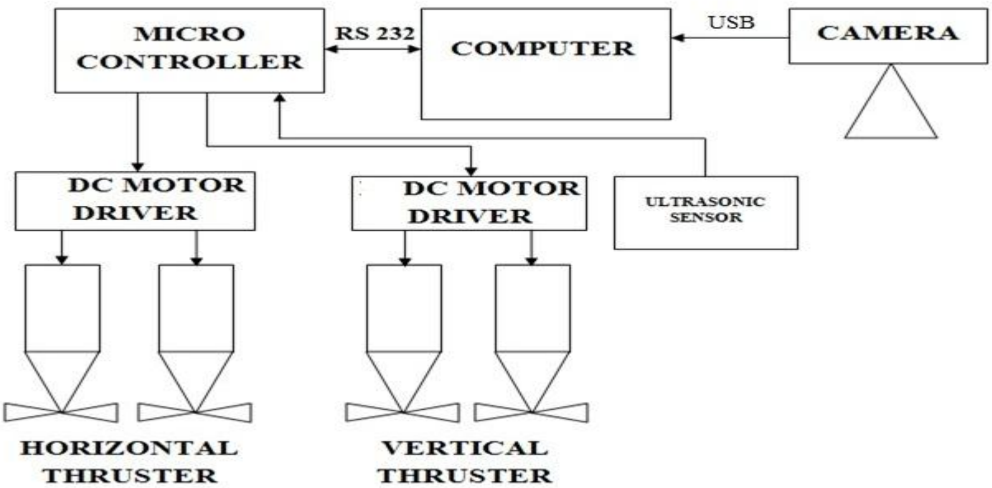

Fig. 2 Block Diagram

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B. Experimental Setup

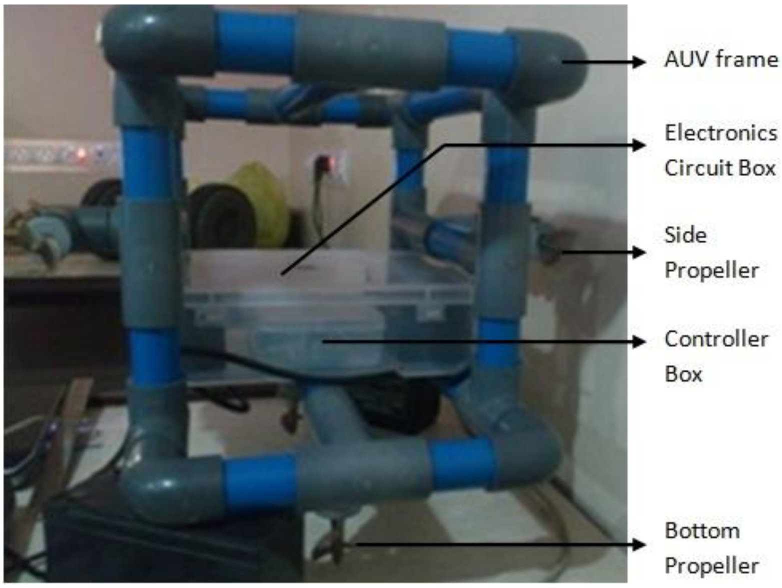

Fig. 3 Experimental setup

IV. CALCULATION

A. Buoyancy force

Buoyancy is an upward force exerted by a fluid that opposes the weight of an immersed object. In a column of fluid, pressure increases with depth as a result of the weight of the overlying fluid. Three types of buoyancy force comes role here they are neutrally buoyant, positively buoyant, negatively buoyant when the buoyancy force is equal to the weight of the object (F_b=W) it is neutrally buoyant that time object is partially submerged under the water. If the buoyancy force is less to the weight of the object (F_b<W) it is negatively buoyant that time the object in under the water. If the buoyancy force is higher to the weight of the object (F_b>W) it is positively buoyant that time the object is floating on surface of the water. Buoyancy force is calculated from the equation(1)

$$\mathbf{F_b = \rho \times g \times V} \qquad (1)$$

Where,
F_b - Buoyancy force
ρ - Density of water, ρ = 1000 kg/m^3
V - Volume of the vehicle in m^3
g - Acceleration due to gravity, g = 9.81 m/s^2
This frame made up of 1 inch PVC pipe so 1 inch=2.54 cm

The radius of pipe =1.27 cm
Volume of cylinder =$\pi r^2 h$
41 cm pipe =6 no's
30 cm pipe =4 no's
22 cm pipe =4 no's
24 cm pipe =2 no's
9 cm pipe =2 no's
Volume of the frame

$$= (6x\pi x(1.27x10^{-2})^2x41x10^{-2}) + (4x\pi x\,(1.27x10^{2})^2x30x10^{-2})(4x\pi x\,(1.27x10^{2})^2x22x10^{-2}) + (2x\pi x\,(1.27x10^{-2})^2x24x^{2}) + (2x\pi x\,(1.27x10^{2})^2x9x10^{-2})$$

