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Shallow Water Image Enhancement for Autonomous Underwater Vehicles using Image Processing algorithms Implementation on Raspberry-Pi

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ABSTRACT:

An Innovative method has been proposed to improve the quality of underwater images by removing the shading and low contrast artifacts commonly found in them. During the process of capturing underwater images, scattering, reflection and absorption are caused by the various effects of light. These effects can make the images hazy or blurred and more noisy. To overcome these degrading factors, the enhancement techniques are required. In this paper, we present a strategy that involves a classic algorithm to improve the quality of underwater images: contrast-limited adaptive histogram equalization. The goal of this paper is to design a low-cost Underwater vehicles that can be used with a simple electrical assembly. The Underwater vehicles would be built using the mini computer SOC known as the Raspberry-Pi. The paper proposes an algorithm that can be used to enhance the images captured by the Underwater vehicles. The sensors are also attached to the device using a pair of GPIO pins to measure the depth and detect the obstacles. In order to enhance the images, various methods were tested using Python 3. The results of these tests were then analyzed. Three parameters, namely, PSNR, Root Mean Squared Error and the Entropy, have been analyzed to compare the results of the proposed method with the state-of-the-art techniques. The proposed system is said to perform better than the existing techniques when it comes to improving underwater images.

Keywords: Image Enhancement, Raspberry Pi, Autonomous Underwater Vehicles.

I. INTRODUCTION

While taking underwater images, the light that hits the camera can cause degradation and loss of its wavelength due to scattering. While scattering is caused by particles in the water, the light coming from the camera can also cause loss of its wavelength as it goes deeper underwater. Red light got absorbed first, and blue light can go much deeper. Due to these factors, images taken underwater may have low quality. They can also affect the functionality of underwater cameras. Backscattering, light absorption, and forward scattering are some of the factors that can affect the quality of images captured underwater. In order to enhance the quality of images captured underwater, researchers have been developing various techniques that can be used to transmit images and videos to the base computer. One of these is by using umbilical cord, which is a type of electrical device that carries both power and signal. When the base computer receives an image or video, it then sends the signal to the next step. However, this process can be very time consuming and limits the functionality of UUV. In this paper, we presented a method that involves an electrical assembly that can perform various tasks, such as enhancing the quality of images captured underwater. Aside from enhancing the quality of images, this assembly can also be used to collect other information such as temperature and depth. In order to perform these tasks, a device known as the Raspberry Pi 3B was proposed. The device, which is a mini computer, is powered by the 1.2GHz processor and 1GB of RAM. It runs on the Linux operating system known as Raspbian. Other third-party applications such as the Ubuntu mate can also be used to run the device. The device has four USB ports, which can be used to connect various peripherals such as sensors and cameras. It also has a pair of general purpose pins that can be used to connect sensors. The camera attached to the device is used to take images and videos. It then processes the captured images and retrieves information about the target detection. Based on the data collected, the device can control the propellers. The device also comes with a pair of external modules inbuild, namely a wifi module and a bluetooth module. These allow the device to send enhanced videos to the base computer.

Despite the numerous studies that have been conducted on these strategies, they still suffer from various issues that prevent their practical applicability. This paper presents a method, an innovative algorithm that aims to improve the images taken from deep water. The work flow is organized as follows. In the input image, a preprocessing operation called as white balancing operation is performed. The resulting white balanced image is then converted into a LAB color space after performing gamma correction. The resulting image is then enhanced with CLAHE and luminance component of the image is enhanced. The resulting image is then reconstructed to the RGB color space and output image is a high resolution enhanced image.

The remaining section of the paper is arranged as follows .The second section of the paper talks about the various techniques involved in underwater image enhancement i.e Literature Survey. The third section covers the aspects related to proposed algorithm and flowchart and the fourth section discusses the implementation details regarding hardware aspects, sensors and Raspberry pi and the fifth section discusses the experimentation results and comparision with state of the art techniques, quantitative and qualitative analysis with mapping results and the final section concludes the paper.

