Balancing Algorithm and Active Shutter Improved ROV Monitoring and Control Platform Using Mobile Phone

Zihao Tao
School of Information Science and Engineering
Harbin Institute of Technology
Weihai, China
e-mail: 170220119@stu.hit.edu.cn

Juhua Qiao
Weihai Beiyang Optoelectronic Info-Tech Co., Ltd
Weihai, China
e-mail: qiaojuhua@beiyang.com

Laixiang Jiang
Weihai Oceanic Fishery Monitoring and Hazard Mitigation Center
Weihai, China
e-mail: 279309542@qq.com

Liang Han*
School of Information Science and Engineering
Harbin Institute of Technology
Weihai, China
e-mail: hanliang@hit.edu.cn

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***Abstract*—In this paper, we propose a novel and convenient Remote Operated Vehicle (ROV) monitoring and control platform based on Virtual Reality (VR) system and virtual rocker control system. In general, conventional monitoring and control platforms for ROV is bulky and lack of real-world interaction. To overcome these problems, we design a portable monitor and control platform that offers 3D visualization and control interface based on mobile phone. Besides, to improve the immersion perception of mobile phone VR platform, an algorithm based on Kalman filter is proposed to improve the accuracy of controlling data. Active shutter technology is also applied to enhance the image resolution in VR visualization.**

Keywords-VR; monitoring and control platform; ROV; mobile phone; virtual rocker; Kalman filter; active shutter

I. INTRODUCTION

In the past 30 years, ROV is regarded as one of the most essential approaches to explore and analyze the underwater area all over the world. The manipulation of the ROV underwater requires the screen to provide real-time visualization. In the meantime, several control signals are generated and transmitted from the ground to the ROV. In the past, the conventional platforms were viewed as the most excellent choice since they could meet almost all the requirements. Fig. 1 shows one of the conventional monitoring and control platforms for ROV. Meanwhile, 2D visualization derived from conventional platforms is not enough to provide new experiences by accepting manipulators to interact with physically and emotionally in a virtual world that is almost same as the real world. [1-2]. In this circumstance, the solution to the above problems is necessary.

With the flourishing of digital devices, the performance of the mobile phone is apparently improved based on the advancement of CPU, GPU, screen and so on. Smartphones are playing a more significant role in our life since they are convenient and multifunctional with the assistance of applications [3]. In this case, shifting the monitoring and control platform for ROV from the conventional style to a novel and portable phone platform is taken into consideration.

Figure 1. Conventional platform for ROV

In this paper, we work on a balancing algorithm and active shutter enhanced ROV novel and portable platform based on mobile phones. There are two kinds of working modes provided by the platform including monitoring mode and control mode.

The monitoring mode is designed to offer advanced immersive 3D VR display with Head Mount Display (HMD). In fact, there are about three types of VR facilities. The first one is VR helmet based on personal computer. The best VR performance is offered by this type of VR facility since the immersive interaction and excellent screen cultivate the desirable experience. However, the cost of this facility is up to 800 dollars. The manipulation of this VR facility is also difficult, which suggests that it is uncomfortable for a researcher to spend several hours to arm this device. The second type of the VR devices is integrated VR facility which combines the computer and helmet at the same time. The cost of the device is around 300~600 dollars, which suggests that it is more affordable than the first one. Nonetheless, the bulky and uncomfortable helmet is also the

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obstacle for the researchers. The third one is portable VR device based on the mobile phone. Even if the comparatively low performance of this type of VR is criticized by the consumers, the attributes of portability and economy meet the requirements of the research for the open sea [4]. The comparison between three types of VR devices is shown in the table I. Therefore, the VR based on phone HMD is chosen to be applied in our research since it is portable enough to meet the requirements. The manipulator is shown in Fig. 2. Several simple control functions are also designed in monitoring mode like controlling the pose of the ROV based on the pose of the mobile phone and controlling the location of the ROV by voice recognition.

TABLE I. COMPARISON BETWEEN VR DEVICES

Products	**Comparison**		
	Cost ($)	***Advantages***	***disadvantages***
VR helmet based on PC	Over 800	Best performance Immersive interaction Excellent experience	Bulky High-cost Uncomfortable
Integrated VR helmet	300~600	Integrated design Less expensive	Comparatively inconvenient
VR based on phone	Less than 15	Economic Portable	Low visual performance

Figure 2. The manipulator of the phone platform

In the control mode, a kind of virtual rocker control interface is designed to accurately control the movement of the ROV. The manipulators are capable to accurately change the pose and the location of the ROV, which meet the basic requirements of the platform.

Comparing with the conventional platform, the novel platform based on the mobile phone decreases the weight by 80 percent and spares the volume by 90 percent.

