Low Cost Assembly Design of Unmanned Underwater Vehicle (UUV)

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Abstract*—Unmanned Underwater Vehicle (UUV) drives underwater without requiring any real-time input from a human operator. These robotic vehicles are mostly used to explore the underwater world. These vehicles can be designed to perform underwater specific tasks like the exploration of the underwater world and spying etc. The readily available UUV's present in the market is of high cost ranging from 2000$ to 3000$. To reduce the production cost of a UUV, many pieces of research are in process worldwide. A lot of physics concepts have to be used while designing such vehicles. Image Processing is an essential feature of UUV based on which it performs underwater tasks. There are many constraints in performing underwater image processing as the turbidity of the water changes when one goes deep in the water. It mostly suffers scattering, limited range, low contrast and most importantly blur in the images that create problems for UUV to perform it's tasks efficiently. We propose a basic software, electrical and mechanical hardware design for UUV. PVC pipes were used for designing the structure of UUV, Raspberry pi acts as the processor of the UUV and bilge pumps act as propellers. Our design is much simpler than the readily available UUV's in the market. It is a low-cost UUV that performs specific tasks like goal post-detection, color detection and obstacle detection based on template matching. It is developed under 300$. One can add more features to a UUV to perform underwater photography and observation of marine life. The efficiency of the UUV system and battery life is enhanced for better functionality. A special waterproof container is being developed and attached to the UUV structure for waterproofing of the whole circuitry.

***Keywords*—** Image Processing, Low-cost UUV, Raspberry Pi, UUV, UUV Assembly

I. Introduction

Scientists have shown a lot of interest to explore the underwater world in recent years. It is not easy to explore the underwater world without the help of specially designed devices for oceanography and deep water world because of the characteristics of water and dynamic pressure as one goes deep into the water. Several concepts are being used in designing UUV which includes image processing technique for analyzing the object's data and allowing UUV to perform specific actions based on the results obtained during the process. Underwater image processing is not a simple task as compared to the processing of an image on land. Several challenges like scattering in images and noise have to overcome while doing underwater image processing.

Contributions of this paper mainly include:

- Hardware designing (Structure & circuitry) of a UUV which can perform tasks in shallow water at the low cost.
- Software designing for controlling movements i.e motor controlling, object detection and color detection etc.

The rest of the paper is divided as follows. Section 2 gives a brief introduction to work done in the field. Section 3 explains the hardware designing of UUV. Section 4 deals with the explanation of software designed for the task. Section 5 shows the results obtained and expenditure for designing the hardware. Section 6 concludes the paper with future suggestions and drawbacks of work.

II. Previous Work

A. Underwater Image Processing

Image processing is a method used to enhance the blurred, unclear and noisy image to obtain the information residing in a particular image by applying different algorithms or filters. An unmanned vehicle is completely based on the image processing technique. The idea is to scan the object and perform specific tasks based on data obtained. The underwater imaging is difficult as it suffers scatter due to transportation characteristics of water along with the noise in the background. There are many constraints in performing image processing under the water as compared to image processing on land. The numerous constraints include blurring effect which arises due to medium, color reduction due to wavelength absorption, electronic noise, non-uniform lighting and flickering effect during sunshine [1]. The research is in process all around the globe to enhance the techniques which helps to obtain clear images and observe an underwater activity with the help of special optical devices designed for this purpose. In UUV's, the optical sensors and video devices are well integrated by underwater community for short-range operations. The video may be blur or of bad quality due to the propagation of light in water. The question arises what makes images blur and video quality bad.

The main reason is light attenuation in processing under-water images which limits the visibility distance at about 20 meters in water. The light attenuation occurs due to absorption and scattering which arises due to water itself which causes difficulty in underwater imaging. The rapid attenuation of light requires an artificial lighting source to overcome this difficulty which itself causes another problem due to which a blurred image is processed containing bright spot and poorly illuminated surroundings. The distance between the scene and camera induces blue and green colors. It also encounters with the variables or species floating underwater which increases absorption and scattering effects. According to [2] image processing can be addressed from image restoration technique or from an image enhancement technique.