II. LITERATURE SURVEY

2.1 Electrical Assembly of UUV systems model

Electrical Assembly is a process that involves combining software and mechanical hardware. One of the most challenging tasks in this area is the design of an unmanned underwater vehicle (UUV). For instance, in Evans et al.'s[1] case, they designed a crawling UUV that can collect visual data. The umbilical cord, which is the connection point between the UUV and its ground system, carries a signal and power cable. The main objective of the project was to collect oceanographic data. The engineers integrated a variety of hardware components, such as a micro-controller and a CCD camera, into the system. The engineers from Smith et al.[2] created a system that allows them to create underwater world models and UUV localization. They used the data collected by the camera to perform various tasks, such as mapping the underwater environment. For the electrical design of the system by cadena[3], the engineers used the Cyclone II FPGA Kit Development. The CPU was equipped with various features, such as GPS Reciever, compass, and Accelerometer. The system also received signals through a RF Transceiver. The CPU was also equipped with multiple control pins. The engineers also used external batteries to power the propellers. In their case, Sulzberger et al.[4] and his team designed an underwater vehicle that can be used to hunt underwater mines. They used electro-optic and magnetic sensors to achieve their goal. In their case, Wang et al.[5] designed an underwater vehicle that can navigate through a series of sensors, such as GPS, sonar, and DVL. They were able to communicate with the system through wireless and acoustic devices. For the data acquisition, used the mini CT and side-scan sonar. The controllers were connected to a battery and a receiver. Jeet Banerjee et al.,[6] for their project, used an onboard micro-controller to control the movement of the underwater vehicle.

2.2 Image Enhancement and color Restoration

Several studies have been conducted in the area of image enhancement and color correction for unmanned underwater vehicle systems (UUVs). One of these studies was done by Garcia et al.,[7] which focused on the use of a technique for resolving non-uniform illumination problems. The researchers used a method known as point-to-point division to estimate the illumination field and then to improve the image contrast. They also remapped the grey-scale levels in the image. The researchers, who were led by Li and Wu et al., [8] were able to achieve a significant improvement in the image contrast and illumination field using a computer-based technique. Rajesh et al., [9] had already done some work on the Dark Channel technique. Through this, he was able to convert the image into a human eye's perception domain, which is called the Long, Medium, and Short (LMS) domains. Through a combination of trigonometric filtering and wavelength conception, the researchers Lu and Serikawa [10] were able to improve the image contrast and enhance the colors in the image. The researchers Galdren et al. [11] were able to enhance the appearance of underwater images by focusing on the red channel. This method works by reducing the red wavelength's degradation underwater. Their method was able to enhance the artificial illumination areas and give natural color correction. According to Panetta et al.,[12] their findings could be useful in developing underwater cameras that can capture various attributes such as contrast, brightness, and color. The researchers, who were led by Lu et al., [38], were able to improve the image contrast and illumination field using a computer-based technique. They also used a weighted normalization domain filtering method to enhance the optics in shallow water. The two researchers, who were led by Guo and Li [29], were able to reduce the haze in the image by using a global atmospheric light transmission map and a medium transmission map. They were also able to improve the brightness and visibility by using various other techniques including color saturation, color compensation, intensity stretching and histogram equalization. In order to enhance their images, Kim and Cho [12] took into account scattering, noise, and forward and back blur. They used an artificial light modal to achieve these results. They exploited the different properties of two images to enhance their images. Deep learning was then used to enhance the images by Perez et al. [13]. They trained a deep learning network to dehaze the images. Their approach was superior to other image enhancement methods. The proposed algorithm by Lu et al. [14] was able to achieve high-resolution images with scattered and non-scattered features. They then used a convex fusion rule to achieve their final image. generative adversarial networks were then used to restore the colors which was proposed by Li et al [15]. Through their generator and discriminator, they were able to generate surface images. The algorithm then converted the underwater images into their corresponding color patterns. Balcers and Boudhane et al., [16] then used various techniques to enhance their images, such as map estimation, background estimation, and global color estimation. They applied histogram equalization and texture removal to denoize and enhance the images. Huang et al., [17] were able to achieve their results through simultaneous mapping and localization. They first converted the image to the HSV domain using guided filter. They then used the Retinex theory to get a reflective image and converted back to RGB domain. They then applied gamma correction to enhance the contrast. Through their network, Xu et al., [18] were able to recognize the target image. Due to its ability to perform distance and outlier estimation, they voronin et al [19] were able to enhance the images by using a global and local image processing network. They used log transform and spatial equalization to enhance the images. Instead of providing features, Li et al [20] CNN uses a combination of these techniques to enhance the images. Before they started training their modal, they used the water scene to train it. Li et al [21] then proposed a neural modal that can enhance the images. To enhance the images, they fed them to the neural modal, which then applied various features to improve their results.

