Real-time Shallow Water Image Retrieval and Enhancement for Low-Cost Unmanned Underwater Vehicle using Raspberry Pi

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ABSTRACT

Unmanned Underwater Vehicles (UUV) operated underwater without any human interference. UUVs can be used for many purposed i.e. exploration or spying. They have several designs and each one can be used for a specific purpose. Main problem that limits the functionality of UUV is poor image quality. Reason behind this poor image quality is scattering and wavelength absorption. Purpose of this paper is to propose an electrical assembly design of low-cost UUV. In order to carry out this work use of Raspberry-Pi is proposed which is a small computer own it's own. It can be used to enhance image quality and detect objects along with color detection. For controlling the propellers in accordance to any hindrance, pulse width modulation(PWM) GPIO pins are used. GPIO pins are also used to attach sensors. For enhancement of images python 3 was used and different image enhancement methods were tested on basis of execution time per frame. In the end, best model is selected which is more suitable on basis of execution time and image enhancement. In order to transmit the images from UUV to base computer wi-fi module of Raspberry pi is used.

KEYWORDS

Video Enhancement, Color Restoration, Raspberry Pi, UUV, Real-time Video Processing, Video Transmission

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1 INTRODUCTION

While capturing underwater images light that falls on the camera suffer from loss of wavelength and degradation due to scattering. Reason behind scattering is particles present underwater while wavelength loss occurs as light goes deeper underwater. Red light got absorbed first, and blue light can go much deeper. When a camera takes images underwater, these images suffer from light absorption, backscattering (a portion of light reflected back to the camera by water) and forward scattering (random light sent to the camera by an object) [1]. Due to these factors image captures has low quality and can cause a loss in functionality of UUV. This makes image enhancement a crucial process in underwater images.

For transmission of images and videos to base computer most of the researches has used umbilical cord which carried both signal and power for operation of UUVs. In most recent approaches RF signals or acoustic transmission has been used. After the base computer gets the image or video it sends the signal for next step. While performing this whole step i.e. sending and receiving signal time is wasted. This limits the functionality of UUV.

In this paper we proposed an electrical assembly that performs the task of real-time image enhancement and color restoration along with target detection. Sensors are used to acquire additional information like depth, direction and temperature. In order to perform all these tasks Raspberry Pi 3B is proposed. Raspberry Pi is a mini computer with 1GB RAM and 1.2GHz processor, It uses it's own operating system which is called "Raspbian Linux". Many third party operating systems like "Ubuntu mate" can also be used. It has ability to connect with sensors through GPIO pins. It also has PWM pins to control the movement of propellers. It also has 4 USB ports which can be used to connect with webcam. Webcam is used to get videos, Raspberry Pi processes those images and extract information i.e. target detection. On basis of data extracted from the frames of the video Raspberry Pi controls the propellers. Raspberry Pi also has a bluetooth module and wifi module. Wifi module is used to transmit final video (enhanced and with detected target) to base computer.

Our main contributions include:

- Use of Raspberry Pi for UUV circuit designing.
- Software designing for image processing and video transmission to base computer

- Analysis of different image enhancement and color restoration techniques on the basis of execution time and quality on Raspberry-Pi.

The rest of the paper is divided as follow: Section 2 describe the past work done in image enhancement and methods of communication. Section 3 investigates the methodology used.

The rest of the paper is divided as follows: Section 2 will discuss the past work done in designing UUVs, image enhancement and color restoration, and methods of communications between UUV and base computer. Section 3 will discuss the methodology and experiment environment. It will also explain the circuit design using UUV. In section 4, results will be discussed. In the end, section 5 will give future recommendations and will conclude the paper.