- Image restoration is a method to obtain an original image from the degraded image by knowing the degraded factors [2]. It usually requires model parameters like attenuation factors and diffusion coefficients that characterize the water turbidity [2]. This method is considered to be vigorous as the model parameters are extremely variable and it gets change as the depth increases under the water.

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- Image enhancement is a method that uses qualitative subjective criteria to obtain pleasing images. It does not require any parameter models and is considered to be the fastest technique compared to the image restoration technique [2].

In underwater image processing, one can encounter two major losses like sediment scattering and light absorption. To overcome them, two techniques are mostly used which are wavelength compensation (sediment scattering) and color reconstruction (light absorption). There are both physical and non-physical ways to do that. Fattal et al. [3], [4] designed the color lines method to estimate the thickness of haze and then used the Markov Random Field model to get clean the image. He used a dark channel prior to estimate depth map and then used guides filtering to refine the depth map and get a clear image. Chiang et al. [5] proposed wavelength compensation method for underwater imaging, wavelength absorption for underwater imaging was considered first time by Chiang. Lu et al. [1] proposed robust light estimation method to tackle flickers that exist in underwater images. Similarly, there are many non-physical methods. Garcia et al. [6] proposed local histogram equalization to tackle haze and non-uniform lightening. Although, it does not work well in dark places. Gibson et al. [7] proposed a method to tackle noise and scattering simultaneously. This method was named as Kernel size de-scattering method. After using this method, some artifacts and halos remain in the image. Lu et al. [1] using depth map refinement proposed single image dehazing method. Bazeiile et al. [8] use YUV color space and enhance images in the frequency domain. Iqbal et al.[9]proposed an algorithm using integrated color model to enhance the image, but this method causes color distortion issues. Gao er al.[10] used principal of fish eye to solve the problem of underwater image degradation raised by the blurring and nonuniform color biasing.

Due to advancements in technology and in field of machine learning and deep learning, scientific community is also using it for the task of underwater image restoration. Uchida et al.[11] proposed non-blind CNN-based image restoration processor based on blind CNN-based image restoration processor. Li et al.[12] used CNN to remove dust from high turbid underwater images. Lu et al. [13] used Multi-Scale Cycle Generative Adversarial Network (MCycle GAN) System by using Structural Similarity Index Measure loss (SSIM loss) to restore underwater images affected by turbidity and color distortion. Yu et al.[14] used conditional GAN for underwater image restoration process and called it underwater-GAN.

B. Underwater Object Detection

Due to low light, blurring effect and many other water parameters, it is always being a challenging task to detect objects under the water without any effort. In the past, different methods were used to detect objects from images taken underwater. Many researches were conducted to find an optimal solution for obtaining an original image with all features. According to [1], the corners of an object can be detected by using fourier transform as frequency change when color changes in an image. Panetta et al. [15] proposed a method that combines colorfulness, contrast and sharpness measure. This method is known as non-reference underwater image quality measure (UIQM). Lu et al. [1] introduced a method to calculate both the visibility of artifacts and overall quality in images. It is a human prediction method which is called High-Dynamic Range Visual Difference Predictor 2. Zuiderveld et al. [3] proposed a model that use the histogram technique to focus on a specified region according to interpolation between neighboring region's histogram. This technique is called contrast limited adaptive histogram equalization (CLAHE). It does not help with non-uniform light as it operates on local regions instead of the whole image. Ancuti et al.[4] gave espouse fusion method to combine different images using filtering. Galdren et al.[16] uses red-channel based image restoration method as red channel is not always a minimum channel in RGB color space.

