Improvement of Performance of Navigation System for Supporting Independence Rehabilitation of Wheelchair - Bed Transfer

Jin Kato [1], Genbu Deguchi [2], Jun Inoue [1] and Masami Iwase [1]

[1] Dept. of Robot and Mechatronics, Graduate School of Future Sciences, Tokyo Denki University (TDU), 5 Senju-Asahicho Adachi, Tokyo 120-8551, Japan
[2] Dept. of Healthcare, International University of Health and Welfare (IUHW), 1-2-25 Shiroyama Odawara , Kanagawa 250-8588, Japan

*kato@ctrl.fr.dendai.ac.jp

Abstract. The purpose of this research is to improve the position and angle estimation accuracy of the wheelchair guide system for Hemiplegic patients. The wheelchair guide system aims to assist the patients to transfer between their wheelchair and bed. This system prompts properly to user depending on the situation as same as care worker. Therefore, the system is developed to prompt the measured position and angle of wheelchair. The position estimator uses an AR marker to detect the wheelchair position. However, its estimation is contaminated by measurement noises and sometimes fails because the marker is out of the camera's field of view. To improve the estimation of position and moving direction, we introduce the kinematic model of the wheelchair and utilize the Extended Kalman Filter with the model. In this paper, we describe the self-position estimation method of the navigation system and AR marker, with the estimation method using Kalman Filter.

1. Introduction

The purpose of this research is to improve the estimation accuracy of position and angle of wheelchair-bed transfer support system for hemiplegic patients. Wheelchairs are often used for hemiplegic patients to move [1]. In life using a wheelchair, it is necessary to transfer safely from a wheelchair to a bed or toilet. Therefore, in order to achieve safe transfer, patient need to recognize the current posture of wheelchair against the bed or the toilet, but it is difficult to visually grasp it [2]. Caregivers who support patient movement can realize safe movement. However, the care worker constant support puts a burden on the caregiver's body and mind. Therefore, it is necessary to support the independence of transfer of hemiplegic patients.

To achieve transfer between wheelchair beds, the patient must know the current position of the wheelchair and stop the wheelchair at the proper position and angle. However, patients may move to bed and fall without recognizing that the wheelchair is stopped at the wrong position or angle [3]. Therefore, it is necessary to guidance the wheelchair so that it can be stopped in the proper position.

Deguchi has defined a position and angle suitable for transferring to the bed as the target stop position and developed a system that uses a mat switch to guide the position [4]. Saito has developed a system have estimates the position and angle of a wheelchair using Kinect sensors and markers [5]. However, with the Kinect sensor, the estimated value may be disturbed due to sunlight interference.

Therefore, we developed a system that estimates the position and angle of a wheelchair using wearable augmented reality markers (AR marker) and RGB cameras (cameras) [6]. However, if the AR marker is deleted from the camera, the position and angle cannot be estimated. To solve this problem, there is a method called Kalman filter (KF) for estimating unobservable states from observable data. Using this method, the position and angle of the wheelchair can be estimated even when the AR marker is out of the field of the camera [7].

In this paper, we section first discuss the navigation system. Then, a self-position estimation method using an AR marker is described. Then, we state the problem of self-location estimation of AR marker. Finally, we show the self-location estimation method using KF.

2. Navigation systems

In this section, the configuration of the navigation system is described first.

2.1. Configuration of navigation system

This subsection describes the configuration of the navigation system. In the navigation system, an AR marker is installed on the bed side, and the position of the wheelchair is grasped by a camera attached to the wheelchair (Figure 1). Based on this position, We use the monitor and speakers to guide the patient to the bed to the appropriate stop position and angle [6]. However, the appropriate stop position is indicates by the marker in Figure 1. This marker is located at 30 ° to the side of the bed.