2 LITERATURE REVIEW

2.1 Electrical Assembly

Designing of electrical Assembly is a crucial task as it is a medium that combines software with mechanical hardware. Some starting work for collecting visual data and processing it for UUV includes designing of crawling UUV for tidal shores by Evans et al. [16]. Power to the system was given through a power generator on the surface. The umbilical cord connects the ground system to the UUV and this cord carries power and signal cable. A CCD camera was used for visual input and the circuit was basically made up of standard embedded PC components and micro-controller. The main purpose of the UUV was to make oceanographic measurements. Smith et al. [46] designed a system for underwater world modeling and UUV localization. They used a CCD camera to take 2D greyscale input images and send it to the ground system through the umbilical cord. Then they used those images to reconstruct underwater environment modal on CAD and used it for localization and orientation of UUV. Cadena [9] designed an AUV(Autonomous Underwater Vehicle) that can be used for launching UAV(Unmanned Aerial Vehicles). For designing the electrical circuitry, Cyclone II FPGA Development Kit was used as CPU. CPU was equipped with GPS Reciever, Accelerometer, Gyro and compass. Signals were received through RF Transceiver. For controlling the propellers PWM pins in the CPU were used and propellers were powered through external batteries. Sulzberger et al. [48] worked on designing UUV that can be used for hunting underwater mines. They used a magnetic and electro-optic sensor for achieving the task. They used RTG sensors to achieve the purpose of the Geomatric sensor. Wang et al. [50] designed a small UUV that navigates through a series of sensors which includes depth sensor, GPS, DVL, MTI-G and USBL. Communication was done through acoustic and wireless communication devices. For environment data acquisition side-scan sonar and miniCT were used. Matthews [40] designed UUV and used PICAX as the controller. This controller was connected with battery, the receiver and current controller. Amin et al. [5] designed UUV and for controlling the motor movement they used Arduino Uni board. Ali et al. [4] used a camera in UUV to set the target position and used Arduino to calculate the difference from the target location. All these designs deal with controlling UUV through assemblies which used self-designed circuits and some latest designs use Arduino.

2.2 Image Enhancement and Color Restoration

There has been a lot of work present in the domain of image enhancement and color restoration for UUVs. Garcia et al. [18] proposed a technique for solving non-uniform illumination issues. They applied point-to-point division of image by the estimate of illumination field and then to enhance image contrast they used remapping of grey-scale levels. Wu and Li [52] worked on underwater image enhancement, they combined Jaffer-McGlamery computer modal and spread characteristic of underwater light. Rajesh [44] worked on image enhancement and color correction using Dark Channel prior to the thesis work. He then converted the image into Long, Medium and Short (LMS) domain as human eye Perceive colors in this domain. Lu and Serikawa [39] used trigonometric bilateral filtering and wavelength conception for image enhancement and color restoration. Their technique provided less noise, better view of the dark region and better contrast. Galdren et al. [17] enhanced the color of underwater images by working on the red channel as the red wavelength is degraded the most underwater. Their method gives natural color correction and enhances artificially illuminated areas. Panetta et al. [41] considered three attributes of images underwater that are colorfulness, sharpness and contrast measure. These three were chosen because they are important properties of the human visual system. Lu et al. [38] improved image contrast, illumination and reduced noise. Using weighted normalization convolution domain filtering they enhanced image optics in shallow water. Li and Guo [29] reduced the haziness of the image using global atmospheric light and medium transmission map. They further improved contrast, brightness, color and visibility using color saturation, color compensation, intensity stretching and histogram equalization. Lu et al. [36] worked on enhancing underwater images. They first white balanced the image and removed BF Highlight, using these two images they did distance estimation and then dehazed the image using median dark channel prior dehazing. In the end, they corrected the colors using the spectral properties of the image. AbuNaser [1] proposed using particle swarm optimization for underwater image enhancement. They did RGB adjustment using the PSO algorithm and after converting the image from RGB to HSV domain to feed it to the proposed algorithm. Banerjee et al. [6] proposed RGB YCbCr Processing method (RYPro), they first removed noise through linear and non-linear filters. After that, they applied color stretching and histogram equalization in RGB domain. After that image was converted to the YCbCr domain for Y component stretching. After that median and laplacian filter was applied to the Y domain. At the end, the image was converted back to the RGB domain. GÜRAKSIN et al. [20] worked on contrast enhancement in RGB domain using a differential evolution algorithm. This algorithm was applied to each RGB channel and then the image was sharped through unsharp masking. Lu et al. [37] used weighted guided trigonometric filter for image enhancement and spectral properties of the camera for color restoration. They achieved better contrast, better exposure in the dark and better signal to noise ratio than state-of-the-art models. Boudhane and NSIRI [8] exploited Poisson-Gauss theory for image enhancement. They pre-processed the raw images for denoising does image segmentation using the mean shift algorithm and then does statistical