However, the inaccurate pose data collected from mobile phone in the monitoring mode distorts the pose control of the ROV. The drift of phone pose data detrimentally distorts the pose of ROV, which causes the instable work circumstance. To overcome the problem, we propose the Kalman filter to stabilize the pose data derived from the mobile phone to improve the accuracy of control data.

Furthermore, the image resolution ratio is totally decreased in the process of reconstructing 3D visualization since the image on the phone is directly enlarged by the HMD to construct immerse perception environment, which causes the low viewing performance experienced by the manipulator. To enhance the quality of the 3D visualization, the active shutter technology is applied on the mobile phone.

This paper is organized as follows. Section II describes the architecture of the mobile platform. The measurement results and discussion are shown in the section III. Finally, the conclusion of the paper is shown in section IV.

II. ARCHITECTURE OF ROV MONITORING AND CONTROL PLATFORM

In the structure of the whole communication system for the ROV, Power line Communication (PLC) technology is applied to build the communication between the ROV which is underwater and the platform which is on land. Fig. 3 shows the communication system [5]. In the water, the data from the Web Camera is caught by the MCU of the ROV in the water. Then the data is filtered and packed to be transmitted to the MCU on land with the assistance of PLC. Furthermore, the data is conveyed to the phone platform based on WIFI. The data can also be transmitted from the phone platform to the MCU on land. Later the data will be conveyed into the MCU in the ROV based on the PLC to control the ROV. In general, there are two PLC modules on the land and in the ROV respectively.

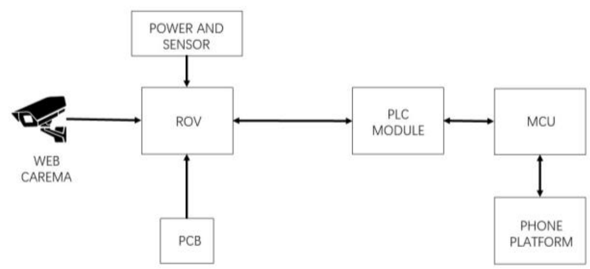

Figure 3. Communication system of ROV

There are two different working modes in the phone platform, which can be manipulated independently including monitoring mode and control mode.

A. Monitoring Mode

The architecture of monitoring mode is shown in Fig. 4. 3D VR visualization is offered in monitoring mode based on the mobile phone platform, which enables realistic physical behavior of the virtual objects in the real-world [6]. The Web Camera provides stereo images which are conveyed to the MCU on land. The data is packed and transmitted to the mobile phone through WIFI signals. Then the data is unpacked to stereo images. The stereo images are implemented to build a 3D visualization with the assistance of mobile phone application and HMD, which suggests that it is sufficient to offer interaction between the virtual reality and real-world [7].

In this case, it is impossible for manipulators to control the ROV with the rocker since the view of the researchers is filled with the images of VR visualization. Therefore, several auxiliary functions in the monitoring mode are designed to

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help to control the ROV properly. The first auxiliary function is executed based on gyroscope and accelerometer sensors. These sensors are implemented together to detect the movement of the mobile phone, that is to say, the movement of people's head. The yaw, pitch and roll angle information are detected and computed to figure out the specific pose of the manipulator. Then the pose of the ROV follows and simulates the pose of the manipulator's head to achieve the pose control of the ROV roughly. Fig. 5 shows the yaw, pitch and roll angle of the mobile phone. The second auxiliary function is voice recognition control based on the microphone and AI in the mobile phone. The voice recognition consists of several commands like March, Retreat, Come-up, Dive, Turn left, Turn right and so on. With these two auxiliary functions, the ROV is easily controlled to change the pose and the location underwater. Eventually, the data including pose control information and location control information is packed and transmitted from the phone to the MCU on land through Bluetooth Low Energy (BLE) signals [8-9].

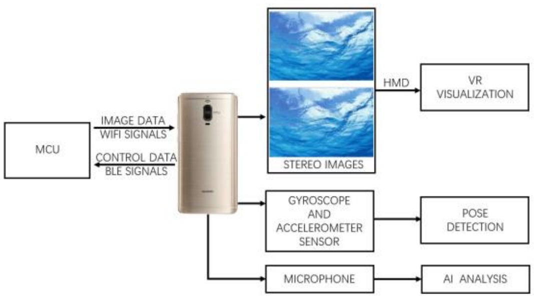

Figure 4. Architecture of Monitoring Mode

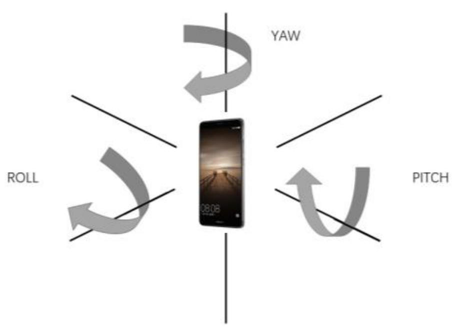

Figure 5. Angle Detection of Phone

To improve the stability of ROV control data, we propose the Kalman filter to enhance the accuracy of phone pose data [10-12]. The approximate equation is expressed as follows:

$$Z_t = \Phi_{t-1} Z_{t-1} + \omega_{t-1} \quad (1)$$

where Z, Φ, ω stand for state vector, state transition matrix and estimation error respectively.