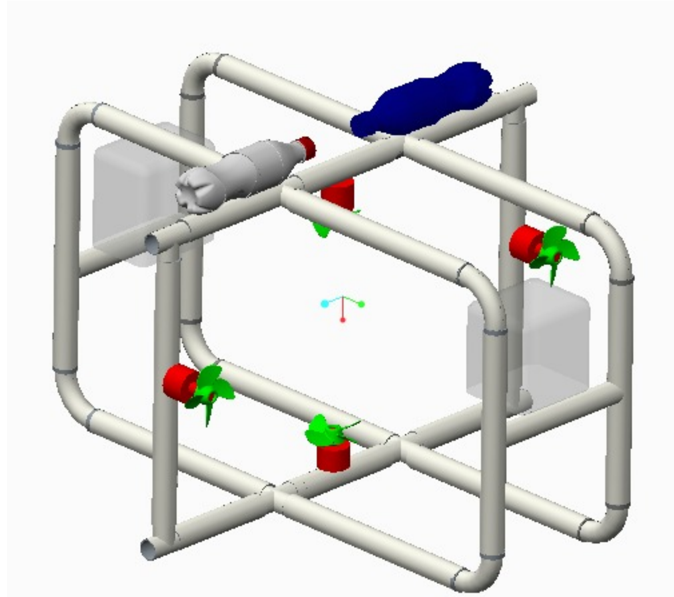

Fig. 1. Main PVC structure of UUV with propeller configuration and indication of circuit units

C. Hardware Design

There has been work done in designing of the underwater vehicles. Xu et al.[17] worked on designing UUV on basis of swimming modes of aquatic animals. By doing this flapping propelled model was proposed. Roper et al.[18] designed a UUV that operate on swimming patterns of aquatic animals. Wang et al.[19] designed a Hull based on different underwater conditions. Aras et al.[20] worked on 4 degree of freedom(DOF) motion of underwater vehicles and proposed a design. Yuh et al.[21] did a survey and gave the overview of different designs and studied them on the basis of different parameters i.e design and control.

Along with structural design, controlling of UUV is also a challenge. There have been many ways to control UUV's and many researchers proposed the models in their research. Hardy et al.[22] worked on the deployment and retrieval of UUV for submarines. Caccia et al.[23] worked on the kinematics of UUV, how to keep track of vehicle motion, the interaction between vehicle and it's environment. Das et al.[24] worked on controlling multiple UUVs and worked on inter-vehicle communication. Bian et al.[25] proposed an assembly where thrusters are placed in X-shape to give horizontal and vertical motion to UUV.

III. Proposed Hardware Design/Assembly

The main goal was to create low-cost UUV that performs underwater tasks perfectly through image processing.

A. Structure

The UUV structure is made up of PVC pipes. The PVC pipes are 1.25" in diameter. There are a total of 40 segments. The pipes are cut to various lengths and are joined together by elbow, T-joint and cross-T connectors. The PVC structure weighs about 3.6 kg without the electrical circuitry. The central unit containing all the electrical circuitry is placed inside the plastic waterproof container and is attached to the UUV structure. The wiring of all electrical components, sensors and external motors is passed through the plastic containers. The motors are attached to the UUV structure at such a distance so that it provides torque in order to move the structure appropriately.

Fig. 2. Propeller configuration on UUV

TABLE I
SPECIFICATIONS OF PROPELLERS

Blade Width	31.2mm per 1.23 inch
Aperture	2mm per 0.078 inch
Compatible	with 2mm shaft motors

B. Raspberry PI

The main purpose of underwater image processing is to detect specific objects and help UUV to perform specific tasks on the basis of objects recognized. The Raspberry Pi 3B module is used for image processing. Raspberry pi is a pocket-size CPU. Just like other CPU, it also operates using an operating system. Raspbian linux is used as operation system for Raspberry Pi. It has Quad Cortex A53 @ 1.2GHz CPU and 1GB RAM. Storage depends upon the size of the SD-card that is being used. There are 40 GPIO pins to connect sensors or operate motors. Video can be seen on a monitor through the HDMI port. For audio, there is an audio jack or audio can also be retrieved through HDMI. There is an Ethernet port, Bluetooth and WIFI module to connect external devices.

Raspberry pi is used as a backbone of project. It is powered by a power bank. Raspberry pi is connected with the camera to take visual input and H-Bridge/actuators to drive motors.