In this system, a gyro sensor is mounted in the wheelchair brake, a pressure sensor is mounted under the mat, and a footrest sensor is mounted under the foot support for safe movement (Figure 1). From each sensor information, the guide system determines whether the brakes are worked, whether user is sitting in the wheelchair, whether user’s feet are on the ground when moving from wheelchair to bed ,and instructing user to move safely based on that information.

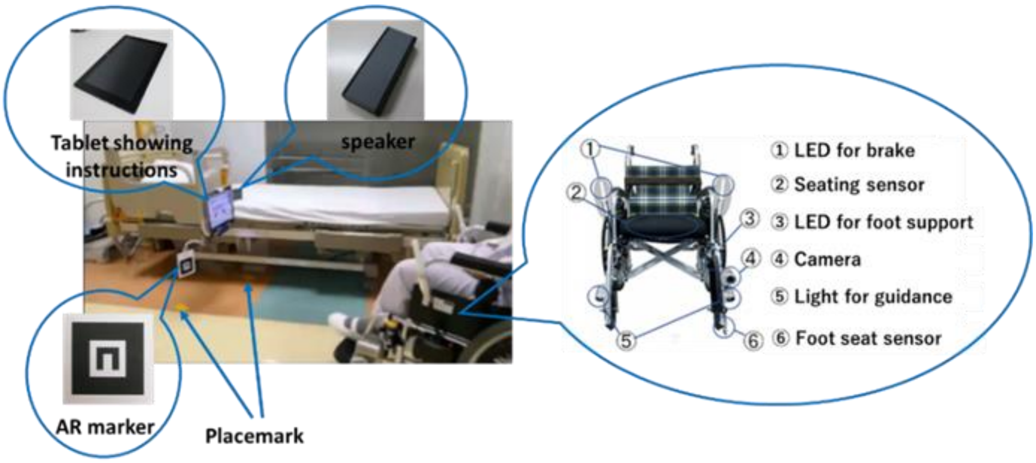


Figure 1. Configuration of navigation system

3. Wheelchair position and angle estimation method using AR marker

This section describes derivation of the appropriate stop position using AR markers, as the appropriate stop position differ from patient to patient. We also confirmed that the position and angle of the wheelchair can be estimated by the position angle estimation method using AR markers. Finally, we show the problem of position estimation using AR markers.

3.1. Derivation of appropriate stop position

This subsection describes the derivation of a suitable stop position that varies from patient to patient. The appropriate stop position and marker mounting location will vary from patient to patient. Therefore, it is difficult to determine an appropriate stop position from the camera coordinate system. Therefore, by replacing the coordinate system fixed to the marker coordinate system with the sheet coordinate system, a stop position suitable for each user is derived and guided based on that position (Figure 2).

The $\overrightarrow{\boldsymbol{O'}}$ in the sheet coordinate system shown in Figure 2 represents the origin of the sheet coordinate system viewed from the marker coordinate system. $\boldsymbol{p}$ represents the left tire of the wheelchair viewed from the marker coordinate system, and $\boldsymbol{q}$ represents the position of the left tire of the wheelchair viewed from the sheet coordinate system. $\boldsymbol{\theta}$ represents the angle of the sheet coordinate system with respect to the marker coordinate system. The method for deriving $\overrightarrow{\boldsymbol{O'}}$ is (1).

$$\overrightarrow{\boldsymbol{O'}} = \vec{\boldsymbol{p}} + \boldsymbol{R}(\boldsymbol{\theta})\vec{\boldsymbol{q}} \tag{1}$$

From (1), the origin of the sheet coordinate system viewed from the marker coordinate system can be derived. The wheelchair tire position viewed from the marker coordinate system can be converted from the simultaneous conversion matrix to the wheelchair tire position viewed from the seat coordinate system.

