Web page remote control for Raspberry Pi mobile robot using ORB-SLAM

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Abstract. This paper presents a novel remote control framework for mobile robot, consisting of two core hardware systems: Raspberry Pi as the information processing computer , STM32 single chip microcomputer as the logic control computer and other auxiliary systems. Based on the mobile robot and RealSense D455 camera, Oriented FAST and Rotated BRIEF Simultaneous Localization and Mapping (ORB-SLAM3) algorithm is utilized to establish sparse map and location. The sparse map and more accurate synchronous positioning of the mobile robot environment are established. At the same time, in the actual SLAM environment map construction, we use the Web page as the interactive interface for the mobile robot's remote control. Through the Web page, we can achieve the slow change of the position and posture of the mobile robot. Then the RealSense D455 camera can accurately obtain the surrounding environment information. Web pages are used to build human-computer interaction interface and establish remote slam map construction control, which greatly reduces the cost of system communication. And the interface is simple and easy to maintain. Finally, experiments show that the system can run stably, and the final effect is also good.

Keywords: Web page, ORB-SLAM, Raspberry Pi

1. INTRODUCTION

In recent years, with the continuous expansion of robot application fields, intelligent robots serve human beings in more and more fields. For some workplaces with complex environment, bad conditions or certain dangers, it is usually necessary to operate the robot through remote control to complete the corresponding tasks. In addition, the autonomy of the robot is very significant. In the research of robot autonomy, autonomous navigation is one of the major research directions, and SLAM has always been an important research topic in the field of autonomous navigation [1]. The Visual SLAM is used to build the map of the robot for the unknown environment with the help of the camera. Compared with laser SLAM, visual sensor or camera has the advantages of rich visual information and low hardware cost. It is the research hotspot of SLAM recently [2]. At the same time, SLAM is also the basis for robot to achieve autonomous navigation.

In the complex environment, the autonomous navigation of the robot is of great help for the practical application of the robot [3]. In addition, in the complex environment, it is also necessary to control the specific action command of the robot, observe the environment and view the map of the unknown surroundings. The combination of Web technology and robot remote control technology promotes the rapid development of robot remote control technology. Compared with traditional remote car control technology [16-17], there are numerous advantages of Web page based control, such as its cost is low and its interactive interface is complete but concise. And it has good portability and can run on all kinds of clients; The interfaces are simple and easy to be accepted by users, so it has important research significance and broad application prospects [4].

In the research of this paper, we combine Web page technology [4], SLAM technology [7], Internet communication technology and robot control technology and apply them to the Raspberry Pi car [8-9]. With the help of RealSense D455 camera, we bring about the information collection of unknown environment, and use Raspberry Pi as the information processing computer for camera information processing and map construction, Transfer the obtained map to the Web page for display for users to view [12]. In addition, Web pages and human-computer interaction interfaces are designed through Web technology. With the help of buttons or other input methods in the Web pages, the user's control instructions are packaged and sent to Raspberry Pi through communication protocol. Then, Raspberry Pi processes the control instructions on the Web side through the data line, generates specific control instructions and transmits them to the STM32 processor[10], and controls the specific motion of the robot car with the help of STM32[11].

The main contribution of this paper is designing and implementing the Web page control of intelligent car based on visual SLAM under the Raspberry Pi platform. In this system, first we use Web pages to control the mobile robot to move slowly, then the camera capture the surrounding environment information, and build a sparse map to locate the mobile robot by the Raspberry Pi. At the same time, the designed motion control method is integrated into STM32 single chip microcomputer to reduce the workload of Raspberry Pi; Using the Web

page as the client, the data communication between the Web page and the Raspberry Pi is achieved by using HTTP protocol. The Raspberry Pi is taken as the core of the intelligent car control system to coordinate the communication between the Web page terminal and the designed motion control terminal of the car. At the same time, based on Web pages, it can be easily compatible with browsers on various platforms, and control the system on PC, Android and IOS.
The innovation of this paper lies in:

(1) Adopt Web page as GUI interface;

(2) Use the HTTP protocol and TCP protocol implemented by wireless LAN to communicate;