C. Propulsion System

Normally thrusters are used in order to move the UUV structure from one point to another. The only problem with the thruster is their cost. Each thruster costs about $200 due to which the production price of a UUV gets high. As the goal was to decrease the production price, modified bilge pumps were used as they are 9 times cheaper than thrusters. Our designed UUV propulsion system consists of 4 modified bilge pump. Normally the bilge pumps are used to take out the water from the tank, lakes, etc. Each bilge pump has the capacity to take out 1100 gallon water per hour. Each pump is normally operated at 12 volts and is capable of pulling 8 amps at maximum. The pump is modified in such a way that a plastic propeller is attached to its shaft to make it work like a thruster. The plastic mostly slips out when the shaft of the pump gets heat up. In order to make sure, the propeller does not slip out from the motor shaft, an extended silver shaft was used to connect both the pump shaft and plastic propeller. The interface between them was made tight with the 3mm nut. Two modified bilge pumps are being used for forward and backward movement while the other two bilge pumps are used for upward and downward movement. The bilge pumps are attached to a UUV structure with the help of tyes.

Specification of propeller are shown in Table 1.

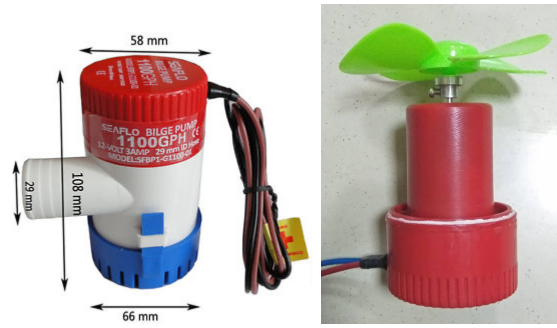

Fig. 3. Commercially made bilge pump(Left), Modified Bilge Pump acting as thruster(Right)

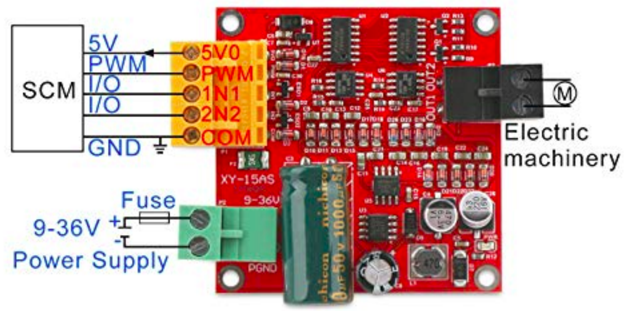

Fig. 4. XY-15AS motor controller labeled diagram

D. XY-15AS Motor Driver

XY-15AS Motor Driver Module is a dual H-bridge module that is mostly used to drive inductive loads like DC motors and stepper motors etc. It is also used to control the speed of motors. The maximum voltage that XY-15AS can withstand is about 36V and is capable of driving about 15A current. It is capable of driving one motor at a time. XY-15AS motor driver is interfaced with GPIO pins of Raspberry and it drives motors when any of the GPIO pin gives high output. Bilge pumps with load require current greater than 4A and without load it take between 3A-4A.

E. Waterproofing

The biggest issue that arises during the designing of an UUV is the waterproofing of the electrical components. If the electrical components are not made secure from water, a little drop of water can short circuit the electrical circuity. In order to avoid such issue, air tight and waterproof containers are being used and whole electrical circuitry is placed inside it. Glue gun was used to seal the openings used to cross wires.

F. Batteries

To power Raspberry Pi, a rechargeable power bank was used with standard 5V, 1.5A USB port. For the purpose of powering bilge pumps, two 12V 5000mAh lead-acid batteries were used where each battery powered 2 bilge pumps.

G. Pi-Cam

Pi-cam is a camera module for Raspberry pi. Web cams can also be used with Raspberry pi but because of their large size they cannot be used where small size and weight matters. Pi Cam board is tiny with dimensions of 25mm x 20mm x 9mm and weight of just over 3g. It attaches with Raspberry pi by one of two small sockets on the upper surface of Raspberry pi. It uses CSI(Camera Serial Interface) which carries pixel data and is capable of high data rates. Camera

