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The application of navigation technology for the medical assistive devices based on Aruco recognition technology *

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Abstract— **In order to improve the convenience of operation for the medical assistive devices and reduce the use and maintenance cost, the Aruco recognition technology is applied to the navigation and positioning of visual guided electric assistive devices. Firstly, the differential control kinematic model of the electric wheelchair is analyzed. We discuss the feasibility of Aruco recognition technology in the application of medical assistive devices. The camera on wheelchair captures the Aruco marker data and transmits it to controller. The controller calculates the position and posture information of electric wheelchair, which provides reference for the next movement of electric wheelchair. Combining with the kinematic model of electric wheelchair, this method can realize the navigation and positioning of electric wheelchair. Experiments show that the vision guidance of Electric Wheelchair based on Aruco recognition is accurate, stable, low cost, and can be flexibly applied to the auxiliary equipment of medical institutions.**

I. INTRODUCTION

With the aging of the population becoming more and more serious, there are more and more disabled elderly people. Retirement and medical institutions adopt related assistive devices to make up for lack of caregiver resources. These assistive devices are mainly electric, such as electric wheelchairs, electric medical beds, etc. They all have an electric moving chassis that can be moved by the user. In the process of movement, the device needs to be artificially manipulated in part of the location. Because the user group is mainly the elderly and the motors of some assistive devices mobile chassis do not achieve closed-loop control, the elderly are difficult to achieve the precise control for the mobility of the assistive device. They are not able to simply move to the target location on their own, so they need medical staff to assist in the manipulation, which causes a waste of manpower costs.

To reduce labor costs and improve ease of operation, assistive devices moving chassis move actively to required position by guiding. At present, the main guiding methods are laser guiding, inertia guiding, vision guiding, etc. However, the cost of laser guiding is higher and the error of inertial guiding is larger. Vision guiding is done by installing a camera on the moving chassis and putting a black-and-white line on the ground to solve the problem of auto-navigation movement. This method, however, requires placing a sufficient length of guide wire on the ground and moving the chassis camera to capture the guiding wire at the starting position. It also requires the disabled elderly to have a good level of operation.

In this paper, taking the electric bed-chair (E-Bed) as an example, we try to solve the problem for autonomous navigation of assistive devices for the disabled elderly by the way of monocular camera vision navigation based on the identification of Aruco markers [1] [2] [3].

Figure 1. Two states of E-Bed. Image a is the state of wheelchair. Image b is the state of bed.

II. THE MECHANICAL STRUCTURE OF E-BED

The system of E-Bed, shown in figure 1, includes a fixed bed frame on the outside and an electric wheelchair in the middle that can be extended to the bed. At ordinary times, the electric wheelchair hides in the bed frame, forming a bed plane together with the bed frame. When the user needs to leave the bed, the wheelchair plane changes into a sitting pose. When sitting pose the E-Bed can move freely along the front of the bed body. This design avoids some problems of direct combination of bed and chair, and achieves a good balance between bed comfort and wheelchair mobility. The process of separation and combination is simple and comfortable.

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E-Bed realizes the function of bed-chair transformation through bed-chair transformation mechanical structure, which is driven by electric push rod to realize the transformation between bed and chair. The movement of leg frame and back frame is realized by the linkage mechanism. The transformation mechanical structure is shown in figure 2.

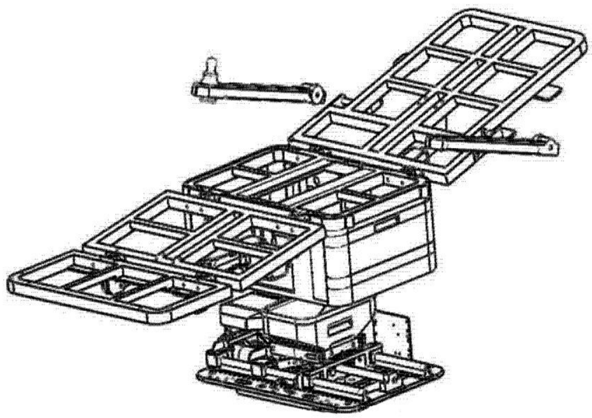

Figure 2. Bed-chair transformation mechanical structure of E-Bed.