$= (1.2465x10^{-3}) + (6.0805x10^{-4}) + (4.4590x10^{4}) + (2.4322x10^{4}) + (9.1207x10^{-5})$

$=2.6349x10^{-3}\ m^3$

Due to the many number of joints the residual volume is available take approximate residual volume

$=0.5x10^{-3}\ m^3$

Inside the frame one cubic rectangle shape container is there that volume

$=L\ x\ B\ x\ H$

$=15x10^{-2}x26x10^{-2}x9x10^{-2}$

$=3.51x10^{-3}\ m^3$

Total volume of the vehicle

$= (2.6349x10^{-3})+(0.5x10^{-3})+(3.51x10^{-3})$

$=6.65x10^{-3}\ m^3$

Buoyancy force (F_b)

$= \rho\ x\ g\ x\ v$

$=1000\ kg/m^3 x9.81\ m/s^2 x6.65x10^{-3}\ m^3$

$=65.2365\ kg\ m/s^2$ (Newton)

B. Drag force

In fluid dynamics, drag (sometimes called air resistance or fluid resistance) refers to forces which act on a solid object in the direction of the relative fluid flow velocity. Unlike other resistive forces, such as dry friction, which is nearly independent of velocity, drag forces depend on velocity. Drag forces always decrease fluid velocity relative to the solid object in the fluid's path.

Drag force is calculated by equation (2)

$$\mathbf{F_D = \frac{1}{2}\ x\ \rho\ x\ v^2\ x\ C_D\ x\ S} \qquad (2)$$

Where,

F_D - Drag force in N

ρ - Density of water, $\rho = 1000\ kg/m^3$

v - Velocity of vehicle, take it as= 0.5 knots (0.25 m/s)

C_d- Coefficient of Drag, $C_D = 1.2$

S - Vehicle Surface facing the water in m^2

This vehicle having two drag force depending up on the vehicle displacement there are

- Horizontal drag force
- Vertical drag force

1) Horizontal drag force

Horizontal drag force is used to move the vehicle front and back.

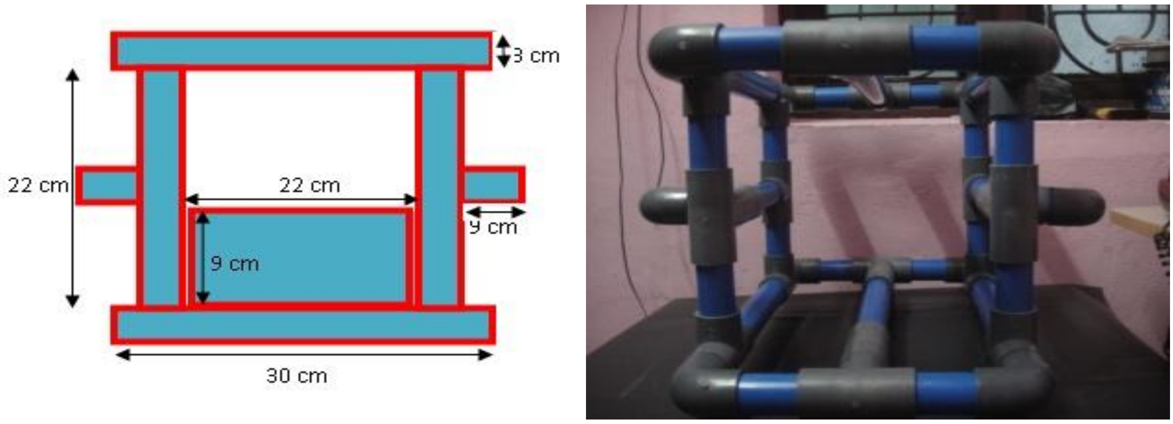

Fig. 4 Vehicle dimension for horizontal drag force

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Facing area in water

30 cm pipe = 4 no's
22 cm pipe = 4 no's
9 cm pipe = 2 no's

Area of rectangle =WxH
$= (22\text{x}10^{-2}) \text{ x } (9\text{x}10^{-2})$
$= 0.0198 \text{ m}^2$

Surface facing area in water= $(4\text{x}30\text{x}10^{-2}\text{x}3\text{x}10^{-2}) + (4\text{x}22\text{x}10^{-2}\text{x}3\text{x}10^{-2}) + (2\text{x}9\text{x}10^{-2}\text{x}3\text{x}10^{-2})$
$=0.036+0.0264+ (5.4\text{x}10^{-3})$
$=0.0678 \text{ m}^2$