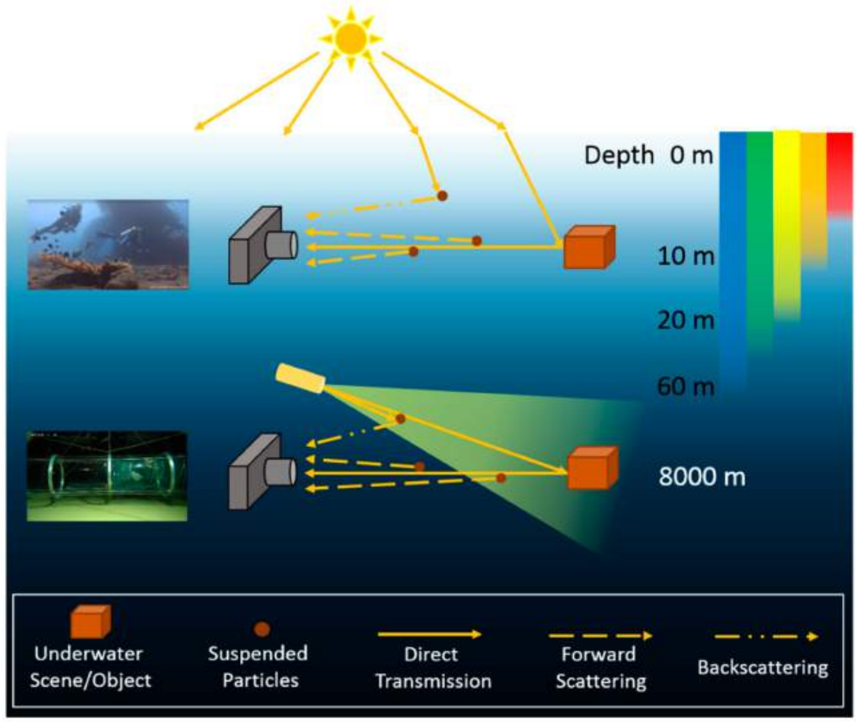


Figure 1: Light Scattering and Color Loss due to suspended particles and depth [34]

estimation on each image. Cho and Kim [12] took into consideration forward, back, multiple scattering, blur and noise. They used artificial light modal for enhancing the images. They used two images of the same scene with different turbidity and exploited it to enhance the images. Perez et al. [43] used deep learning to enhance the images. They trained a convolutional neural network for dehazing the images and their approach outperformed other image enhancement approaches. Lu et al. [35] proposed a super-resolution algorithm for high turbidity underwater images. They first used self-similarity based super-resolution algorithm to get scattered and non-scattered high-resolution images. Then they used convex fusion rule to get the final high-resolution image. Li et al. [30] used generative adversarial networks for color restoration. They reconstructed images through generator and for discriminator they give surface images. So their algorithm converted underwater images according to the color pattern of surface images. Boudhane and Balcers [7] enhanced images using background estimation, map estimation, global color estimation and Medium transmission. They applied texture removal and histogram equalization for denoizing images and final color estimation. Huang et al. [23] worked on Simultaneous localization and mapping (SLAM). They first converted the image from the RGB domain to the HSV domain and applied guided filter. Then they used Retinex theory to get a reflection image and converted the image back to the RGB domain. Then to enhance the contrast they applied gamma correction. Xu et al. [53] used robust principal component analysis network (RPCANet) for image enhancement in order to recognize the target. They used this network due to it's ability of outlier removal and distance estimation. Voronin et al. [49] used local and global image processing in the frequency domain. They used spatial equalization and log transform histogram matching to achieve a better image. Li et al. [28] build CNN for image enhancement which instead of providing features, directly enhances the images. For training their modal they used the water scene prior to generate underwater data. Li et al. [32] proposed a neural modal for enhancing the images. They first color corrected the images to fed them to neural modal which then applied the channel-wise linear shift and self-adaptive refinement to enhance the images. Yang and Xu [56] used Retinex theory for balancing RGB multi-channel energy as each channel has different energy, especially the green channel has the highest energy. Liu and Fang [33] used DeepLabv3+ for image segmentation. First, they used an unsupervised method of color correction, then they applied up-sampling and obtained target features and object boundaries.

