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Mobile Robot Capable of Crossing Floors for Library Management

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***Abstract* - In order to reduce the labor and material of library management and contribute to the development of unmanned library, an intelligent mobile robot for library management is proposed. The robot consists of a mobile platform, a three-DOF rise-and-fall robotic arm and a multi-source image recognition information fusion system. Besides recognizing data and position of the book, the robot is also able to conduct book grasp and shelving in order task. To adapt to the existing library environment and enlarge its move area, an efficient autonomous elevator button recognition system based on neural networks is designed, which enables the mobile robot span floors by elevator. Combined with visual recognition technology, the mobile robot has functions of autonomous navigation and obstacle avoidance. There is also a data monitoring center and graphical user interface corresponding to the mobile robot, which is developed to simplify the operation instructions. The effectiveness of the proposed research is examined by simulation and experiments. The innovation of the robot is that it can complete shelving book task on the premise of adapting present library to the most extent.**

Index Terms - library management, mobile robot, autonomous navigation, unmanned library

I. Introduction

With the rapid development of library, book arrangement work has become harder. At present, most libraries in the world still rely on librarians to organize books, which costs a lot of labor and material. Applying intelligent robots to daily management and service of library has become an important research topic [1]. However, the existing library robots have the weakness of single function and they can't replace human work completely.

In China, some libraries have made active exploration and practice in developing intelligent consultation robots, mainly based on open-source chatting robot platform. There are four main ways of development:① Intelligent consulting system based on ALICE open source system ② Intelligent IM robot based on BotPlatform open source platform ③ Intelligent IM robot based on AIMBOT open source platform ④ Mobile application of chat robot based on wechat and mobile APP.

Abroad, a few colleges have applied library robot successfully, such as Humboldt University, University of Utah, Waseda University and etc. Those robots have different functions such as intelligent consultation, book transport, book inventory and remote reading [2]. An automated shelf scanning robot designed by A*STAR can scan library shelves by reading RFID tags that save book information [3]-[5]. The robot has a robotic arm that can make RFID antenna scan books in a proper distance. When the robot move between bookshelves, it can generate a book position report. A bookshelf scanning robot [6] developed by I2R equipped with two-DOF robotic arm also reading RFID tags to obtain book's position. The robot can transmit book information in the process of reading RFID tags. However, none of them can take and shelve books [7], [8]. For these robots can't move between floors, their move area is limited in one reading room. Therefore, these robots can reduce work burden of librarian to some degree but they can't replace the librarian completely. This paper proposes an original intelligent robot that contributes to unmanned library management.

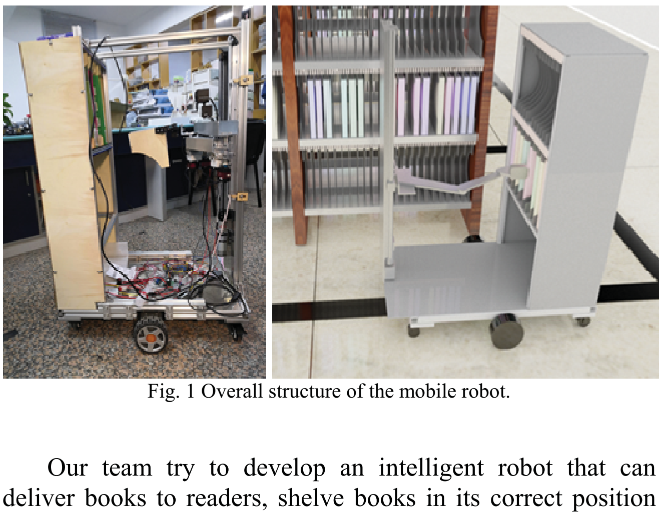

Fig. 1 Overall structure of the mobile robot.

Our team try to develop an intelligent robot that can deliver books to readers, shelve books in its correct position and can interact with readers without labor participation. The overall structure of the mobile robot is shown in Fig.1.

As shown in the Fig.1, the mobile robot is consist of a wheeled mobile platform, a screw, a 3-DOF robotic arm, an electric claw that can grasp book and a small shelf for depositing books temporarily [9].