(3) The control method of Web page is used to complete the movement of mobile robot and the construction of map;

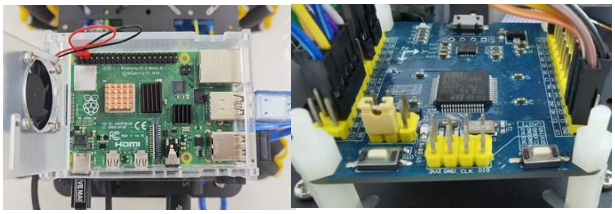
(4) Implement orb-slam in Raspberry Pi;

The SLAM intelligent car control system divides the design of Web page end, slam end and STM32 motion control end, and integrates these modules with the help of raspberry Pi. Therefore, in the follow-up research, the system can easily increase and improve the functions.

2. INTELLIGENT CAR HARDWARE STRUCTURE

2.1. Controller Module

The mobile robot built in this paper takes the Raspberry Pi 4B main control board as its main controller and acts as the information processing computer. Using the computing power of the CPU owned by Raspberry Pi, it achieves the visual SLAM algorithm and the communication function of the intermediate server. It is mainly responsible for the implementation and operation of the experimental algorithm, the communication with the Web server and the communication with the logic control computer. The physical drawing is shown in Figure 1 (a). The system takes STM32F103RC as the logic control computer used by the mobile robot platform, which is mainly responsible for the sensor data acquisition task, chassis control task and communication task of the mobile car. The physical drawing is shown in Figure 1 (b) [13].



(a) Raspberry Pi 4B (b) STM32F103RC
Fig. 1 Mobile robot controller module

2.2. Power module

The mobile robot platform uses GB37520 DC reduction motor and TB6612FNG motor to drive the motor. The physical object is shown in Figure 2. The aircraft model battery is used to supply power to the voltage stabilizing module and TB6612FNG motor drive board at 12V voltage. The Raspberry Pi and the camera are powered by a power bank with a voltage of 5V.
The mobile robot car uses the scheme of independent power supply between the information processing and logic control layers. The information processing computer and camera use the power bank as the power supply; Lower motor, logic control computer and various modules use aircraft model battery as power supply. The independent power supply makes the upper and lower layers work separately without communication, simplifies the power supply design and improves the stability of the power supply.
The mobile robot uses the Mecanum wheel chassis, and the wheels are Mecanum wheels, which can move in all directions and improve the mobile flexibility of the car. The physical drawing is shown in Figure 3.

(a) GB37520 DC reduction motor (b) TB6612FNG motor
Fig. 2 Mobile robot power module

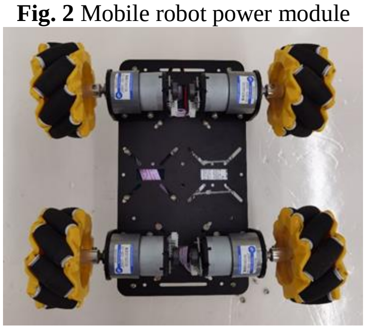


Fig. 3 Mecanum wheel chassis

Mecanum wheel can achieve the forward, lateral, oblique, rotation and combination of the trolley without large angle steering [14]. It greatly reduces the space required for the car to change the moving direction, improves the flexibility of the car, and brings convenience to Web page control and program design.

2.3. Sensor Module

The smart car uses the hall encoder and connects the hall encoder to STM32, so that the motor speed, steering and other information can be obtained by reading the output of the encoder. The physical drawing is shown in Figure 4 (a).
The intelligent car control system adopts RealSense D455 camera. The module is small and easy to install on the car. There are four round holes on the front of D455 camera, as shown in the figure below, from left to right. The first and third are IR stereo camera; A second is an IR projector, and the fourth is a color camera. At the same time, the camera has powerful functions and can easily run ORB-SLAM. It brings great convenience to the implementation of the system. The physical drawing is shown in Figure 4 (b).