The chassis mechanical structure of E-Bed consists of two drive wheels and universal wheels, shown in figure 3. The driving wheel is driven by two 24 V DC motors, and the direction control is realized by differential speed.

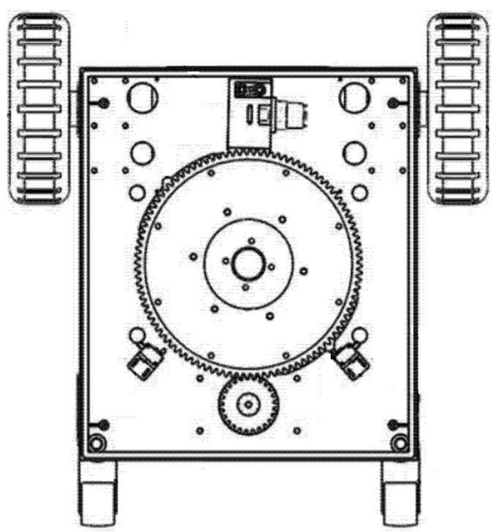

Figure 3. Chassis mechanical structure of the E-Bed

III. KINEMATIC ANALYSIS OF DIFFERENTIAL VELOCITY FOR E-BED

The E-Bed system consists of a movable body and a bed frame. And the movable body of E-Bed has two states: the bed and the electric wheelchair. The transformation of states can be performed with the control board buttons. E-Bed provides medical bed function combined with the bed frame when E-Bed body is the bed state. After the E-Bed body transformed into a wheelchair, it can be separated from the bed frame and moved freely through a joystick to provide the function of an electric wheelchair. The differential motion of the motor is controlled by incremental current to realize the movement control of the electric wheelchair. The direction of rotation and the radius of curvilinear motion can be realized by the velocity difference of two wheels (ΔV). The kinematic model of the motorized wheelchair is shown in figure 4.

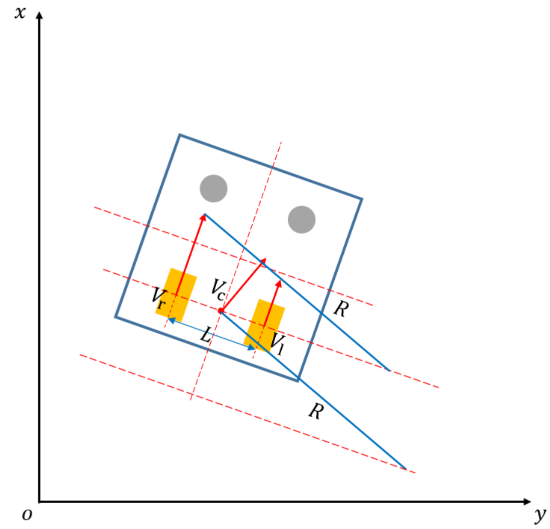

Figure 4. The kinematic analysis of E-Bed.

We assume that the chassis of the E-Bed shown in figure 4 does curve motion, and we can get the equation (1) from kinematic calculation.

$$V_c = \frac{V_l + V_r}{2} \tag{1}$$

V_c is the center point velocity that drives the axle, i.e. the center point velocity of the E-Bed body. V_l is the left drive wheel velocity. V_r is the right drive wheel velocity.

$$\omega = \frac{V_l - V_r}{L} \tag{2}$$

ω is the angular velocity of curvilinear motion. L is the distance between two driving wheels. The curvilinear motion radius R can be obtained by combining the above two formulas.

$$R = \frac{V_c}{\omega} = \frac{L(V_l + V_r)}{2(V_l - V_r)} \tag{3}$$

According to the above three equations, we can get that when $V_l = V_r$, $V_c = V_l = V_r$, and $R = \infty$, i.e. the direction of E-Bed body velocity is forward; When $V_l = -V_r$, $V_c = 0$, $R = 0$, the E-Bed rotate in situ; When $V_l \neq \pm V_r$, $V_c = \frac{V_l + V_r}{2}$, the E-Bed body moves in a curve with radius $R = \frac{L(V_l + V_r)}{2(V_l - V_r)}$. According to the above equation, we can get that the E-Bed body can move in a circle around any point and any radius on the axis of the two driving wheels, and the body can move in any direction through the differential motion of the two driving wheels [4].