From the above analysis of literature older approaches used simple image processing algorithms for image enhancement that uses less processing power and can work with less processing power in real-time low-cost UUVs. The most recent approaches use deep learning to enhance the images which use more processing power and more cost. Thus they can not be used in real-time stand-alone UUVs as they need high processing power which increases the cost of UUVs or a system that can transmit images to the ground system and process them there as done in old approached discussed in designing subsection.

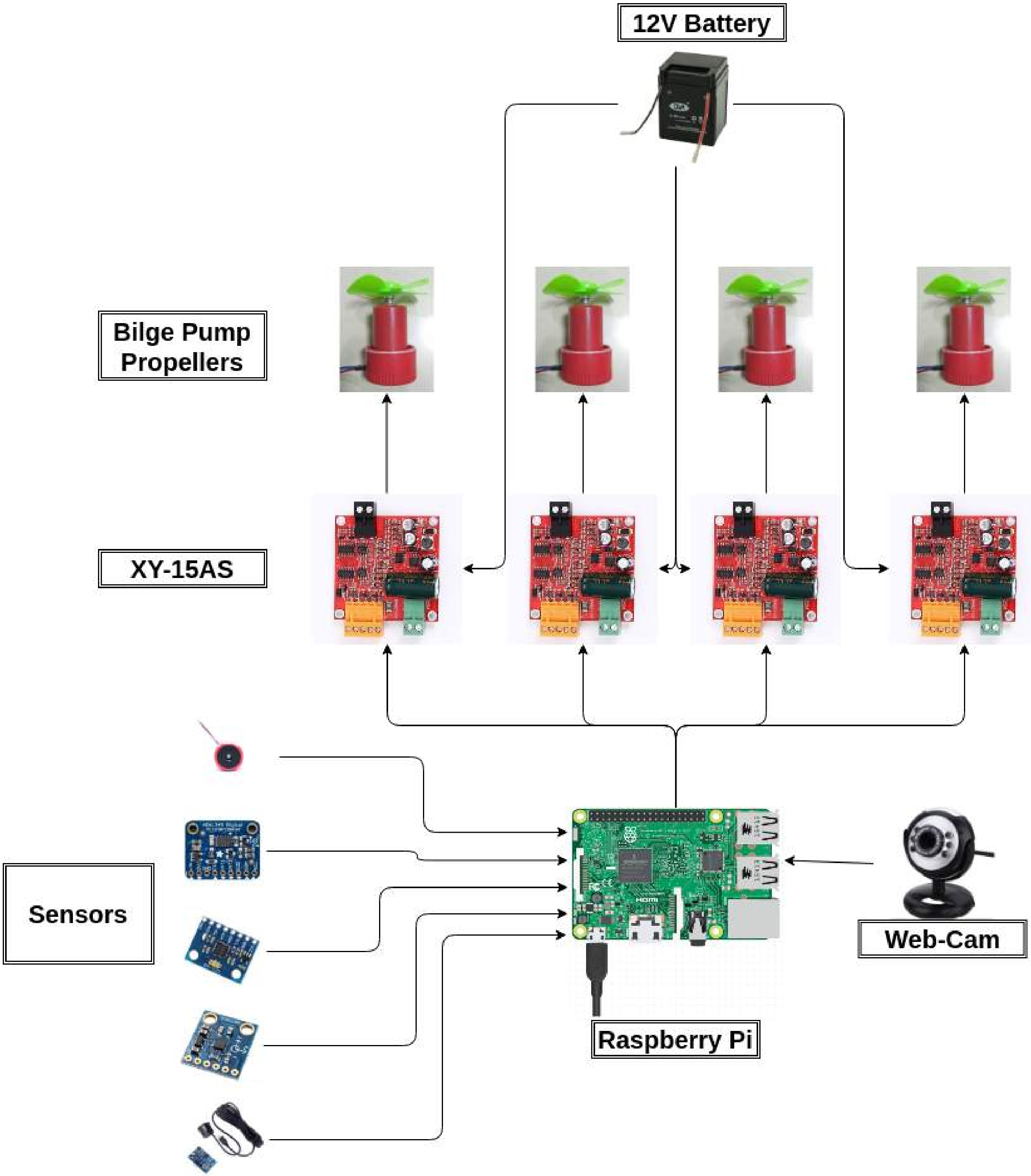


Figure 2: Proposed electrical assembly of UUV

2.3 UUV Communication

Communication with UUV is an important feature as it can help in localization and real-time observation of the underwater world. Past approaches used the Umbilical cord for communicating with UUV but it has constraints of movement and depth. To tackle this problem wireless communication helped a lot over the years. Rubino et al. [45] proposed the use of RF link for communication with UUV, they also considered using compression techniques for fast and better communication. Ahn et al. [3] used image compression for fast image transmission and used acoustic image transmission. They used 16-colors color pallets for compression and then transmitted the image, colors in the received image got replaced by most similar colors in color pallets. Krishnaraj et al. [27] used discrete wavelet transform for image compression. They used CNN for encoding the images. Danckaers and Seto [13] used vector quantization to compress side scanned sonar images and to transmit it to the operator. Ahn et al. [2] worked with enhancing underwater images, transmitting them, segmenting the region of interest and compressing the images. They used acoustic transmission for the transmission step.

Most of the methods used acoustic transmission for sending the images to the surface vessel and to make the transmission fast they apply compression algorithms.

3 METHODOLOGY