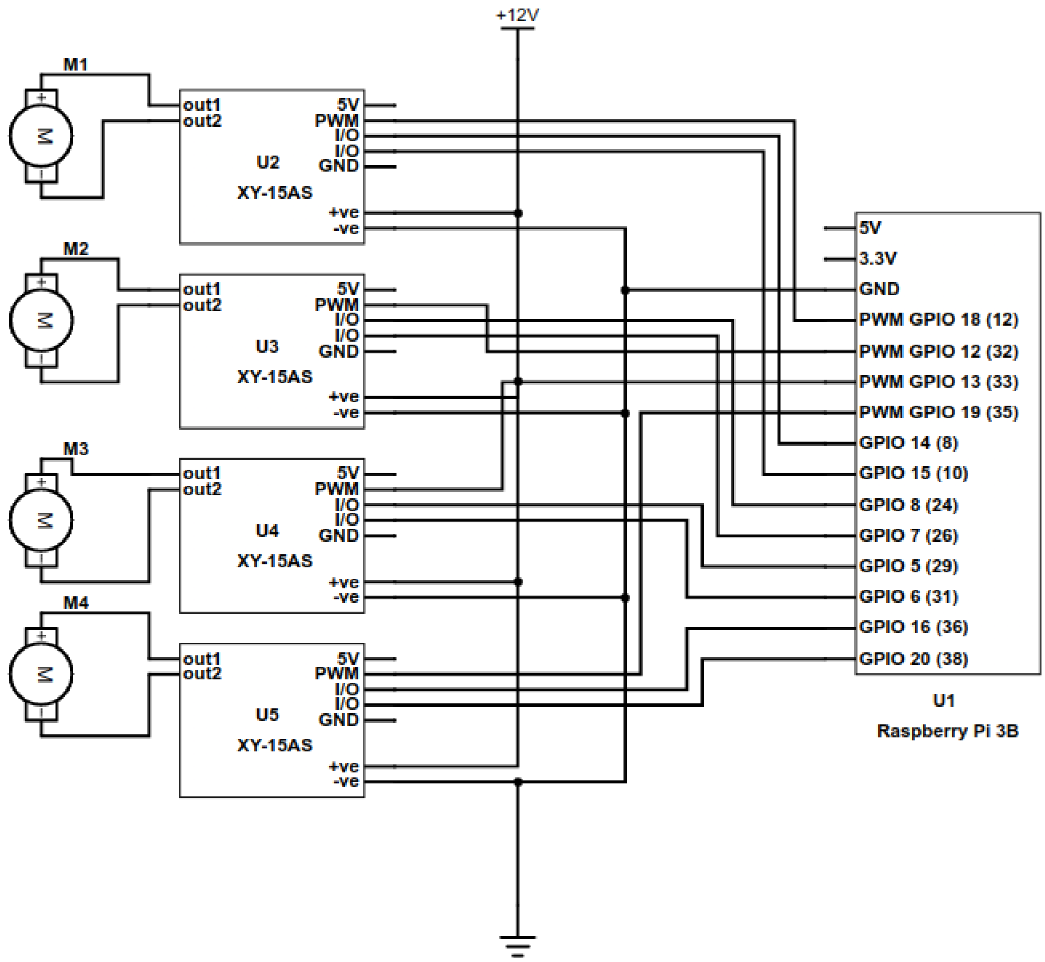

Fig. 5. Circuit Diagram of Electrical assembly of UUV (connections between motors, motor controllers and Raspberry pi)

module has a ribbon cable that attaches it with Raspberry pi. CSI bus connects camera to BCM2835 processor that is located on Pi, which is a higher bandwidth link and carries pixel data from the camera back to the processor. This bus travels along the ribbon cable that attaches the camera board to the Pi. Pi cam has resolution of 5 megapixel. It can take static image of 2592 x 1944 pixel and supports 1080p30, 720p60 and 640x480p60/90 video.

IV. Proposed Software and it's working

For designing the software part which include image processing, object detection and motor controlling "Python" was used as programming language along with OpenCV for image processing task. To make the UUV portable wi-fi was used.