III. Shallow Water Image Enhancement Method

This paper presents a method, an innovative algorithm that aims to improve the images taken from deep water. The work flow is organized as follows. In the input image, a preprocessing operation called as white balancing operation (color equalization) is performed where as the White balance is a process that removes unrealistic color casts from objects in your photo. The resulting white balanced image is then converted into a LAB color space after performing gamma correction. The resulting image is then enhanced with CLAHE and luminance component of the image is enhanced

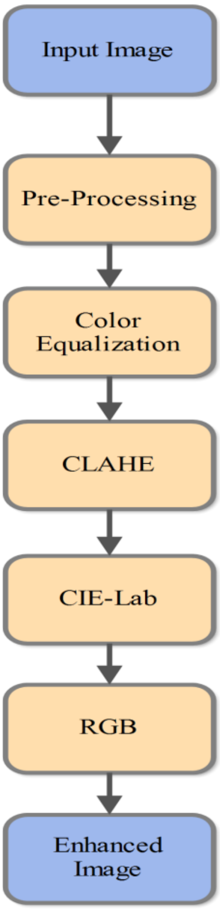

Fig1 : Proposed Algorithm

$$L^\star = 116\, f\left(\frac{Y}{Y_n}\right) - 16$$
$$a^\star = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right)$$
$$b^\star = 200\left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right)$$

CIE Lab color space mathematical model

A variant of Adaptive histogram that takes into account the over-amplification of the contrast is known as CLAHE. Instead of the entire image, CLAHE focuses on the small regions in the image that are called tiles. Instead of the whole image, CLAHE focuses on the small regions within it. Adapthisteq takes into account the tile's contrast transform function and computes the optimal value for each tile within images. The contrast of each tile is enhanced, so that its output region matches the histogram specified by the "Distribution" value. Bilinear interpolation is used to eliminate the artificial boundaries between the neighboring tiles. The resulting contrast can be adjusted to avoid amplifying the noise in the image. When Applying CLAHE there are two parameters to be remembered : ClipLimit: and the grid size

This sets the number of tiles in the row and column. By default this is 8x8. Its used while the image is divided into tiles for applying CLAHE. Properties of Adaptive Histogram Equalization include the size of a neighborhood region is a parameter that affects the contrast of the image. It is a characteristic length scale that allows for enhanced contrast at smaller scales and reduced contrast at larger ones. The result value of a pixel is computed by taking into account its rank among the neighboring pixels. This method can be used to compare the center pixel with the other nearby pixels. Unnormalized result values can be computed by adding 2 for each pixel with a smaller value than the center pixel, and adding 1 for each pixel with equal value. When the image region containing a single pixel's neighborhood is relatively homogeneous, its histogram will be strong enough to peak, and its transformation function will map the region's pixel values to the whole range. This result can cause AHE to overproduce small noise in the image. The resulting image is then reconstructed to the RGB color space and output image is a high resolution enhanced image. A color-corrected and contrast-enhanced output image can be generated, which can be perceivable and visible in the final output image.

3.1 Hardware Implementation Model

The Raspberry Pi is a credit-card-sized computer that can plug into your TV and a keyboard. It can be used in various electronics projects, and it can run a variety of programs, such as word processing and spreadsheets. It can also play high-quality video. The low-cost computer, which plugs into a TV or monitor, uses a standard mouse and keyboard and is capable of handling a variety of programs. It's also good for people of all ages to learn how to program in various languages including python. It can do everything a desktop computer would do, such as playing video games and browsing the internet. It can also run various programs, such as word processing and spreadsheets and playing games. The Pi can also interact with the outside world, which is very useful in a wide variety of digital maker projects. For instance, it can be used to create weather stations and music machines. There are four different types of models of the Pi, and they use the same CPU, the BCM2835. However, the different hardware features of these models vary.