The brain of the UUV is Raspberry pi 3B. Raspberry pi 3B has a 1.2GHz Quad Cortex A53 with 1GB SDRAM. An SD-card is used as a storage medium in Raspberry Pi and Raspbian Linux operating system is also installed on the same card. There are 40 GPIO pins which include 5V and 3V power pins, ground pins, logic pins and PWM pins. These pins can take signals from sensors and can control the speed and direction of motors on the basis of sensor and visual input. For powering the Raspberry Pi 5V power bank was used. We used a 5V webcam connected to Raspberry Pi through a USB port for video acquisition. Programming for image and color enhancement was done on Raspberry Pi through Python3 on Theano.

The circuit diagram of our proposed is shown in figure 2. As shown in figure our proposed modal has the capacity to act as a full-fledged operating module for UUV. It can take input from sensors, control thrusters and control all this according to visual input. The demonstration of motor controlling and use of GPIO pins was done through detection of a pole gate underwater i.e. when the gate is detected UUV passes through it. This can be used in detecting and approaching target applications. For detection of the gate, template matching was applied, where a simple pole gate image was fed to the system and when the system detects the pole gate above a specific threshold value it sends the signal to the Raspberry Pi.

For this demonstration, UUV was controlled using 4 propellers that were made using bilge pumps and plastic propellers. A bilge pump operates on 12V, 3.4A. It has a diameter of 1.25 inches and can through 1100 gallons of water per hour. Specification of propellers are as follow:

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

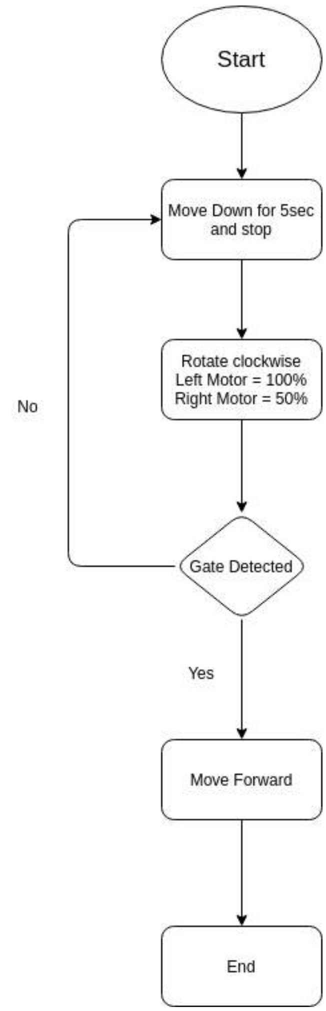


Figure 3: Mechanism for testing operation of thrusters

For controlling the speed of propellers, four motor controlling modules XY-15AS were used. These modules can carry up to 15 Amps of current. At last for powering the propellers 12V Li-ion batteries were used. The operation of motors was tested on the surface and speed of propellers were monitored when the pole got detected. The algorithm for testing of the motor driving process is shown in figure 3.