IV. DESIGN OF NAVIGATION PRINCIPLE

Aruco markers belongs to a kind of two-dimensional markers, which is composed of a set of black borders on the periphery and a two-dimensional matrix containing the marker ID inside. The black border can improve the recognition efficiency of the Aruco marker in the image, and the internal two-dimensional code can mark the ID information of the code and can detect and repair errors. The size of the internal matrix also determines the capacity of the marker dictionary [5].

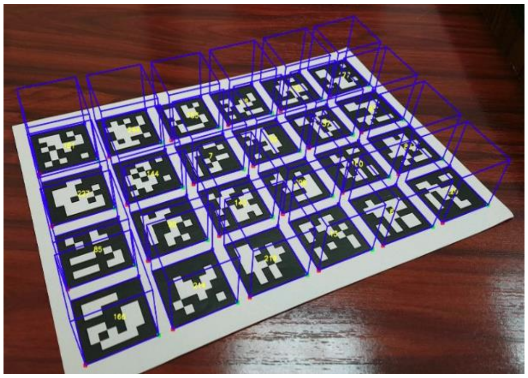

Figure 5. Aruco markers.

Maker recognition is mainly connected to the camera through raspberry pi3 platform. The camera captures the image. When the image contains a complete Aruco marker image, the detection program can detect the Aruco marker information and return the marker data. The marker results of each test include the position of four corner points in the image and the ID of the marker. The detection process mainly consists of two processes: the candidate region of marker was detected and the marker was determined by analyzing the two-dimensional code.

Based on the detection results, we can calculate the rotation vector *rvec* and the translation vector *tvec* of Aruco. Then we can calculate the rotation matrix through the transformation of Rodriguez formula and calculate the Euler Angle combined with the camera related parameters, we could calculate the specific coordinates and attitude of the body in the world coordinate system [6] [7].

Since the E-Bed moving chassis is controlled by the current-controlled motor to rotate, it is difficult for the user to manually manipulate the E-Bed when moving the E-Bed moving chassis to the specified location and placing the E-Bed body to the position of the bed frame. Additional auxiliary implementation can improve the user's ease of operation, by adding camera and Aruco markers, auxiliary to achieve the navigation and positioning of fixed locations.

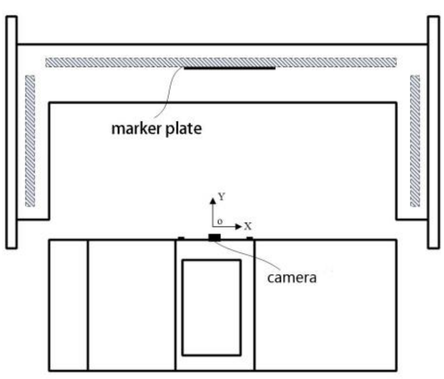

Figure 6. E-Bed calculates its position based on the Aruco marker.

V. RESEARCH ON NAVIGATION ALGORITHM

The ultimate goal of the movement of E-Bed body is to make the Aruco marker in the screen to be in the middle of the screen and realize a fixed parallel distance with E-Bed body. After the camera catches the Aruco marker, the computer can calculate the coordinates and attitude of the E-Bed body. In the process of moving, the coordinates and attitude will change with the movement. While E-Bed body reset needs to move to a specific coordinate, it also needs to achieve the embedding of the body and the bedstead, that is, the body attitude also needs to reach a fixed state.

In this paper, E-Bed body navigation is divided into two steps: coordinate navigation and posture navigation: coordinate navigation needs the E-Bed body to move to a certain coordinate point in the world coordinate system; posture navigation needs the ontology to adjust the attitude to a certain attitude, this paper only needs to modulate the body heading angle. This paper provides a method of coordinate navigation and attitude navigation in the navigation process, which can assist the user to reset or move the E-Bed body to a specific position.

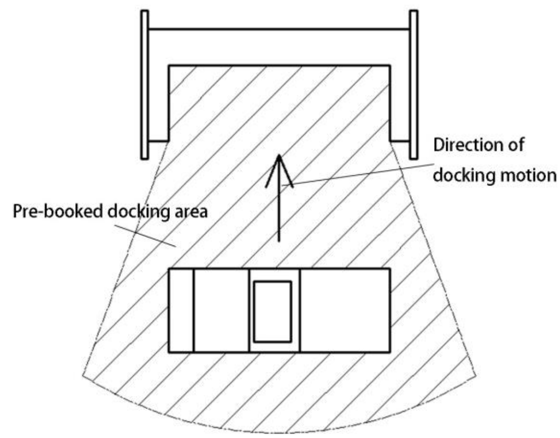

Figure 7. Pre-booked docking area and bed frame..