Specifications

- Chip Broadcom: BCM2835 SoC
- Core architecture: ARM11
- CPU: 700 MHz Low Power ARM1176JZFS Applications Processor
- GPU: Dual Core VideoCore IV® Multimedia Co-Processor Provides Open GL ES 2.0, hardware-accelerated OpenVG, and 1080p30 H.264 high-profile decode Capable of 1Gpixel/s, 1.5Gtexel/s or 24GFLOPs with texture filtering and DMA infrastructure
- Memory: 512MB SDRAM
- Operating System: Boots from Micro SD card, running a version of the Linux operating system
- Dimensions: 85 x 56 x 17mm
- Power: Micro USB socket 5V, 2A

Connectors:

- Ethernet: 10/100 BaseT Ethernet socket
- Video Output: HDMI (rev 1.3 & 1.4) Composite RCA (PAL and NTSC)
- Audio Output: 3.5mm jack, HDMI
- USB: 4 x USB 2.0 Connector
- GPIO Connector: 40-pin 2.54 mm (100 mil) expansion header: 2x20 strip Providing 27 GPIO pins as well as +3.3 V, +5 V and GND supply lines
- Camera Connector: 15-pin MIPI Camera Serial Interface (CSI-2) JTAG: Not populated
- Display Connector: Display Serial Interface (DSI) 15 way flat flex cable connector with two data lanes and a clock lane
- Memory Card Slot: Micro SDIO

3.2 The Compute Module

The compute module is a small form factor device that can be used in industrial applications. It features the following components: the BCM2835, 512MB of DDR3, and 4GB eMMC flash memory. The device can be connected to a base board using a 200 pin DDR2 parallel port. It should be noted that this is not compatible with standard SODIMMs. The device's various features can be accessed using the device's dual-channel SODIMM connectors. The B/B+ and A/B only have one of these. The compute module is commonly used by companies to quickly develop new products by providing them with a complete package that includes a CPU, memory, and storage. This eliminates the need for additional peripherals and allows them to focus on the development of their new product.

3.3 BCM2835

The chip used in the popular Raspberry Pi models A, B, and B+ is the Broadcom BCM2835. It is a cost-optimized, full HD multimedia applications processor that can handle most demanding embedded and mobile applications. The BCM2835 is a cost-optimized, full HD multimedia applications processor that can handle most demanding embedded and mobile applications. It features the company's VideoCore IV technology, which enables various applications such as 3D gaming and media playback.