A. Tool Used

The software tools that are used to make a UUV unmanned are as under:

- Open Source Computer Vision (OpenCV)
- Raspbian
- Linux
- Python

B. Video Acquisition

Raspberry Pi has a wifi module which help us in connecting it to Internet. We used same wifi signal to connect our Laptop and Raspberry Pi. Then in wifi settings we extracted ip address of Raspberry Pi, where "tightvncserver" is already installed. Then on VNC viewer we not only acquired the video coming from Pi but also whole operating system on a virtual environment. So that we can also make any code changing while the vehicle is already on the mission.

C. Image Clarification

First task was to clarify the video acquires underwater as underwater images are not clean. For this purpose different image clarification algorithms were studied and one that we used in our code was "Parameter Free algorithm"[8]. As the name says it doesn't take any input from the environment and is simple to implement. It consist of seven steps that remove noise, adjust intensity and equalize color mean.

D. Real Time Gate and Color Detection

Then real time color and gate detection was to be performed. This was done by taking real time video from camera and then comparing each frame for pattern which is specified i.e pattern recognition was applied. For the purpose of color detection, RGB channels were used. Three windows were displayed where each window showed red, blue and green channel. Other colors can be formed by the combination of these three and can be shown in more than 1 window.

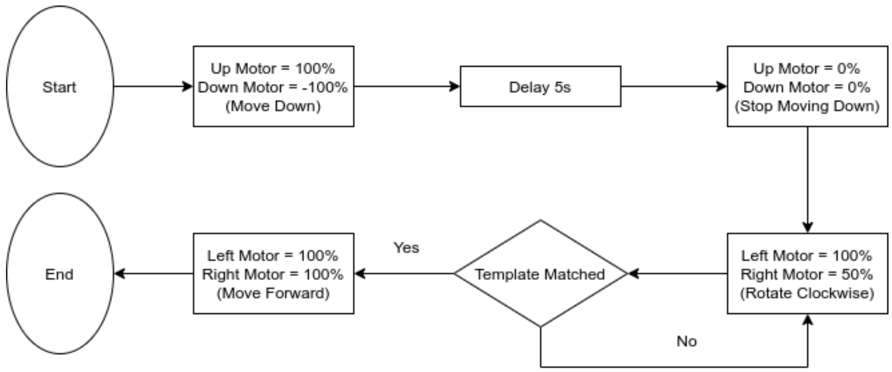

Fig. 6. Motor Control Algorithm for Gate Detection and gate crossing

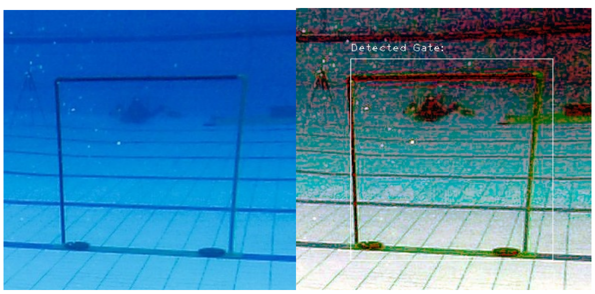

Fig. 7. Template matching results. 1. Original(Left) 2. Template matched(Right)

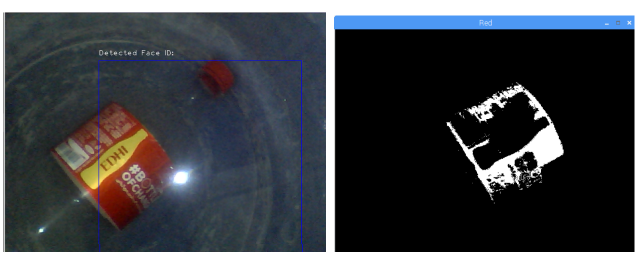

Fig. 8. Color Detection (Red)

TABLE II
RATES

Component	Quantity	Rate
1100 GPH Bilge Pumps	4	10,621 pkr
5MP Raspberry Pi Camera	1	1350 pkr
PVC Pipes	-	2370 pkr
4 Sided Propeller	4	200 pkr
12V 5000mAh Battery	2	1350 pkr
Raspberry Pi 3B (with charger+case)	1	7890 pkr
Power Bank	1	2000 pkr
16GB Class 10 SD Card	1	1000 pkr
Shaft Connectors	4	1100 pkr
Air Tight Containers	2	1196 pkr
XY-15AS Motor Driver	4	7000 pkr
	Total	36,077 pkr

E. Configuration of Software & Hardware

The next task was to configure software to control hardware. GPIO (General Purpose Input Output) pins on Raspberry Pi were used. These pins can give PWM (Pulse Width Modulation), DC 5V and Logic Zero through coding.