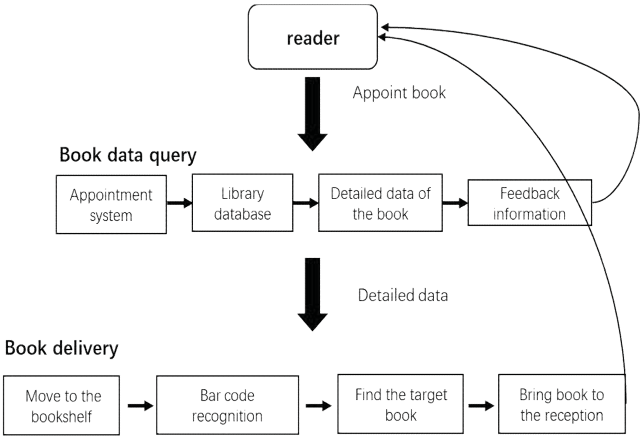

Fig. 2 Basic workflow of the robot.

The basic workflow of the robot is shown in Fig.2. In our research, each book has a bar code attached to its spine, which saves the book data. Through recognizing the bar code, the mobile robot can obtain the detailed information of the book. When reader appoint a book in the system, library database saving data of all books will send book data to the mobile robot. Relying on wheeled mobile platform and autonomous navigation system, the mobile robot can move to the specific bookshelf. And the robot can take the elevator by itself to other floors in library. Through image recognition, the robot can obtain the position of target book. And after kinematics calculation, the robotic arm can take the book accurately. Finally, the mobile robot will bring the book to the reception desk and the reader will be informed. In the robot's daily work, it will move following the specific route and check every book on the bookshelves. If any book is not in position, the mobile robot will bring it to the right place. In this way, the mobile robot can replace human librarian completely to arrange books on the bookshelf.

II. MOBILE PLATFORM WITH AUTONOMOUS NAVIGATION

We used the slam-gmapping package in ROS (Robot Operating System) to build a two-dimensional raster map [10], where the posture data and lidar data play a crucial role. The posture data of the robot is calculated by integrating the moving speed and the yaw angular velocity provided by the odometer. Based on the lidar data, the coordinates of the obstacle can be obtained. After using the straight line generate algorithm of the Bresenham to mark the grid where the obstacle is located and defining the probability distribution of the grid state by multi-beam laser scanning, we can build a two-dimensional grid map of library. We repeatedly adjusted the threshold in repeating experiments and got a two-dimensional grid map of library that is shown in Fig. 3.

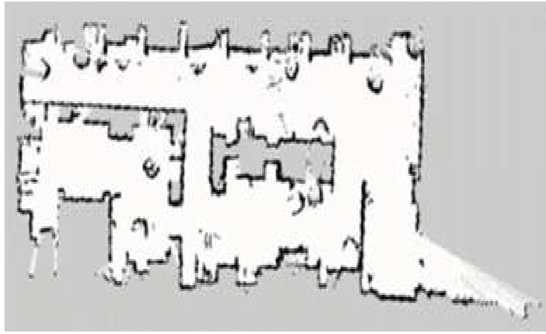
Fig. 3 Two-dimensional grid map of library.

The obstacle avoidance function is implemented by using the move-base package in ROS [11]. Combined with the above map information, current posture of the robot and target location, the robot navigation is realized through path planning of global and real time.