Total surface facing area in water
$= 0.0198 + 0.0678$
$= 0.0876 \text{ m}^2$

Horizontal drag force $= \frac{1}{2} \text{ x } \rho \text{ x } v^2 \text{ x } C_D \text{ x } S$
$= \frac{1}{2} \text{ x}1000 \text{ kg/m}^3 \text{ x } (0.25)^2 \text{ m}^2/\text{s}^2 \text{ x}1.2\text{x}0.0876 \text{ m}^2$
$=3.285 \text{ N (kg m/s}^2)$

Horizontal drag power $=F_{dh} \text{ x } v$
$=3.285\text{x } 0.25$
$=0.82125 \text{ w}$

2) Vertical drag force

Vertical drag force is used to move the vehicle down. Fig 5 shows vehicle dimension for vertical drag force calculation.

Facing area in water

41 cm pipe = 6 no's
30 cm pipe = 4 no's
9 cm pipe = 2 no's

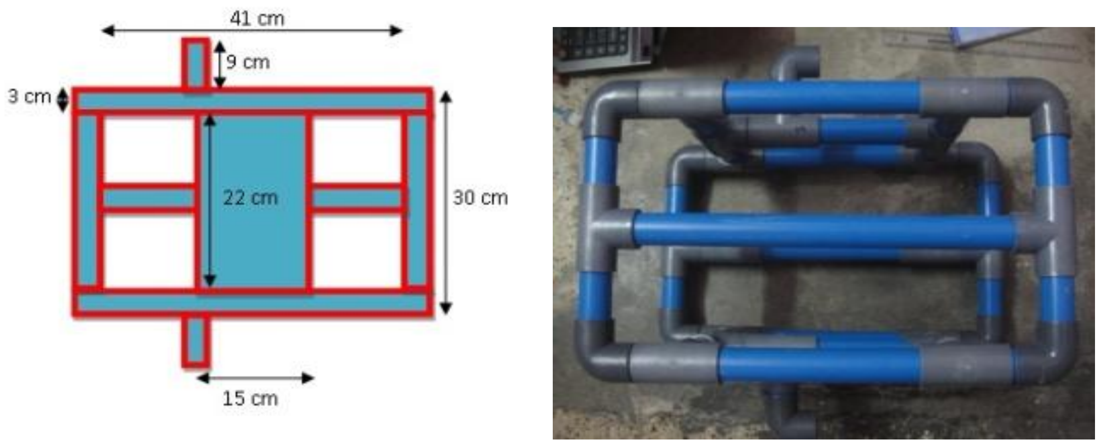

Fig 5 Vehicle dimension for vertical drag force

Area of rectangle
=W x H
$= (22\text{x}10^{-2}) \text{ x } (15\text{x}10^{-2})$
$= 0.033 \text{ m}^2$

Surface facing area in water=$(6\text{x}41\text{x}10^{-2}\text{x}3\text{x}10^{-2}) + (4\text{x}30\text{x}10^{-2}\text{x}3\text{x}10^{-2}) + (2\text{x}9\text{x}10^{-2}\text{x}3\text{x}10^{-2})$
$= 0.0738+0.036+ (5.4\text{x}10^{-3})$

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$=0.1152\ m^2$

Total surface facing area in water

$= 0.033 + 0.1152$

$= 0.1482\ m^2$

Vertical drag force

$= \frac{1}{2} \times \rho \times v^2 \times C_D \times S$

$= \frac{1}{2} \times 1000\ kg/m^3 \times (0.25)^2\ m^2/s^2 \times 1.2 \times 0.1482\ m^2$