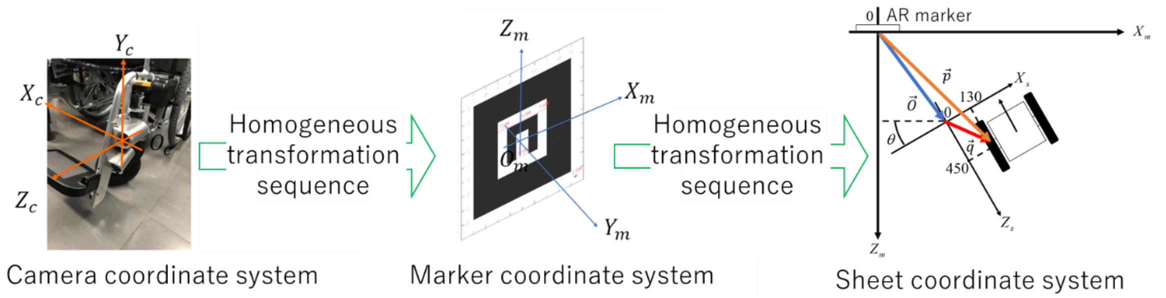


Figure 2. Conversion from camera coordinate system to sheet coordinate system

3.2. Wheelchair position and angle estimation experiment using AR marker

In this subsection, we will confirm that the position and angle of the wheelchair can be estimated by the self-position estimation method using AR marker. Figure 3 shows the experimental environment. The experiment assumes that the wheelchair is at least 3 meters away from the bed. In addition, the AR marker is placed 15m away from the bed railing. In addition, the wheelchair is 30 deg position relative to the bed. The experimental results are shown in Figure 4.

From Figure 4, it was confirmed that the position and angle can be estimated from the angle from the trajectory of the left and right tires.