Firstly, the E-Bed user operates the E-Bed body to move to the pre-booked docking area, so that the camera can capture the Aruco marker. Then the user starts the auto-reset function, and the E-Bed starts docking: According to the pose of the captured Aruco marker, the pose of E-Bed can be calculated. We convert the E-Bed pose into the speed value of the chassis motors, and realize the closed-loop control of the chassis motors through the way of visual servo. The E-Bed will complete the direction alignment and close to the bed frame in the docking process, and finally realize the body and the bed frame fit together to complete the reset.

The E-Bed body relies on the two drive wheel differential velocity in the process of movement to achieve direction control. Through visual navigation to achieve the closed-loop control of the direction of movement, we need the Aruco marker can always be captured by the camera. Therefore, boundary detection needs to be added to the navigation program. When the marker is about to slide out of the capture screen and exceed certain thresholds, the E-Bed body moves in the direction of the suppression slide out so that the marker state is below that threshold. At the same time, the closer the camera is to the marker, the faster when the E-Bed body steer the marker moves in the picture, the easier it is to slide out of the picture. Therefore, it is easier to realize the navigation of coordinates and posture by aligning the E-Bed body at a distance (the distance between the body and the marker is smaller in the Y-axis) [8].

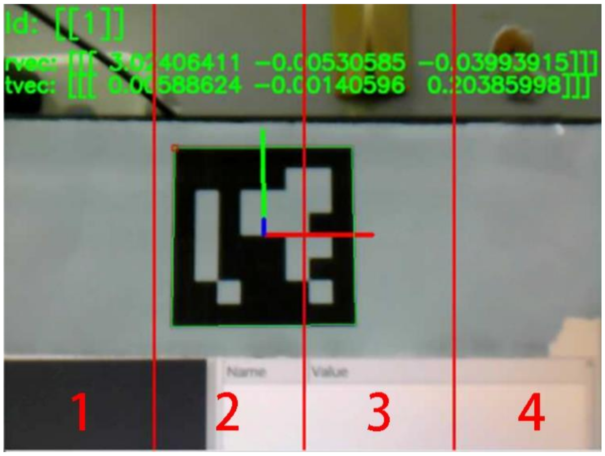

Figure 8. Pieces of camera image.

In this paper, the capture screen is divided into four pieces: zone 1, 2, 3, 4. With the sufficient steering space, the E-Bed body is located in front of the marker left (based on the marker), and the right border of the marker in the screen is in the 4-zone grid during navigation[9]. When the E-Bed body and marker in the Y-axis direction distance is less than a certain threshold, the head of the correct body can complete navigation, or the body is in front of the marker right (based on the marker), in the navigation process, the right border of the marker in the screen is in the 1 zone. When the E-Bed body and marker in the Y-axis direction distance is less than a certain threshold, the head of the E-Bed body straight to complete the navigation [10].

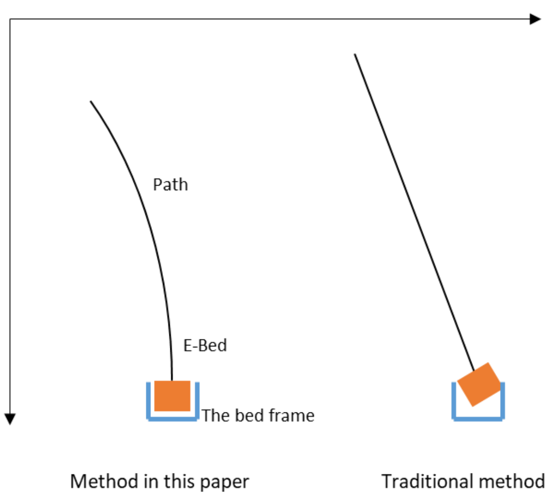

Figure 9. Kinematic paths of E-Bed.