III. IMAGE PROCESSING

A. Autonomous elevator button recognition based on neural networks

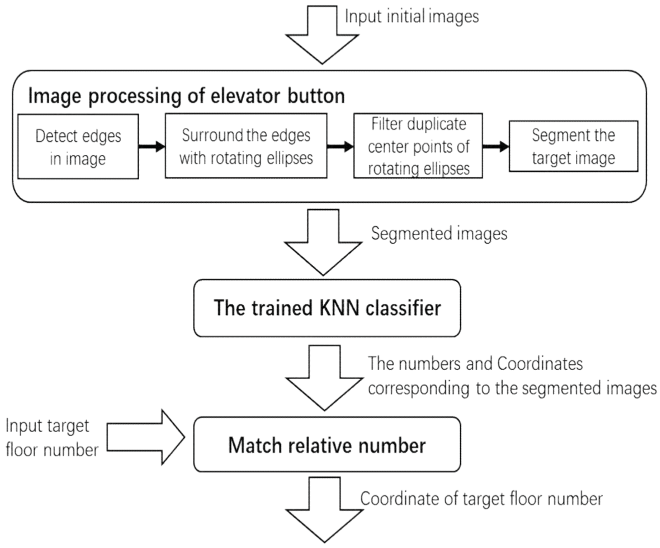

Fig. 4 The flow chart of elevator button detection

Autonomously taking the elevator is an important function of the robot, which is vital to expand the working range of the robot. The autonomously taking the elevator requires the robot to press the elevator button, and the most key point of this process is the elevator button recognition [12], [13].

Our goal is to be able to detect elevator button. The flow chart of elevator button detection is shown in Fig.4. We use the Canny algorithm to detect the edge of the image, surround the edge with a rotating ellipse, and filter the repeating center point. We can get the segmented images with color image conversion of the image of gray scale. Segmented images are as input factor of k-nearest neighbor classifier [14] for recognition. Sample images is adopted to describe texture feature for model training and sample classification. Determining the specific number on the elevator button based on our model. Thus, we can obtain the elevator button coordinate information corresponding to the target floor.

B. Book detection based on multi-source information fusion

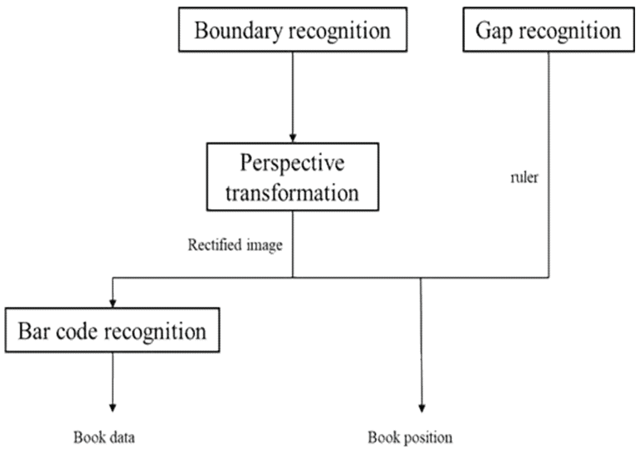

Fig. 5 Workflow of the book recognition .

As shown in Fig.5. Through the rotatable camera, the mobile robot can get the image of the books. After recognizing the effective area and gap recognition, the position of the book can be obtained. Finally, through extracting the partial image and bar code recognition, the book data can be obtained.

Fig. 6 Boundary recognition.

First, we complete color reduction (white balance) based on OpenCV (open source computer vision library). After transforming the picture taken by camera into black-and-white diagram, the boundary of bookshelf can be found through contour search function in OpenCV [15]. The result is shown in Fig.6. In the actual situation, books may lean on the bookshelf, which has a detrimental impact on visual recognition. We solved this problem through perspective transformation [16]. The result is shown in Fig.7.

To grasp the specific book accurately, image processing result should provide position for micro controller to control robotic arm. By getting pixel number of groove we can determine the distance of the bookshelf from the camera [17]. Baffles between books can be easily recognized for its low light. Fig.7 shows light and shade recognition results. Combined with pixel number of groove, book's position can be found accurately.

Fig. 7 Gap recognition and book recognition

Another task of visual recognition is reading information of books. Every book's information is saved in a bar code attached on the spine. First, we make white area of code larger by opening operators and choose the largest outline to get the position of code after transforming the picture into black-and-white image. Then sharpening the picture to get more distinguishable image and reading codes [18]. The result is shown in Fig.8.

Fig. 8 Bar code recognition.