(a) Hall encoder (b) RealSense d455 camera

Fig. 4 Physical diagram of mobile robot sensor module

2.4. Overall appearance

The physical diagram of the mobile robot built by the system is shown in Figure 5. The information processing computer Raspberry Pi and the logic control computer STM32F103RC are used as the controller. TB6612FNG motor drive board, GB37520 DC reduction motor and Mecanum wheel are used as motion modules. Hall encoder and RealSense D455 camera are used as information acquisition module. Rechargeable treasure and aircraft model battery are used as power modules. The metal plate made of aluminum alloy is used as the trolley chassis. Based on the above hardware, the mobile robot is built.

Fig. 5 Overall physical drawing of mobile robot

The electrical connection diagram is shown in Figure 6.

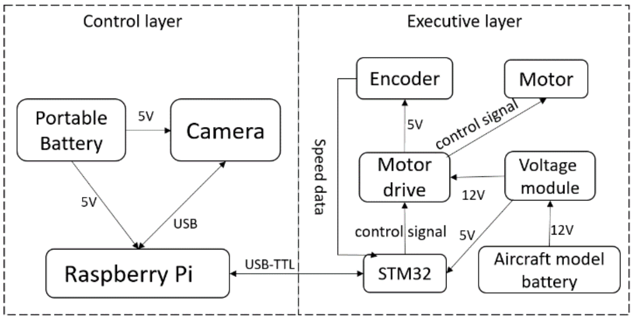


Fig. 6 electrical connection of mobile robot system

3. SYSTEM FRAMEWORK

In this section, we will introduce the system framework design of slam and Web page control based on the Raspberry mobile robot built in the previous section:

3.1. ORB-SLAM Framework

The SLAM algorithm implemented by this system is orb-slam, which is a visual slam. In this system, we implement it with the help of RealSense D455 camera. The orb-slam based on the camera still adopts the classic visual slam system framework, as shown in Figure 7, which includes four modules: visual odometer, nonlinear optimization, loop detection and mapping. This framework has been very mature and perfect, so this system still adopts this visual slam framework.

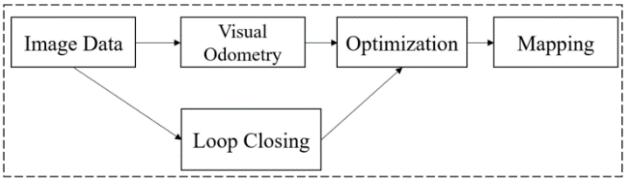


Fig.7 Visual SLAM framework

The slam designed in this system is based on Raspberry Pi control board, and achieve image processing, feature frame acquisition, map construction and car positioning with the help of Raspberry Pi.

3.2. Web Page Control Framework

A large part of the system design is Web page control for mobile robot. Therefore, in addition to the implementation of SLAM algorithm, the implementation of Web page control, communication with mobile robot and the transmission of control instructions are also very important. The system framework of Web page control is shown in Figure 8.

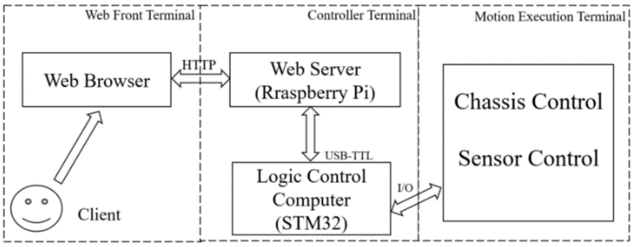


Fig.8 Web page control framework

The Web page control framework is mainly divided into three layers: Web browser layer (Web Terminal), Server layer (Controller Terminal) and Motion bottom layer (Execution Terminal) [15]. Each layer is independent and interrelated to jointly achieve the Web page control of mobile robot.

The Web browser layer is the Web front end, which can be used by mobile phones or computer browsers that support Java. After the user enters the corresponding Web address in the browser, the browser will send a resource request to the server. After receiving the response, the Web page will be displayed on the browser. After that, the user can control the mobile robot and view the slam results through the Web page. The controller side includes a Web server and a logic control computer. The communication between the Web server and the Web browser is achieved through HTTP in the Raspberry Pi in the Web server. Now the user obtains the camera image through the Web browser interface. The communication between the Web server and the logic control computer is carried out through USB-TTL. Finally, the logic control computer controls the motor and sensor of the mobile robot, and returns the sensor data of the mobile robot.