In this method, the motion trajectory is as follows. Compared with the navigation trajectory where the marker in the picture is in the middle of the picture, the method provided in this paper is easier to reset and fit the E-Bed body and the bed frame in theory [11]. At the same time, the visual servo can ensure the E-Bed to move in the right direction.

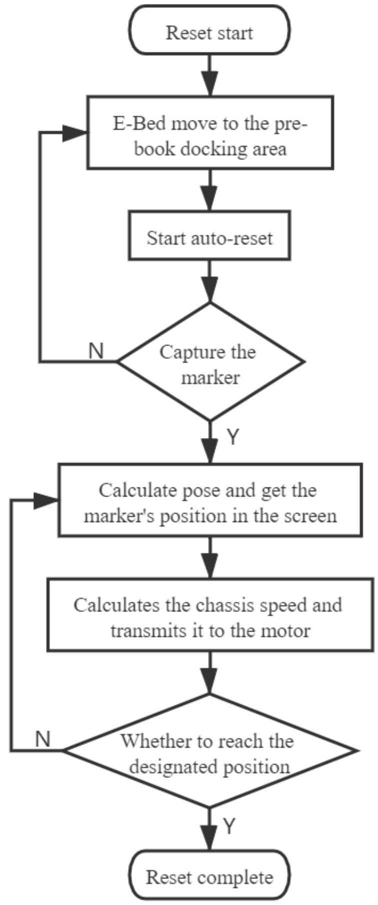

Figure 10. Navigation Process of E-Bed.

It is important to note that using only four coplanar points to estimate the position is prone to ambiguity. As shown in the following image, a marker projects the same pixel on two different camera locations. In general, if the camera is close to the marker, it can be resolved during movement. However, when the mark becomes very small, errors in attitude estimation increase and lead to ambiguity [12].

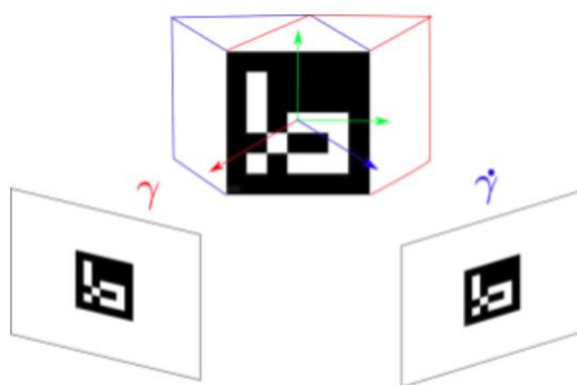

Figure 11. Perspective ambiguity of Aruco markers.

VI. EXPERIMENTAL MEASUREMENT

The navigation method program provided in this paper is built on the Raspberry Pi platform and applied to the E-Bed body. The version of the raspberry Pi is raspberry Pi3 B+; camera model is Logitech C270 and its resolution is 640P; Aruco markers are taken from 6×6 dictionary and the size is 20.0cm×20.0cm.

The E-Bed is controlled to move near the front of the Aruco marker and the navigation camera can capture the marker. We activated the Ebed navigation and auto-reset function and E-Bed starts to move forward slowly and constantly adjusts its direction. Within a sufficient adjustment distance, E-Bed will keep the direction opposite to the Aruco marker and move forward at a constant speed. When the distance between the camera and the marker reaches a certain threshold, the E-Bed will stop moving to complete the navigation and auto-reset tasks.

Figure 12. The experiment of E-Bed navigation.

The results of experiments show that the positioning and navigation of medical mobile equipment based on Aruco marker can meet the needs and run stably; this method can reduce the operation difficulty and improve the flexibility of guidance under the premise of stable operation and navigation. Meanwhile the cost of this method is low, which can be effectively applied in other medical equipment occasions that need guidance.

Figure 13. The E-Bed completes the reset.

Figure 14. The E-Bed body transforms into the bed.

VII. CONCLUSION

In this paper, the electric assistive devices E-Bed in the aged care institution is the research object. According to its non-closed loop differential movement characteristics, the visual guidance problem is studied. The navigation method of medical assistive devices based on Aruco recognition is proposed. We applied this method to E-Bed and did experiment and practice. The results show that this method can improve the efficiency of the use of such assistive devices. From this, we can assume that the application of this low cost navigation technology on traditional electric assistive devices will greatly improve the efficiency of the use of medical accessories and save human resources.

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