IV. 4 Degrees of Freedom Robot Arm

A. Control scheme

After image processing, the position data will be sent to micro controller by serial port. The end of the robotic arm should move close the target book on the bookshelf, open the clap, move in a straight line in the direction that vertical to bookshelf plane and grasp the book. The most important control in this process is the straight line move. Through kinematics calculation, the relation between rotating velocity and time can be obtained. To complete the expected moving trail, we need treat time difference and calculate servo motor angle at different times. During the motion of the robotic arm, servo motors will return angle data to micro controller. After comparing with expected angle in last instruction, the micro controller will send the next instruction to servo motors. Otherwise, the last instruction will be sent again.

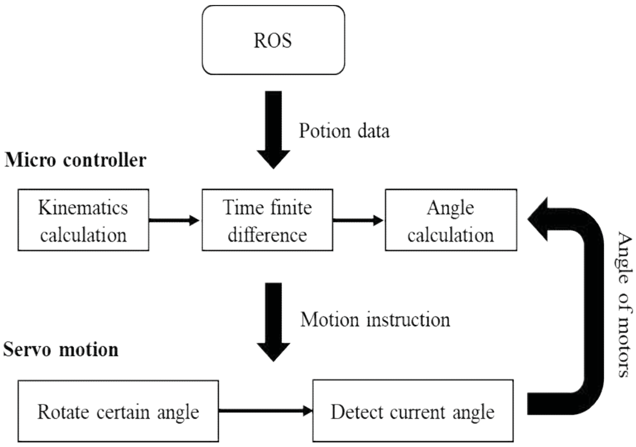

Fig. 9 Control workflow of the robotic arm.

B. Kinematics

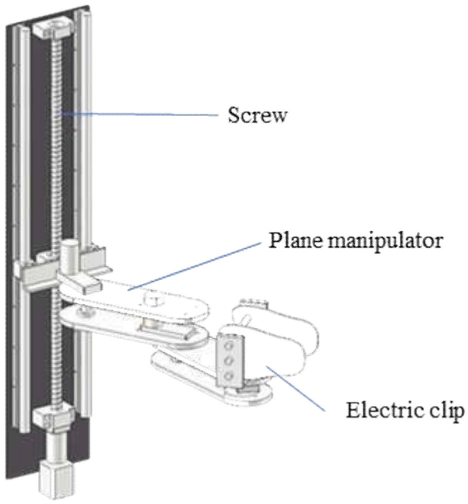

Fig. 10 Mechanical structure of robotic arm.

The four-degree of freedom robotic arm consists of a screw and a three-degree of freedom robotic arm that can move up and down along it. The overview of the robotic arm is shown in Fig.10. The leadscrew nut mechanism allow a movement in vertical direction while the 3-DOF planar manipulator can make the end of manipulator move in horizontal surface. The robotic arm is also equipped with an electric clip that can grasp books. After establishing D-H coordinate system and forward kinematic solution, transformation matrix from O3 to O0 is obtained.Through inverse kinematics analysis, three joint angles are as follows [19].

$$\begin{cases} \theta_1 = \pm a\cos\dfrac{l_1^2 - l_2^2 + p_x^2 + p_y^2}{2l_1\sqrt{p_x^2 + p_y^2}} + a\tan 2\left(\dfrac{p_y}{\sqrt{p_x^2 + p_y^2}}, \dfrac{p_x}{\sqrt{p_x^2 + p_y^2}}\right) \\ \theta_2 = a\tan 2\left(\dfrac{p_y - l_1\sin\theta_1}{l_2}, \dfrac{p_x - l_1\cos\theta_1}{l_2}\right) - \theta_1 \end{cases} \tag{1}$$

$$\theta_3 = \begin{cases} \dfrac{\pi}{2} - \theta_1 - \theta_2, & area = 1 \\ -\dfrac{\pi}{2} - \theta_1 - \theta_2, & area = 2 \\ 0 - \theta_1 - \theta_2, & area = 3 \end{cases} \tag{2}$$

where area=1 represents the bookshelf on robot`s left, area=2 represents the bookshelf on robot`s right and area=3 represents the bookshelf on the mobile platform.