For enhancement and color correction of underwater images different modals were used, these models were reviewed by wang et al. [54]. For image enhancement performance of these modules were tested on basis of execution time per frame:

1. Contrast Limited Adaptive Histogram Equalization, CLAHE by [57]
2. Gamma Correction (GC) by [14]
3. Histogram transformation (HE) by [24]
4. Integrated Color Model (ICM) by [26]
5. Combining Rayleigh-stretching and dual-intensity images (2014) [19]
6. Global Histogram Stretching (RGHS) by [22]

Table 1: Execution time per frame for image enhancement and color restoration methods on Raspberry Pi 3B

Image Enhancement		Color Restoration	
Method	**Execution time**	**Method**	**Execution Time**
CLAHE	0.25s	DCP	653.48s
GC	3.29s	GB	Memory Error
HE	0.08s	IBLA	1151.89s
ICM	25.84s	Low-Complexity DCP	395.41s
Rayleigh-Stretching	257.13s	MIP	377.56s
RGHS	186.09s	NOM	1040.78s
UCM	158.39s	RoWS	420.52s
		UDCP	470.72s
		ULAP	67.45s

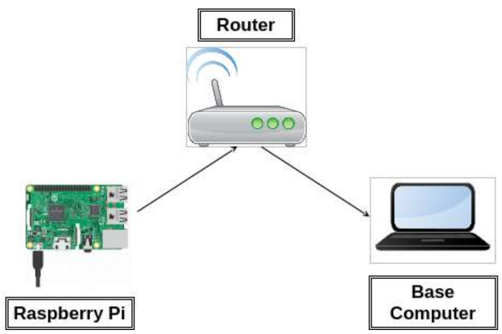


Figure 4: Overview of the video retrieval process from UUV to base computer

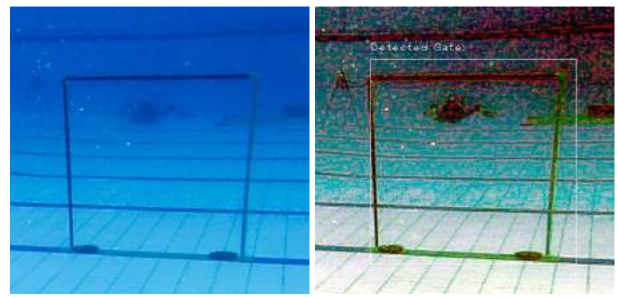


Figure 5: Overview of video retrieval process from UUV to base computer

(7) Unsupervised Color Correction Method (UCM) by (2010) [25]

For color restoration following methods were tested:

(1) Using Dark Channel Prior (DCP) by [21]
(2) Red channel correction and blue-green channels dehazing (GB) by [31]
(3) Image restoration for blurry and hazzy images (IBLA) by [42]
(4) Low-Complexity Dark Channel Prior by [55]
(5) Single image dehazing (MIP) (2010) [10]
(6) A new optical model (NOM) of image enhancement by [51]
(7) Water scattering removal (RoWs) by [11]
(8) Transmission Estimation (UDCP) by [15]
(9) A Rapid Scene Depth Estimation Model Based on Underwater Light Attenuation Prior (ULAP) by [47]

After the image processing is done and the video is clean from noise Raspberry Pi transmitted it to base computer. For transmitting and acquiring the video from UUV wifi was used. The wifi module on Raspberry Pi is IEEE 802.11n. It has a range of 175+ feet indoor. It has a frequency of 2.4GHz and medium of 5GHz. Under ideal conditions, it can reach a transmitting speed of 600Mbps. For communication VNC-viewer was installed on both Raspberry Pi and the base computer. Both machines were connected to the same router and using the IP address of Raspberry pi image was acquired on base computer through VNC-viewer.

4 RESULTS & ANALYSIS

In this paper, a new circuit architecture was presented for operating UUV where Raspberry Pi acted as the brain of the UUV. Different methods for image enhancement and color restoration were discussed above, but does these methods are applicable in our architecture where Raspberry Pi acts as a processing unit? To answer this question Table 1 shows the execution time of mentioned methods on Raspberry Pi 3B. Images obtained as the result of applying image enhancement and color restoration methods are shown in fig 5 and fig 6 respectively. As it can be seen from table 1 that HE processes 1 frame in 0.08 seconds thus it can process 750 frames per second. HE is followed by CLAHE with an execution time of 0.25s. When it comes to image enhancement HE restored images have a bright spot in them but CLAHE was unable to enhance deep blue images. So, HE is the best option to be used in autonomous UUV in our proposed circuitry.