$=5.5575\ N\ (kg\ m/s^2)$

Vertical drag power= $F_{dv} \times v$

$= 5.5575 \times 0.25$

$=1.3894\ w$

V. IMAGE PROCESSING ALGORITHM

A. Edge Detection

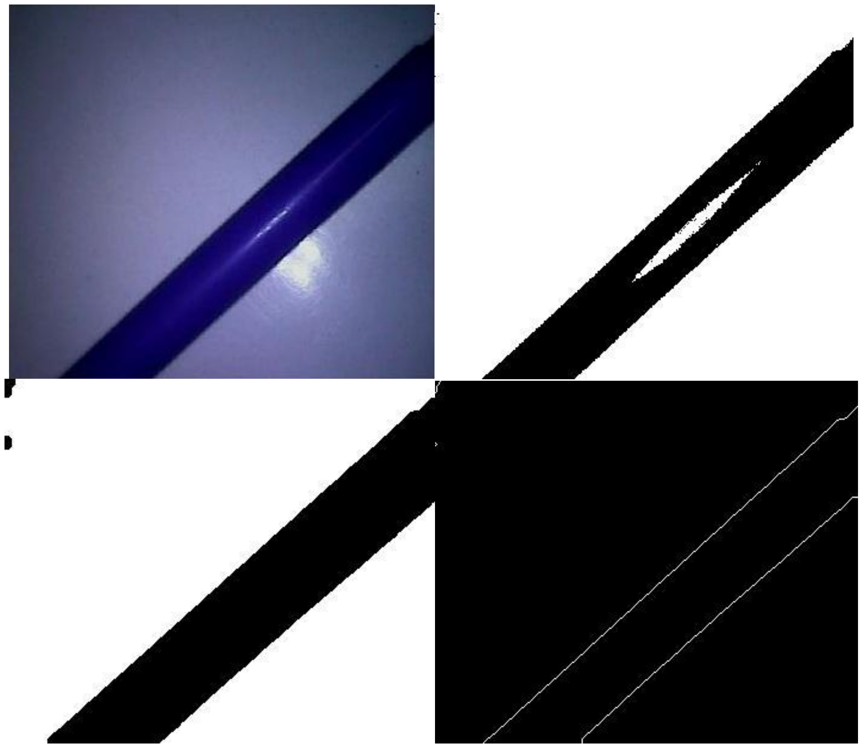

Fig. 6 a.Captured RGB Image b.Binary Image c.Eroded Image d.Axis of the Pipeline

The image is captured by endoscope camera under the water. This captured image is converted from RGB to gray image. The various steps of morphological operations were performed and it is shown in fig 6.

From the dilated image by applying sobel filter the edge of the pipe line is detected so that the symmetry axis of pipe line is found.

B. Pipe Centroid

The centroid of the pipe is found by using regionprops and it is plotted on to the original image.

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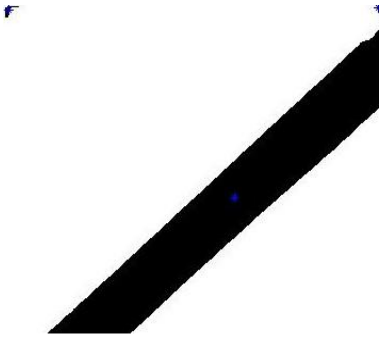

Fig. 7 Centroid of the Pipe

The images are captured continuously and based on the centroid movement the vechicle is allowed to move with the help of the controller.

VI. CONCLUSION

The fabrication was completed as per the design requirements and calculations shown in section IV. The AUV was integrated to the micro controller and camera. The feedback from the ultrasonic sensor combined with controller coding it gives an optimum control over the AUV and maintain constant communication with the surface. The AUV was able to track the pipeline using image processing technique. The performance of the camera under reduced visibility and turbulent current is a future scope in this study. The AUV was tested in shallow calm water of a storage tank. The performance was as desired. The application in real time requires a high pressure resistant materials and HD/IR cameras

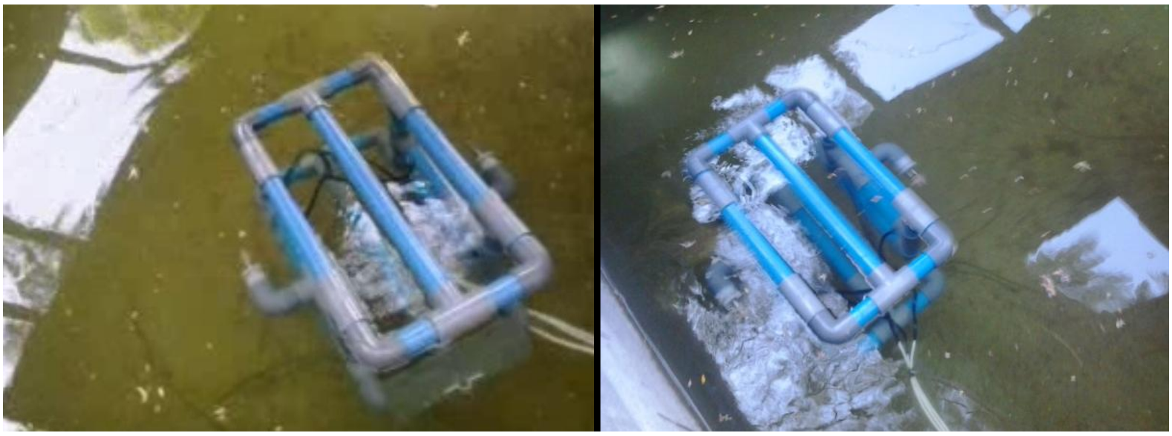

Fig 8 Testing of AUV in shallow waters

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BIOGRAPHY

Manikandan G received the Bachelor of engineering in Electrical and electronics engineering in 2012 from ARM College of engineering and technology Anna University Chennai and he received the Master of Engineering in Mechatronics engineering in 2014 from Madras institute of technology, Anna University Chennai. He is an Assistant Professor at the Department of Mechatronics Engineering in Bharath University Chennai.