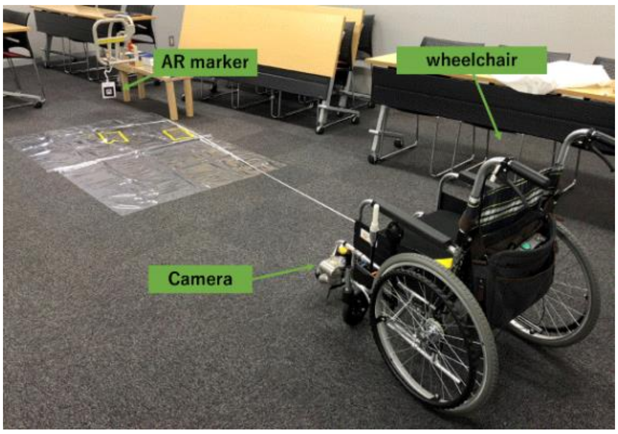


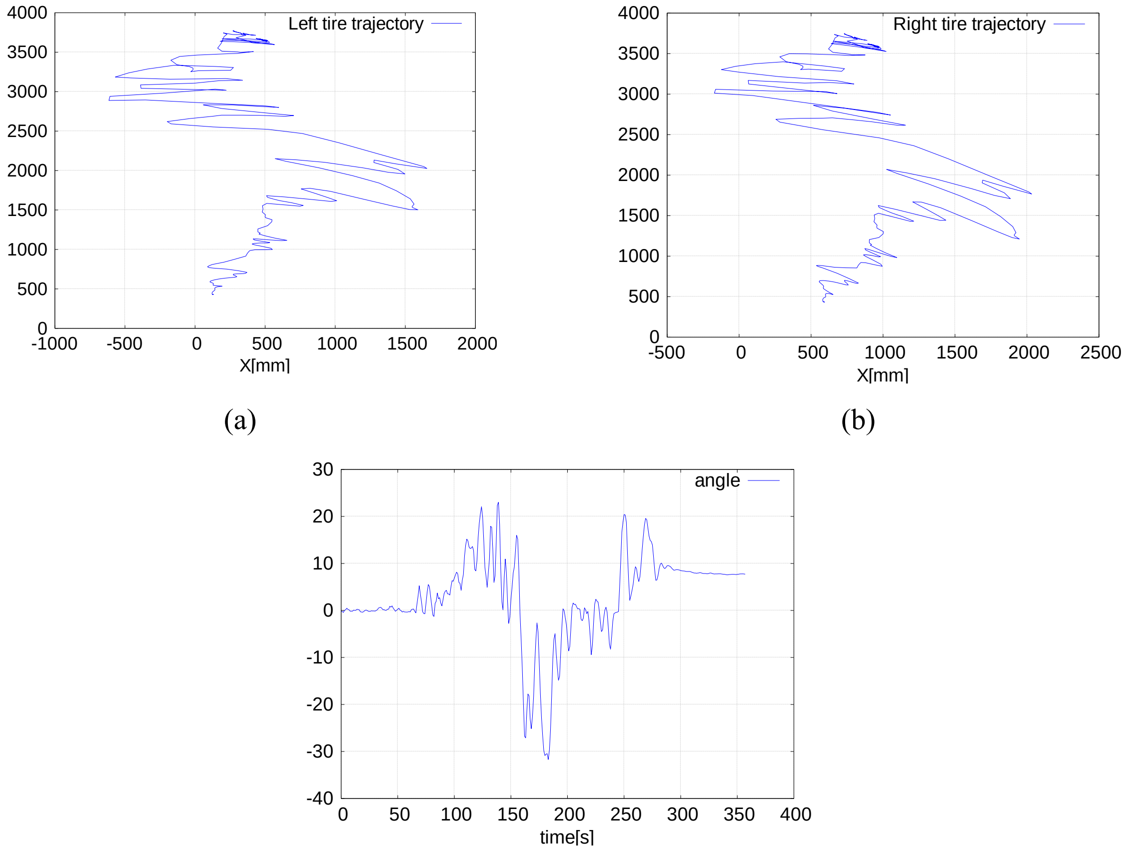
Figure 3. Experiment environment

3.3. Problem of self-position estimation using AR marker

This subsection discusses the problem of the camera lost the sight of AR makers. In this system, there are four cases of lost the sight of AR marker. When the wheelchair moves to the other side of the bed,

IOP Conf. Series: Journal of Physics: Conf. Series **1487** (2020) 012041 doi:10.1088/1742-6596/1487/1/012041

when the wheelchair gets too close to the bed, when the wheelchair approaches the marker, and when the wheelchair is moved violently. If the AR marker lost the sight, the position and angle of the wheelchair cannot be measured, and the wheelchair operated by the user cannot be guided to the proper position and angle with respect to the bed. Therefore, in order to move safely between the wheelchair and the bed, a method that can estimate the self-position of the wheelchair without AR marker is required.



(a) (b)

(c)

Figure 4. Left and right tire trajectory and angles

4. Problem of self-position estimation using AR marker

In this section, we propose a self-localization method using the Kalman filter as a solution to the problem in the previous section. First, the wheelchair model is used to derive the state-space representation of the wheelchair necessary for the design of the Kalman filter. Then, use the derived state space representation to see if the position of the wheelchair can be estimated if the camera lost the sight of AR marker.

4.1. Wheelchair modeling

Describes the wheelchair model. The wheelchair model is assumed to be a two - wheeled vehicle model without skidding. The model is shown in Figure 5. However, the X and Z axes of the marker coordinate system with the AR marker installation point O_m as the origin are X_m and Z_m , and the X and Z axes of the camera coordinate system with the camera installation point O_c as the origin are X_c and Z_c. The coordinates of the wheelchair axle center point in the marker coordinate system are (x, z), and the rotation angle of the axle center is θ. Therefore, the equations of motion for the wheelchair speed system are (2) and (3).