The measurement equation is expressed as follows:

$$M_t = HZ_t + V_t \quad (2)$$

where M, H stand for measurement vector and observation matrix respectively. The approximate equation can also be shown as follows:

$$Z_t = \left(1 - \Delta t y_{G,t-1}^S\right) Z_{t-1} + \Delta t(-Z_{t-1}^S) n_G \quad (3)$$

where y_G, n_G stand for measurement data of gyroscope and measurement noise of gyroscope. Exponent S means oblique symmetric matrix of correlation matrix. Other researchers have analyzed the initial setting of n_G and S, which can be applied in the mobile phone pose detection [10, 13-15].

TABLE II. PARAMETER OF MOBILE PHONE

Category	Parameter
	Value
$y_{G,t-1}$	Sampling value of t-1
n_G	0.01 rad/s
Δt	0.02s

The basic parameter is shown in table II. According to the measurement data of gyroscope and accelerometer, we derive the estimated value shown as follows:

$$Z_t^- = \Delta t(-Z_{t-1}^{+S}) n_G \quad (4)$$

$$\Phi_{t-1} = 1 - \Delta t y_{G,t-1}^S \quad (5)$$

$$Z_t^+ = Z_t^- + K_t(M_t - HZ_t^-) \quad (6)$$

where symbol "+" means results after rectified, symbol "-" means results before rectified.

In the manipulating of VR based on HMD, however, the image resolution ratio is inevitably declined. On the one hand, the single stereo image only occupies less than half of the phone screen, which suggests that the whole quality of the screen is not perfectly performed. On the other hand, to build the immerse perception for the manipulator, the stereo images are directly amplified. In this case, the quality of the image is imperatively destroyed since the pixel dots are apparently viewed. It seems like the mist is between the image and the eye. To solve the problems and get the quality of the image improved, active shutter technology is applied in the platform [16].

In the process of enhancing the quality, the images are shown on the screen separately to be offered to the left and the right eye respectively. In the meantime, the switch of the active shutter 3D glasses is controlled by the signal derived from the screen device, which guarantees the cooperation between the screen and the glasses. By improving the refresh rate, two eyes enjoy different images at the speed of 120 frames. This process is shown in Fig. 6 [17]. In this case, the initial image is totally reserved and shown for the manipulator, which suggests that the performance of the immerse perception is perfectly enhanced.

Active shutter technology has been widely applied in 3D television area. At the same time, active shutter 3D glasses

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are universal and economic. The screen for the active shutter is required for least resolution ratio of 1080 P and least refresh rate of 120 frames. Nowadays, a multitude of smart phones are qualified for meeting the requirements like the 3K resolution ratio and 120 Hz screen, which suggests that it is possible to construct the phone platform to achieve active shutter application for enhancing the performance of 3D visualization. The structure of the active shutter phone platform is shown in Fig. 7. Frame signal is conveyed from the smart phone to the active shutter glasses by wire to indicate the left and the right images. Equipped smart phone is excellent enough to meet the requirements of resolution ratio and refresh rate. In this circumstance, 3K images are directly enjoyed by the manipulator without the loss of the quality.

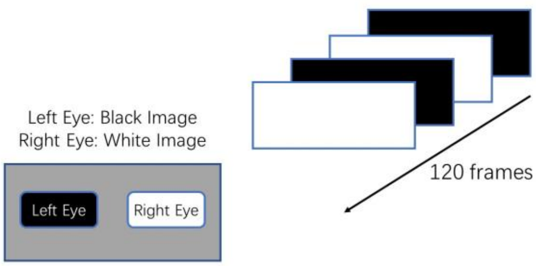

Figure 6. Process of Active Shutter

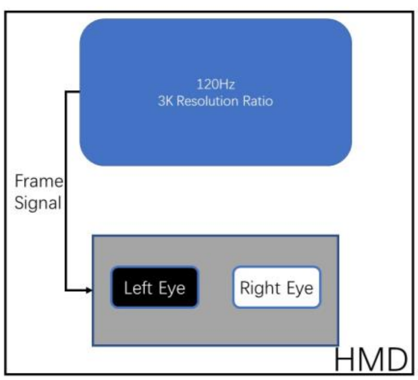

Figure 7. Structure of Enhanced HMD.