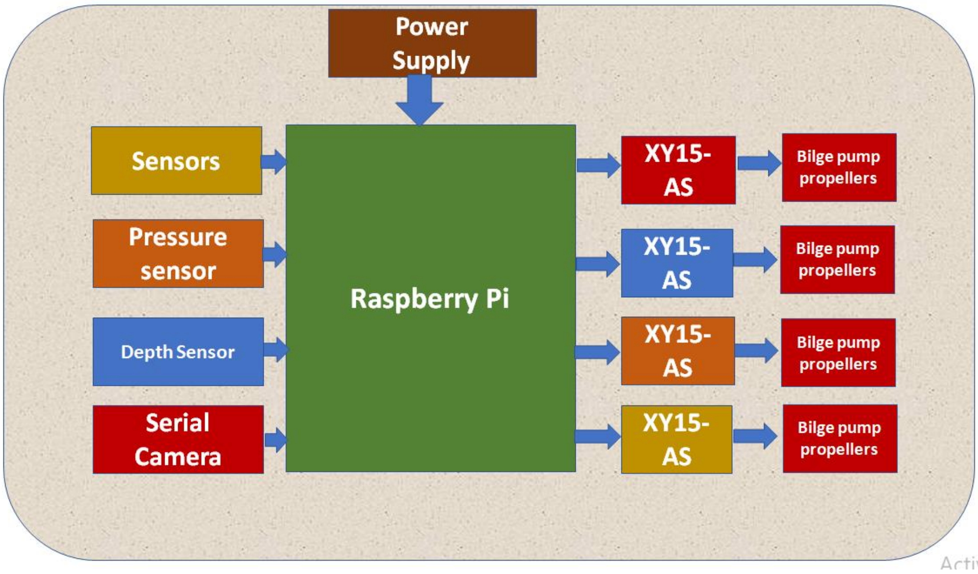

Fig 2: Block Diagram of the Autonomous underwater vehicle system

Fig 3: Real Time Components used in practical Implementation

Fig4: Practical Implementation of the Underwater Vehicle

The Autonomous Underwater Vehicle is powered by the raspberry pi, which has a 1.2GHz Quad Core CPU and 1GB of RAM. It also comes with an SD-card that can be used as a storage medium. There are 40 pins in the device, which include 5V, 3V, and logic pins. The Raspbian Linux operating system also installed on the same card. The 40 pins of the raspberry module can be used to control the speed and direction of the motors using visual and sensor inputs. The raspberry was powered by the 5V connecting to the power bank. Figure 2 shows the proposed circuit diagram of the device. It shows that our proposed module can be used as an operating module for the UUV. The raspberry can be used to control various motors and devices using visual inputs. For instance, it can be used to detect objects underwater. This feature was demonstrated by using the device's 40 pins to control the direction and speed of the motors when the UUV passes through it. This raspberry pi features can be used to detect and approach target applications. We used bilge pumps to control the UUV during this demonstration. The device was able to achieve its goal by controlling the speed and direction of the propellers which are made of steel. The pump, which is powered by 12V, is capable of moving 1100 gallons of water at a time. The specifications of the propellers are as follows: Blade width: 31.2mm, Aperture: 2mm, and compatible with 2mm shaft motors. Four motor controlling modules, namely XY-15AS, were used to control the speed of the propellers. These modules can carry a current of up to 15 Amps. After powering the propellers using 12V Li-ion batteries, they were finally ready to go. The test of the motors was performed on the surface of the device. The speed and direction of the propellers were monitored and controlled by raspberry pi.

IV. EXPERIMENTATION RESULTS

Unlike the general image quality method, underwater images cannot provide the true achromatic image of a target scene. Due to the lack of reference standards for underwater images, a wide range of methods and techniques subjective and objective evaluation are used to evaluate and analyze these images. The image shown in Fig.5 is the original underwater image that will be processed. The methods that are used to improve the image are the CLAHE algorithm, homomorphic filtering algorithm and the last figure shows the proposed algorithm. The sizes of all underwater images are 450*338. The CLAHE algorithm in fig 1 can improve the image's dynamic range and highlight details, but it cannot eliminate the uneven illumination. The homomorphic filtering process fig 1 can improve the image's color cast by reducing the number of details and improving its brightness. However, it cannot significantly enhance the contrast. The results of the study in fig 1 show that the method can improve the image quality in turbid water by reducing the noise points in the image. It can also highlight the water bodies and distant reef in the original image. The natural state of the light and shadow in the image can also improve its clarity. This can also help highlight the details of marine life.