IOP Conf. Series: Journal of Physics: Conf. Series **1487** (2020) 012041 doi:10.1088/1742-6596/1487/1/012041

$$\dot{x} = V \sin\theta \tag{2}$$

$$\dot{z} = V \cos\theta \tag{3}$$

Using this equation of motion, a state-space representation of the wheelchair is derived. The Kalman filter for this study is designed using a camera and an IMU attached to the wheelchair. Therefore, use information about the position and angle of the wheelchair that can be obtained from the camera. In addition, acceleration and angular velocity in the x, y and z axes can be obtained from the IMU. However, since the wheelchair model used this time is two-dimensional, it is used as the acceleration x in the x-axis and y-axis directions. Then, integral acceleration. Therefore, the velocity ẋ, ẏ, and the angular velocity around the z axis are observations. However, the value obtained by integrating the acceleration in the x-axis and y-axis directions is used. Therefore, the velocity ẋ, ẏ, and the angular velocity around the z axis are observations. The state space representation of a wheelchair is shown in (4) and (5). However, the state is $x = [x \quad z \quad \theta]^T$, and the observed value is $y = [x \quad z \quad \theta \quad \dot{x} \quad \dot{y} \quad \omega]^T$. The input is $u = [V, \omega]^T$. $\boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C}$ and $\boldsymbol{D}$ are (6).

$$\dot{x} = \boldsymbol{A}x(k) + \boldsymbol{B}u(k) + v(k) \tag{4}$$

$$y = \boldsymbol{C}x(k) + \boldsymbol{D}u(k) + w(k) \tag{5}$$

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \boldsymbol{B} = \begin{bmatrix} \sin\theta & 0 \\ \cos\theta & 0 \\ 0 & 1 \end{bmatrix}, \boldsymbol{C} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \boldsymbol{D} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \sin\theta & 0 \\ \cos\theta & 0 \\ 0 & 1 \end{bmatrix} \tag{6}$$

The position and angle of the wheelchair are estimated by applying EKF to this state space representation.

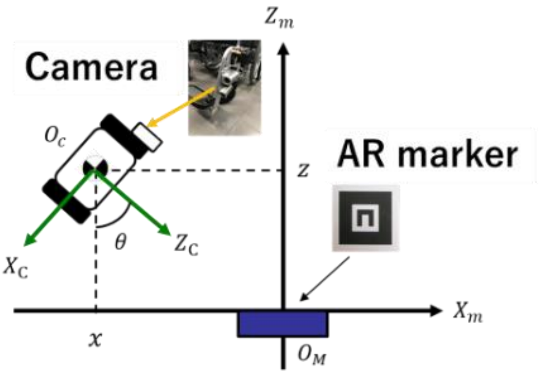


Figure 5. Wheelchair model

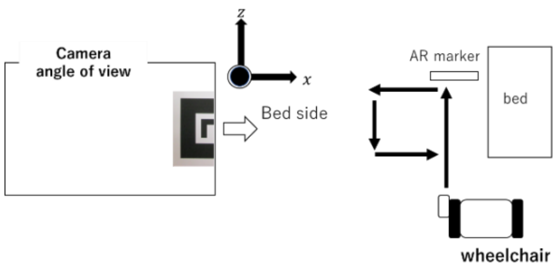


Figure 6. Wheelchair behavior during the experiment

4.2 Self-position estimation by Kalman filter using camera and IMU

Design a Kalman filter from wheelchair position and angle information obtained from the AR marker, acceleration and angular velocity obtained from the IMU, and check whether the position of the wheelchair when the AR marker disappears from the camera can be estimated. In this experiment, it is assumed that the wheelchair with the camera moves in the opposite direction of the bed (Figure 6) and misses the AR marker. Figure 6 shows the wheelchair movement during the experiment, and Figure 7 shows the result of the experiment. In addition, it is confirmed from the measured value in the x-axis direction whether the position can be estimated when the AR marker is lost (Figure 8).