4. SYSTEM FUNCTION REALIZATION

4.1. ORB-SLAM Design and Implementation

The implementation of SLAM is mainly divided into two parts: Front Terminal and Back Terminal.
In the SLAM implementation of the system, the Front-end design mainly does the following work:

4.1.1. Extraction and Screening of ORB Feature Points

ORB feature can detect areas with obvious gray changes in the image. The complete ORB feature is composed of fast corners and brief descriptors. In addition, in order to avoid too many or too few local corners, the algorithm implements 30 * 30 pixel grid segmentation to extract feature points [7].
After extracting feature points, you need to filter the feature points. In order to avoid the missing matching caused by too rich or too sparse feature points, this paper uses the quadtree feature point screening method to select the feature points. Firstly, initialize the feature points in the image as one or two root nodes, and execute the following cycle: if there are more than two feature points in the node, the node will be divided into four regions *ul*, *ur*, *bl* and *br*, each region occupies the same area, classify the feature points into subordinate child nodes according to the region, and delete the parent node; If there is only one feature point in a node, the node will no longer split; If there are no feature points in the node, the node will be deleted, as shown in Figure 9. Stop splitting until the number of nodes reaches the predetermined scale, and select the ORB feature point with the maximum response from each node.

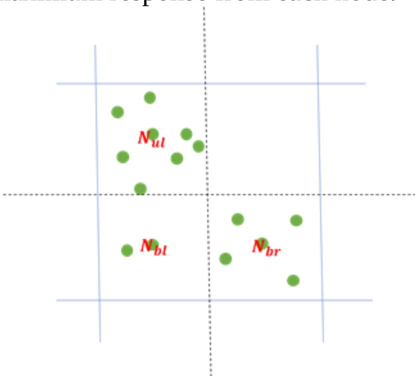


Fig. 9 Schematic diagram of quadtree filtering principle

4.1.2. ORB Feature Matching

The descriptor is combined with the word bag model in ORB-SLAM3, and the algorithm is as follows:

Table 1 Pseudo code of ORB feature matching algorithm

Input: reference frame image feature $\{KP_{ref}\}$ and current frame image feature $\{KP_{cur}\}$;
Preprocessing: According to BOW thesaurus, the lexical feature vectors VB_{ref} and VB_{cur} are calculated respectively;
For each identical word B_i in the vector:
Looking for corresponding BRIEF description subgroup $\{D_{refi}\}$ and $\{D_{curi}\}$ of KP_{ref} and KP_{cur};
Calculate the Hamming distance for each descriptor in $\{D_{ref}\}$ and $\{D_{cur}\}$ and record the minimum two distances H_{min} and H_{second};
If $H_{min} < \lambda_1 H_{second}$:
Two feature points are considered as matching points and recorded to $V_{matched}$;
Calculate the angle difference between two matching feature points Δθ, and count it into the angle difference histogram;
For the three largest regions n_1, n_2 and n_3 in the angle difference histogram:
Release the remaining areas;
If $n_2 > \lambda_2 n_3$ release n_3 groups, if $n_1 > \lambda_2 n_2$ release n_2 groups;
End;

The effect of this matching algorithm is shown in Figure 10[18]:

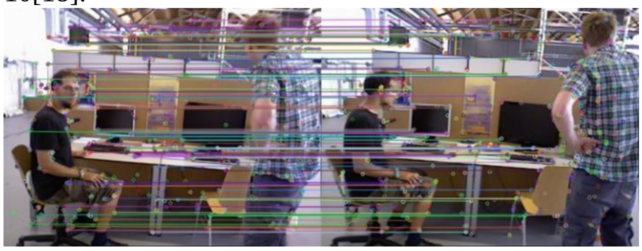


Fig. 10 Matching effect [18]