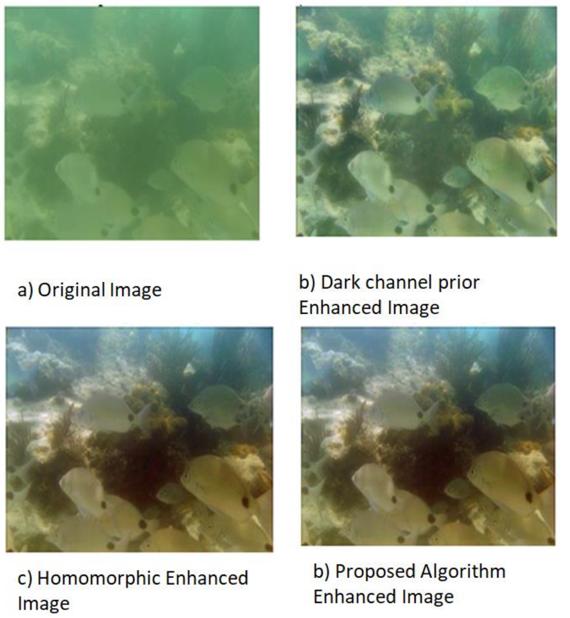

Fig 5: Comparision images of proposed algorithm with traditional algorithms

The table below shows the various features of the image that are related to the peak signal-to-noise ratio, mean squared error, and information entropy. These are also taken into account after the Dark channel prior enhancement and homomorphic filtering techniques and the proposed method. The smaller the MSE after image processing means the better the processing effect. On the other hand, the higher the PSNR, the better the image's processing effect. The larger the information entropy, the greater the disorder of information it contains. The results of this study show that the DCP algorithm has the best performance when it comes to image processing. It has a larger PSNR value and the smallest MSE. Although the DCP algorithm is capable of handling most of the image processing tasks, it cannot properly deal with the issues of uneven illumination and color cast in underwater images. The performance of the homomorphic filtering algorithm is affected by the different values of the PSNR and the MSE. However, it can still perform better than the other methods when it comes to dealing with the issues of color cast and uneven illumination in underwater images. The performance of the proposed algorithm is also higher compared to that of the homomorphic filtering method and DCP method. It has higher objective evaluation indexes and the information entropy is also higher. The difference between the proposed methods and the traditional methods can be attributed to the better recognition of the internal texture and external contours of the image. In terms of both performance and subjective results, the proposed algorithm is clearly better than the results of the previous two methods.

Table 1 Quantitative evaluation by different enhancement algorithms for original Image in fig 5

	PSNR	MSE	ENTROPY
DCP	29.3332	67.939	6.343
HF	25.4332	169.432	7.422
Proposed ALG	28.4643	70.122	7.653

In Figure 2, the data showing the various steps involved in the processing of an underwater image are shown. The first one fig 2. shows the original underwater image with resolution 367*305, while the second one fig 2b shows the results of the DCP algorithm that is used to enhance the image, while fig 2c shows results of homomorphic filtering algorithm and the fig 2d depicts results after processing through the proposed algorithm. The turbid water body of the fish is usually blue in color, making it hard to see its details. After processing using proposed algorithm, the fish can be clearly seen its shape, appearance, texture and the subjective appearance of the image is more natural. The changes in the water caused by the light can be observed, and the contrast between the objects in the water and the fish can be restored.

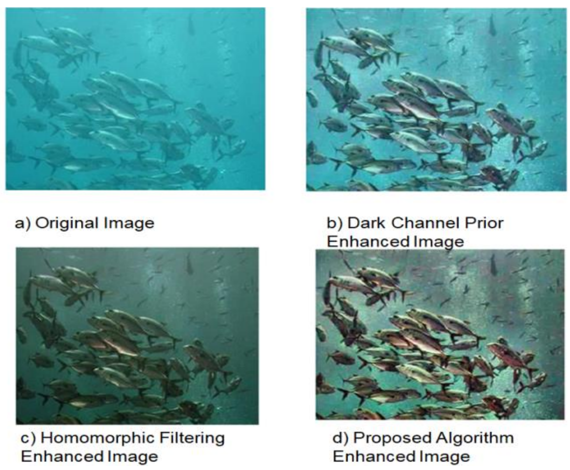

Fig 6: Comparision images of Proposed Algorithm and Traditional Algorithms

Table 2 corresponds to the peak PSNR, MSE, and information entropy of the original underwater image in Fig.6 after DCP enhancement, homomorphic filtering enhancement, and proposed algorithm in this paper. The results also show that the method proposed in this paper is significantly better than the results obtained by the previous two treatments.

Table2. Quantitative evaluation by different algorithms for original image in fig 6

	PSNR	MSE	ENTROPY
DCP	30.654	57.435	7.634
HF	26.866	155.555	6.986
Proposed ALG	29.543	69.433	7.543

V. CONCLUSION

In addition to being able to perform underwater tasks, image enhancement is also a must when it comes to autonomous UUVs. Target detection and path finding is a must for autonomous underwater vehicles. This paper proposes a standalone image enhancement system that can be used for both target detection and autonomous operations. It can be used for both image enhancement and motor controlling operations. The paper proposes a robust image enhancement system implementation using Raspberry pi that can be used with a wide range of sensors. To ensure that the system can perform well in terms of image enhancement, multiple methods were tested on a Raspberry Pi for best image enhancement in very little execution time per frames. Through template matching, target detection was performed on a Raspberry Pi. The system was also tested for motor control operation. The paper's image enhancement system is designed to take advantage of the multiple sensors and image inputs received by the UUV. It can then enhance the image and control the vehicle's propellers using a common wifi signal. Although the paper's image enhancement system is capable of improving the image quality of the UUV, it is still in need of more improvements due to its limited image transmission range. Recently, a new model of the popular Raspberry Pi was released with 8GB of RAM. This will allow the system to improve its image processing speed. Intel's Movidius vision processing unit can also be utilized to boost the system's performance.

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