To reduce the discontinuities for acceleration, angle-time curves are designed to be quintic spline [20].

$$\begin{aligned} \theta(t) &= b_5t^5 + b_4t^4 + b_3t^3 + b_2t^2 + b_1t^1 + b_0 \\ \dot{\theta}(t) &= 5b_5t^4 + 4b_4t^3 + 3b_3t^2 + 2b_2t^1 + b_1 \\ \ddot{\theta}(t) &= 20b_5t^3 + 12b_4t^2 + 6b_3t^1 + 2b_2 \end{aligned} \tag{3}$$

$$\begin{aligned} &b_0 = \theta_0;\ \ b_1 = b_2 = 0;\ \ b_3 = \frac{10(\theta_f - \theta_0)}{t_f^{\,3}}; \\ &b_4 = -\frac{15(\theta_f - \theta_0)}{t_f^{\,4}};\ \ b_5 = \frac{6(\theta_f - \theta_0)}{t_f^{\,5}} \end{aligned} \tag{4}$$

Where θ_0 is initial angle and θ_f is the end angle.

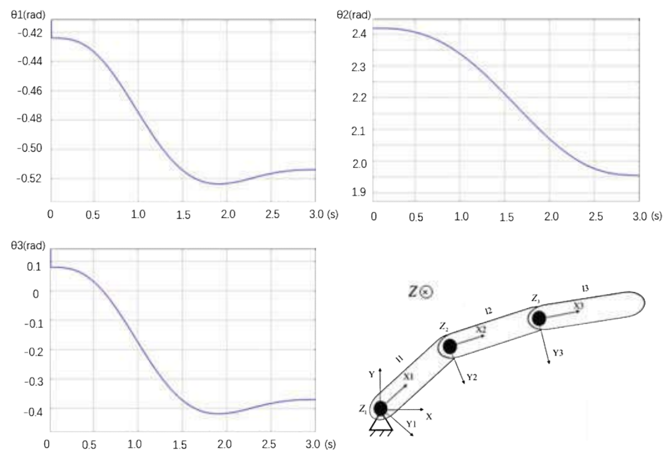

Fig. 11 Angle-time curves.

Through simulation in ADAMS, angle-time curves of straight path are shown in Fig.11. The curves show three joints' angle change in different positions of the robotic arm. From the figure, we can see that the curve is smooth which ensures that the robotic arm can move smoothly and coherently. And the curve is horizontal at the beginning and the end which means acceleration is zero at the beginning and the end. It ensures that robotic arm can start and stop moving without inertial impact.

V. Data Monitoring Center And Graphical User Interface of Library Management Robot

As shown in Fig.12, in order to ensure the robot works well, we used LabVIEW to build a monitoring system [21], [22], and used wireless network to maintain the connection with the library robot. In monitoring system, after reading, processing and saving the serial data in the back panel, the data flow will be displayed in waveform graphics in the front panel. In order to prevent data confusion caused by data loss, we designed a series of protective measures to ensure accurate data transmission.

Meanwhile, to better simplify and streamline the operations, we programmed a graphical user interface of library management robot based on Qt4 [23], [24], which includes message notification, database management, book query, authentication service and simple man-machine dialogue. Running this graphical user interface on the touchscreen of library management robot to assist users and administrators in various operation instructions, which can provide users and administrators with convenient services.