4.2. Web Application Design

Web application design is divided into two parts: Web page design and Web server design.
The Web page is based on MVC design mode. The Web page adopts the front-end design method and the file type is HTML. In this design, VS7.0 is used to design three Web pages: login. HTML, remote control interface control. HTML and error page wrong. HTML. JavaScript is used to establish the click recognition of Web buttons and the transmission of corresponding instructions.
Login Interface Design: the background uses the front-end technology to set the background picture in the body in CSS. The HTML form includes two text boxes of user name and password of type "text", submit button and cancel button. According to the action value of the form, the login page uses the post request in HTTP to send the information entered by the user to the Web server for processing, so as to achieve the user registration and login functions.
Control Page Design: Based on the Mecanum wheel of the smart car, multiple buttons are set in the control page, including forward, backward, turn left, turn right, left translation, right translation, acceleration, deceleration, P1, P2, P3, P4, etc. The above buttons can directly transmit control instructions to the Web server through the Web page. With the help of HTTP protocol, TCP protocol, socket, etc., the Raspberry Pi receives specific control data. As a result, the Raspberry Pi is processed and transmitted to the car motion control. In addition, in the control Web page, you can also view the sparse point diagram generated by orb-slam implemented by RealSense D455 to meet the positioning problem of the car in the control process.

The Web server is implemented in Python algorithm language, and the bottle Library in Python is used to implement the Web server. With the help of get, post and other functions in the bottle library, the communication between Web pages and Web servers is established.

The Web server is built in the Raspberry Pi. With the help of LAN, the connection between the Web server and the Web page (Web browser) is established. This paper adopts the C/S structure. After receiving the data from the Web page, the Web server defines the control intention transmitted by the Web page through data processing and comparison, and then responds to control the car movement. In addition, the Web server will return the processed slam image to the Web page for display [10].

4.3. Motion Control Design of Mobile Robot

As mentioned above, after the instructions are transmitted to the Web server, the Web server (Raspberry Pi) completes the subsequent control tasks.

In this Raspberry Pi car system, Raspberry Pi is the information processing computer and STM32 single chip microcomputer is the logic control computer. Therefore, Raspberry Pi is used to implement Web server and SLAM algorithm, while the underlying control is handed over to the logic control computer.

The logic control computer has three main tasks: sensor data acquisition, chassis control and communication with the information processing computer. In addition, there are some auxiliary tasks, such as LED control. This section only describes the main tasks. The programming language used in the software design of the logic control computer is C language, and the operating system used for task scheduling management is FreeRTOS.

The sensor task of the logic control computer first needs to orthogonally decode the pulse output of the hall encoder to analyze the speed and steering information of the motor.

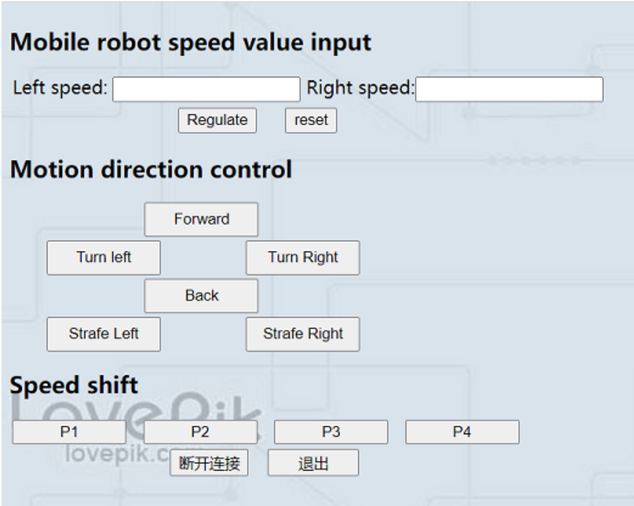
The task of chassis control of logic control computer is to control the speed of four motors, so as to make the chassis move at the target speed. PID controller is used in this system, which has strong robustness. It is widely used in industrial process control.

The communication task of the logic control computer is to send the chassis status data to the information processing computer and receive the motor target speed value sent by the information processing computer. In order to establish a more reliable two-way communication, this paper uses the format of data frame for data transmission. After the information processing computer and the logic control computer have defined the functions of encapsulating and analyzing the data frame, they communicate with the USB-TTL module through the serial port.