F. Algorithm

Algorithm to control motor movement was simple, UUV was placed at 10m distance where it was rotated to 360^o. When template is detected, rotation stops and structure starts moving toward it.The water may not be stable and propellers may not move structure in straight direction, so to remove that outcome, Hall sensor is used,. When template is detected, Hall sensor mark that position as 0^o and tries to keep on moving in that direction.When the angle tries to change, Hall sensor brings it back to 0^o using motors.

G. Depth Control

Depth is being controlled by adjusting speed of motors responsible for vertical motion using PWM. Code is written in such a way that gate should always remains at center of video frame. When frame moves up motors tries to keep it in center same goes for horizontal motors. This algorithm also make sure that UUV passes through gate without touching any of gate's sides.

H. Motor control Algorithm for gate detection

An algorithm was devised to control the working of bilge pumps attached to an UUV structure for vehicle movement depending on the data communicated through Raspberry Pi in the pool. Algorithm is simple and easy. At start, the UUV is placed at 10m distance from the target at the surface of water. It goes down for 5s where it is rotated to about 360 degree. When template gets match, the rotation of the UUV gets stop and the UUV starts moving towards the target. As the water may not be stable and propellers may not move structure in straight direction, hall sensors are used to keep the UUV in the straight line towards the target. When template is detected, hall sensor mark that position as 0 degrees and tries to keep on moving in that direction until it can not detect the target anymore. At that point UUV moves back to the surface. When the angle changes, the hall sensor brings it back to 0 degree position using motors. Here, template is predefined as a gate shown in fig. 7.

V. RESULTS

Underwater image was processed through "Parameter Free Algorithm" and gate was detected through "Template Matching Algorithm". Result is shown in fig. 7. White rectangle around the gate shows the detected region. Image is taken outdoor on a sunny day that's why the image is very bright. For reference result of template matching are also added in image.

As the one of the tasks was to make it cheap so cost estimation of UUV is given in table 2. These are the prices of main components but along with custom charges, delivery charges and other small components it costs us almost 43,607 pkr.

VI. Conclusion and Future Work

This study throws light on how the image processing is being done underwater considering the turbidity facts of the water and factors which cause bad quality of the image underwater. This study tells about the various algorithms developed in past for underwater imaging and how the image is being processed by applying different techniques. On the basis of image processed, one can design UUV to perform specific tasks like gate detection, color detection or explore the underwater world in a better way.

This paper also presents a basic and cheap structure of UUV which can be modified and improved according to one's own need.

Nothing is perfect and there is always room for improvement. UUV that is made in this project is a simple general purpose UUV. The purpose of this UUV is to detect the gate and pass through it using image processing. It also detects colors of objects underwater. We also take camera video on our laptop wirelessly, wifi is used for this purpose. It can be modified in such a way that video data can be transmitted through internet and can be seen anywhere. The structure of this UUV is made of PVC pipes and cannot bear water pressure above a certain range. A better 3D printed structure of same dimensions can bear more pressure and can go more deep into the water, so that it can be used to explore underwater life. By making it's size more smalle,r it can pass through more smaller places. A robotic arm can be attached to UUV so that it can pick up objects underwater and bring them on surface. It can also be used as a spy robot. It can go to it's target, take pictures, audios and videos and then can come back with all the relevant data. With the advancement in technology, machine learning can be implemented for object detection. As it require more processing, some external source such as "Intel Movidius" can be used which is small and effective for machine learning.

Our assembly has a few drawbacks:

- UUV is made of PVC pipes so it can only go to a specific depth.
- Speed is slow as we are using bilge pumps instead of thrusters.
- Our UUV can do image processing in pools not in sea.
- No navigational system.

Despite of these drawback, our aims were fulfilled to give a starting point for designing of low cost UUV which can be modified according to different tasks.

VII. Acknowledgement

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