After the image was enhanced it is to be tested for gate detection. Fig 7 shows the original gate image and resulted image after enhancement and detection of the gate. It can be seen that the pole gate has been detected once that happens GPIO pins present on Raspberry Pi signals the motor to move at full speed in the forward direction. Meanwhile, all the videos acquired by UUV are being directly sent to the base computer after processing and detection through wifi connection.

(a) Original Images

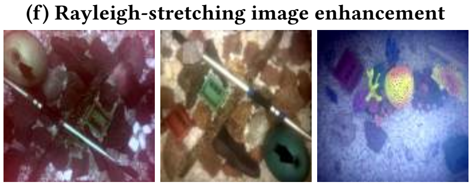
(b) CLAHE image enhancement

(c) GC image enhancement

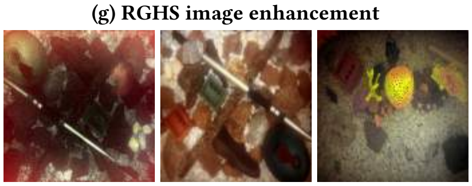
(d) HE image enhancement

(e) ICM image enhancement

(f) Rayleigh-stretching image enhancement



(g) RGHS image enhancement



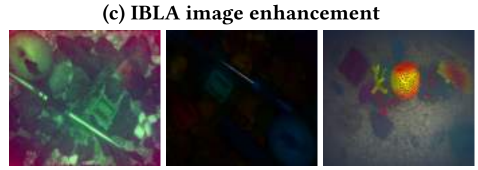
(h) UCM image enhancement

Figure 6: Images obtained from image enhancement methods

(a) DCP image enhancement

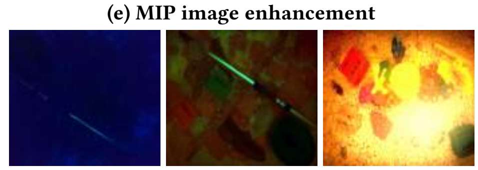
(b) GB image enhancement

(c) IBLA image enhancement

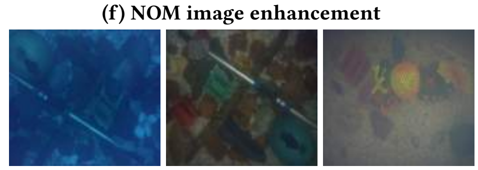


(d) Low-Complexity DCP image enhancement

(e) MIP image enhancement

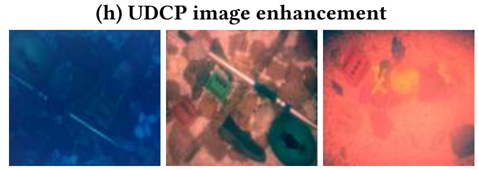


(f) NOM image enhancement



(g) RoWS image enhancement

(h) UDCP image enhancement



(i) ULAP image enhancement

Figure 7: Images obtained from color restoration methods

5 CONCLUSION AND FUTURE SUGGESTIONS

Image enhancement is a basic need when performing underwater tasks. Especially in the case of autonomous UUVs where pathfinding and target detection is a must. This paper proposed a circuitry that can be used as a standalone system for UUV video enhancement, target detection, and autonomous operations i.e. motor controlling. This circuitry also has the capability to accommodate a wide range of sensors. Different methods of image enhancement and color correction were tested on Raspberry Pi to check which method can be used for best image enhancement in less execution time per frame. Target detection was tested through pole gate detection through template matching and motor operation was also tested through this operation. The end product is UUV circuitry that can take sensor and video input, enhance the video and controls propellers accordingly, in addition to that enhanced image is also sent to the base computer using a common wifi signal.

Nothing is perfect and these is still room for improvement, our UUV model is for only shallow water purposes due to image transmission range using wifi. Raspberry Pi has capacity to work with RF transmitters due to it's GPIO pins. Another enhancement can be done with increasing the model of Raspberry Pi. Recent model is Raspberry Pi 4 which has upto 8GB of RAM. This will improve image processing speed. Another boost in performance can be obtained via Intel Movidius, vision processing unit (VPUs).

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