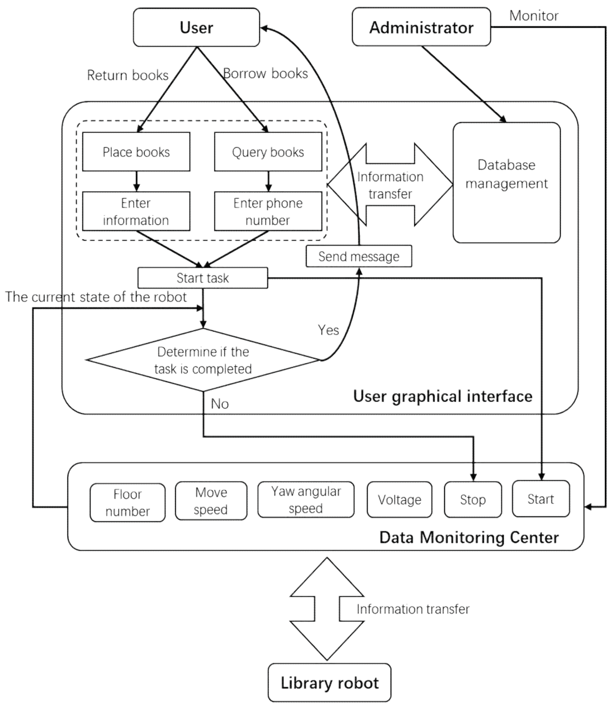

Fig. 12 The flow chart of data monitoring center and graphical user interface

VI. Experimental Results

A. Autonomous Navigation and taking elevator

As shown in Fig.13, we achieved high robust identification of the target elevator button coordinate information finally. We surrounded the edge with a rotating ellipse, filtered the repeating center point as shown in Fig.13 (b), and got the judgment results of elevator button recognition as shown in Fig.13 (c). Based on the target button coordinate information, we implemented the function of controlling the robot arm to move to the target button position and pressing the elevator button.

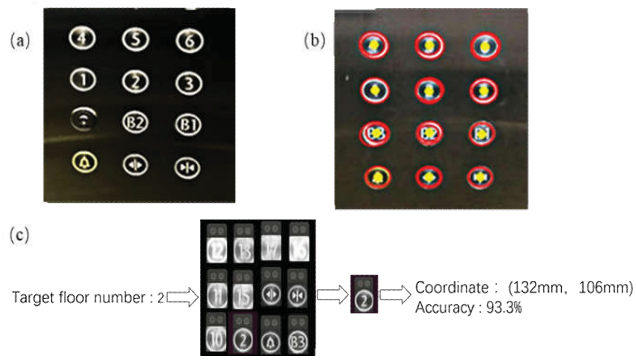

Fig. 13 Test result of elevator button recognition based on neural networks: (a) Original image of elevator button. (b) The image processing of elevator button. (c) Judgment results of the trained k-nearest neighbor classifier.

B. Book grasp and shelving

Fig. 14 The steps of shelving book

In order to verify the feasibility of the robot, we set books of varying thickness and size on robot's bookshelf. As shown in Fig.14, combined with image processing, the robotic arm can find and clip the book precisely. To ensure the accuracy of clip, we planned clamping steps of the robotic arm. When a target position is provided by image processing, the end of the robotic arm will move to the target book. Then the clip will open largely and move a small distance in a straight line to make sure that the book is in the middle of the clip. After the clip is closed, the robotic arm will move in the opposite direction and book grasp is completed. To simulate the work scene in library, the robotic arm turn to the side and shift the book to specific vacancy of another bookshelf fixed to the ground. Finally, the clip open and book shelving is completed. Book grasp and shelving can be completed in the situation that there is a spacing of 1 cm or more between each two books. The spacing requirement is easily met by setting partitions on the bookshelf. The result shows that our robot can realize the functions that unmanned library need after making small changes on bookshelf.

VII. Conclusions

A library management mobile robot considering readers' bad borrow habit was presented. The mobile robot is able to achieve autonomous navigation and obstacle avoidance tasks successfully. The mobile robot also has the functions of autonomously recognize the target book and take it from the bookshelf with four-DOF mechanical arm. An efficient autonomous elevator button recognition system based on neural networks enable the mobile robot to take the elevator by itself, which is vital to enlarging the move area of the mobile robot. During the robot is working, data monitoring center and graphical user interface provide convenient operation for users and administrators, which not only ensures high work efficiency but also simplifies the process. Simulation results and experimental results verify that the robot has advantages of high fault tolerance and good interactivity. Compared with existing book scan robot, our robot has more functions that it can complete the process of shelving books without human assistance and break through barriers between floors. Compared with auto-borrow library, our robot can realize its functions completely on the premise of retaining present library structure which means better adaptability and less cost of reforming library. Applying our robot can make it easy to realize unmanned management based on existing traditional library, which provides a new method for developing modern intelligent library.

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