5. EXPERIMENTAL DEMONSTRATION

Open the browser, enter the login URL and join the login page. When the new user is registered and successfully logged in, the system will enter the control page, as shown in Figure 11.

(a)Login page



(b)Control page

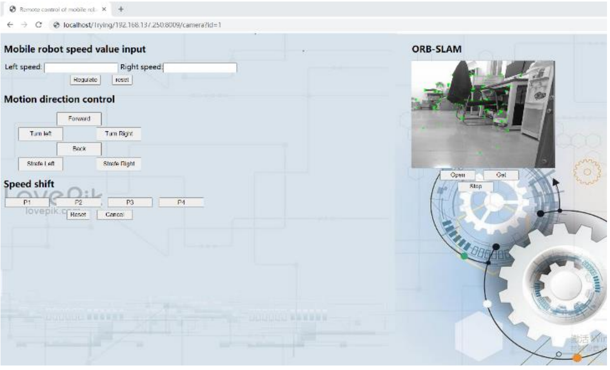
Fig.11 Web page diagram

As shown in the figure, the control page contains four parts.

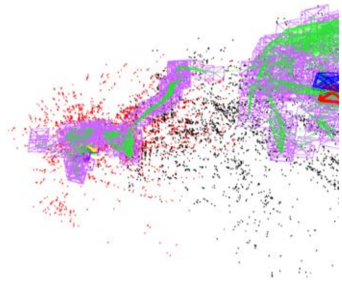
The first is the rotational speed input control module. The second is the button control mobile robot motion module, which includes forward button, back button, left turn button, right turn button, left translation button and right translation button. In the Web page, when we press the corresponding button, we will send the corresponding control command to the Web server. After receiving the data, Raspberry Pi will analyze and compare the data to determine the control intention, establish a connection to the logic control computer, transmit the control command, and finally logic control computer will actually control the motor.

The third part is to adjust the speed of the trolley, which are 'P1', 'P2', 'P3' and 'P4', respectively. The speed increases and can be controlled together with the second part.

The fourth part is ORB-SLAM. When the 'Open' button is pressed, the camera turns on and Raspberry Pi starts to run the orb-slam algorithm. At this time, the camera will transfer the captured image information to Raspberry Pi for slam processing, and the image will also be returned and displayed on the Web page for the operator to view the environment of the car. Then, the operator will slowly control the mobile robot to move, change the pose of the robot, and slowly build the map by controlling each button and speed adjustment in the Web page until the surrounding environment is roughly obtained. When the operator presses the 'Get' button, the Raspberry Pi will display the sparse feature point map established by the camera through orb-slam on the Web page. As shown in Figure 12(a). The sparse map established at the same time is shown in Figure 12(b). Through the sparse map, more accurate positioning of mobile robot can be established.



(a) Display of sports experiment results



(b) Map construction result: sparse map

Fig.12 Actual operation results

6. CONCLUSION

This paper builds the Raspberry Pi intelligent car system, achieves Web page control under the Raspberry Pi platform, and completes slam through Web page control assisted camera.

In this paper, a Raspberry Pi intelligent mobile car is built independently, and their working process, connection relationship and their role in the mobile robot platform are analyzed.

The Web page control system adopts MVC architecture to complete the design of Web application, uses Web front-end to develop user interface, and uses Python's bottle library to build Web server. The operator can send requests and control instructions through the Web page, which are processed by the Web server and establish a communication connection with the logic control computer. Finally, the logic control computer controls the bottom motor of the mobile robot to establish the movement of the robot.

At the same time, combined with the action control of Web pages and the RealSense D455 camera to obtain the image information of the surrounding environment, and use the Raspberry Pi CPU to process the algorithm to obtain the sparse map, and finally locate the position of the mobile robot.

Compared with other mobile robot control methods, Web pages are used for control, the pages are more concise, and the specific algorithm is handed over to Raspberry Pi to improve the speed of data transmission. Compared with the Bluetooth module, the remote control achieved by LAN makes the control more stable.