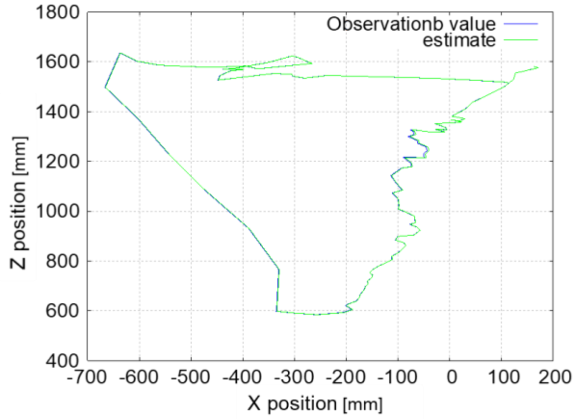


Figure 7. Measurement result

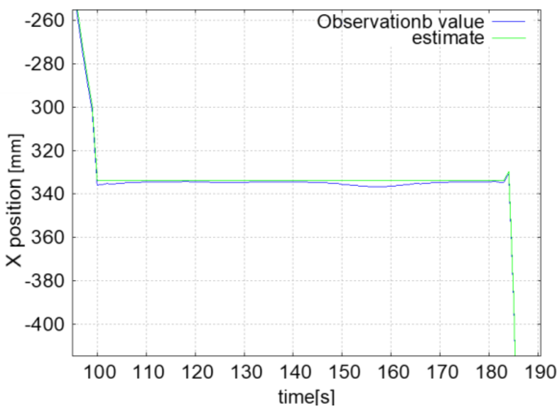


Figure 8. Wheelchair position when losing sight of AR marker (x-axis direction)

Figure 7, it takes 100 to 182 seconds to lost the sight of AR marker. As can be seen from Figure 8, the estimated value by EKF is constant, so the position when the AR marker is lost cannot be estimated. In the future, to solve this problem, check the wheelchair model and the designed filter to find the cause.

5. Conclusions

In this research, we worked to improve the self-position estimation and estimation accuracy of wheelchairs using AR marker. It was confirmed that the position and angle of the wheelchair can be estimated by estimating the position of the wheelchair used AR marker. It was also found that there is a problem that cannot be estimated when the camera lost the sight of AR marker as a problem of wheelchair self-position estimation using the AR marker. Therefore, as a method that can estimate the self-position of the wheelchair even if the camera lost the sight of AR marker self-positioning method of wheelchair by EKF was proposed. In the future, to solve this problem, review the designed Kalman filter and the derived model. In addition, to see if the estimate is valid, use motion capture to measure the true value and check the validity of the estimate.

References

[1] Kazuo Takamine 2005 *Risk Factors for Falls in Stroke Patients with Special Reference to Disturbances of Higher Brain Functions* (The Kitakanto medical journal)

[2] N.Okawara and S.Usuda 2014 *Influence of Visual and Surface Conditions on Standing Postural Control of Patients with Post-stroke Hemiplegia* (Rigakuryoho Kagaku)

[3] Tomoko Takayanagi 2018 *Experience-Based Knowledge of Patients with Post-Acute Cerebrovascular Disease Requiring Observation as a Basis for the Achievement of Bed-Wheelchair Transfer Independence* (Japanese journal of nursing research)

[4] Genbu Deguchi 2012 D*evelopment and evaluation of the device to guide operations to set wheelchair parking brakes and footrests while transfering from a bed to a wheelchair and vice versa : Toward secure independence of left hemiplegias* (Thesis or Dissertation)

[5] Yudai Saito 2017 *Development of Transfer Support Apparatus between Bed and Wheelchair by sing Kinect Sensor* (Tokyo Denki University Master's Degree Proceedings)

[6] Y.Takahashi et al 2018 *Development of Assistance System to Transfer Between Wheelchair and Bed using AR marker* (Proceedings of the Society of Instrument and Control Engineers)

[7] T. Kojima and T. Namerikawa 2014 *Position Estimation of a UAV usg Image Information by Kalman Filter* (Minutes of automatic control federation meeting)