B. Control Mode

The control mode is designed to accurately manipulate the pose and location of the ROV. The surface of Control Mode is shown in Fig. 8. The virtual rockers can be implemented to control the speed and the depth of the ROV. Four buttons are designed to switch the engine, track, jacklight, gravity sensor function. Furthermore, five dials are designed to indicate real-time motor speed and depth. Moreover, the compass and the pose indicator are designed to show the real-time pose of the ROV. The illustration of the surface is shown in Fig. 9. Besides, the background of the surface shows the real-time web camera video, which is shown in Fig. 10. The surface of the control mode meets the requirements of specific control [18].

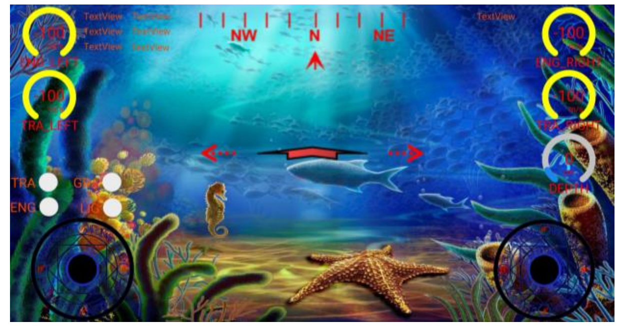

Figure 8. The surface of Control Mode.

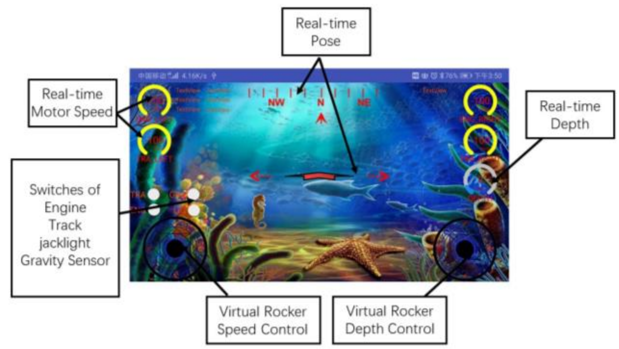

Figure 9. The illustration of the surface

Figure 10. The real-time video shown in the surface

III. Results And Discussion

The proposed ROV Monitoring and Control Platform based on mobile phone is tested on our self-designed ROV. The data is detected and analyzed.

Firstly, based on Kalman filter, the data of yaw, pitch and roll angle is collected in the monitoring mode. In the process of moving the mobile phone, the real-time value is roughly equal with the estimated value, which suggests that there is no drift in detecting the pose of the mobile phone. The results suggest that the distortion in the movement of the ROV is totally ruled out. The accuracy of controlling the ROV is apparently improved.

Secondly, the delay of the video and control signals in monitoring mode is less than 1 second, which suggests that it is sufficient to use in real-time exploration. The delay of the video and control signals in control mode is less than 0.5 second to satisfy the accurate control.

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Besides, in our real-time experiment in the swimming pool, the platform can smoothly and constantly work for over 20 minutes, and the success rate of linking to the ROV for the first time is over 80 percent.

The accurate data of the result is shown in the table III, which suggests that the mobile platform can meet all the basic requirements of a ROV monitoring and control platform. The ROV and mobile platform were exhibited in *The 8th China Marine Vehicle Design and Construction Contest & The International Marine Vehicle Design and Construction Invitational Contest 2019* and received second level award.

TABLE III. DATA OF RESULTS

Mode	Results			
	Video Delay (s)	***Control Delay (s)***	***One Success Rate of Connection (%)***	***Maximum Working Time (min)***
Monitoring Mode	0.8	0.9	81	21
Control Mode	0.5	0.4	92	25

IV. CONCLUSION

In this paper, we propose a Balancing Enhanced and Active Shutter Image Improved ROV Monitoring and Control Platform based on mobile phone. Conventional ROV platform is lack of 3D visualization and portability. Our proposed novel phone platform is designed to overcome the problems. Mobile phone is portable enough to carry on easily. Stereo images in the phone are constructed to the 3D visualization with the assistance of HMD. Besides, virtual rockers are created to control the accurate depth and location of the ROV. Furthermore, we propose the Kalman filter to enhance the stability of pose collect and control in monitoring mode. Moreover, the quality of the 3D visualization is apparently improved by active shutter technology. The mobile platform of ROV perfectly solves the problems.

Results reveal that the practicability is valid and reliable in real-time ROV experiment. There is still some room for improvement of maximum working time. Therefore, the next step of our platform will aim at the improvement of smoothly working hours.

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