The experimental results show that the communication between the components of the system is stable and the control is accurate. The platform has the characteristics of scalability and easy operation. It is of great significance for robot remote control and positioning in complex environment.

REFERENCES:

[1] R. Mur-Artal, J. M. M. Montiel, and J. D. Tardós, “ORB-SLAM: A versatile and accurate monocular slam system,” IEEE Transactions on Robotics, Vol. 31, No. 5, pp. 1147–1163, 2015.

[2] R. Mur-Artal and J. D. Tardós, “ORB-SLAM2: An open-source slamsystem for monocular, stereo, and rgb-d cameras,” IEEE Transactions on Robotics, Vol. 33, No. 5, pp. 1255–1262, 2017.

[3] Krinkin, K.E. Stotskaya, and Y. Stotskiy, “Design and implementation Raspberry Pi-based omni-wheel mobile robot,” Artificial Intelligence & Natural Language & Information Extraction, Social Media & Web Search Fruct Conference IEEE, pp. 39–45, 2015.

[4] Hideki Hirano, Daisuke Yoshizawa, and Masami Iwatsuki, “A Remote Experiment System on Robot Vehicle Control for Engineering Educations Based on World Wide Web,” 35th ASEE/IEEE Frontiers in Education Conference, pp. 24–29, 2005.

[5] Z. Lin, J. Luo, and C. Yang, “A teleoperated shared control approach with haptic feedback for mobile assistive robot,” in 2019 25th International Conference on Automation and Computing (ICAC), pp. 1–6, 2019.

[6] Zaini, N. A, “Remote monitoring system based on a Wi-Fi controlled car using Raspberry Pi,” IEEE Conference on Systems IEEE, 2017.

[7] Mur-Artal, Raul , J. M. M. Montiel , and J. D. Tardos, “ORB-SLAM: A Versatile and Accurate Monocular SLAM System,” IEEE Transactions on Robotics, pp. 1147–1163, 2015.

[8] K. Dumbre, S. Ganeshkar, and A. Dhekne, “Robotic Vehicle Control using Internet via Webpage and Keyboard”, International Journal of Computer Applications (0975– 8887), Vol. 114, No.17, March 2015.

[9] Hu, Z , J. Kong , and H. Wei, “Design of Mobile Monitoring Car Based on Raspberry Pi.” Science Mosaic, 2017.

[10] Rui, Z. "Control system design for two-wheel self-balanced robot based on the stepper motor." IEEE International Conference on Service Operations & Logistics IEEE, 2013.

[11] Huiying Liu, BaoShan Fan, Study of Control System of Multiple Step Motors Based on STM32, Measurement and Control Technology, Vol. 29, No. 6, pp. 54–57, 2010.

[12] Perlman, Stephen G, “System and Method for Multi-Stream Video Compression,” 2010.

[13] C. Pornpanomchai and P. Sukklay, “Operating Radio-Controlled Cars by a Computer,” IACSIT International Journal of Engineering and Technology, Vol. 3, No. 3, June 2011.

[14] XX Wu, XL Zhang, HD Zhou, and WS Chou, “Modeling and Simulation of Omni-Directional Mobile Robot with Mecanum Wheel,” Applied Mechanics and Materials, pp. 417–423, 2014.

[15] Hirukawa H and Hara I, “Webtop robotics,” IEEE Robotics and Automation magazine. Vol. 19, No. 6, pp. 40–45, 2000.

[16] Yang, T, T. Matsuno, and S. Ma, “Development of remote robot control system for snake-like robot based on SSH protocol and iOS system,” 2016 IEEE International Conference on Robotics and Biomimetics (ROBIO) IEEE, 2017.

[17] Kelly, Alonzo, and Chan, “Real-time photorealistic virtualized reality interface for remote mobile robot control,” International Journal of Robotics Research, 2011.

[18] Xu, H. , C. Yang , and Z. Li, “OD-SLAM: Real-Time Localization and Mapping in Dynamic Environment through Multi-Sensor Fusion,” 2020 5th International Conference on Advanced Robotics and Mechatronics (ICARM), 2020.