Simultaneous Estimation of Horizontal Position and Depth Distance by Kalman Filter and Obrid-Sensor

Yuki Horikawa^a, Shenglin Mu^b, Daichi Hamasuna^a, Hidemitsu Arimura^a, Atsushi Matsubara^a, Shota Nakashima^{a,*}

^aYamaguchi University, ^bEhime University

^a2-16-1, Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

^b3, Bunkyo-cho, Matsuyama, Ehime, 790-8577, Japan

*Corresponding Author: s-naka@yamaguchi-u.ac.jp

Abstract

Recently, the demand of nursing care rapidly has been increasing along with the progress of serious aging society in Japan⁽¹⁾. Accordingly, the physical burden to the caregivers is increasing. In care works, it is important to watch over care-receivers with privacy preservation in the house or the nursing home. Thus, it is difficult to use the systems with security or surveillance cameras that might violate the care-receivers' privacy. In order to solve the problems, the Obrid-Sensor that can detect the position and condition of the subject without privacy violation has been developed in previous researches. However, the Obrid-Sensor did not correspond the detection of multiple subjects. Moreover, in order to obtain the subject's position information from a higher perspective, a complex installation of the Obrid-Sensor has to be introduced. Therefore, we propose the tracking method by estimating the horizontal and depth position of the subject simultaneously with one Obrid-Sensor in this research. The installation of the Obrid-Sensor in the proposed method is simple. It is also possible to track multiple subjects respectively at the same time.

Keywords: Obrid-Sensor, Privacy protection, Condition detection.

1. Introduction

Due to the progress of aging society in Japan, elderly people living alone have been increasing. The shortage of labor force in care service has become a serious problem. However, it is impossible for caregiver to watch over the elderlies completely because of the physical and mental burdens and for the caregivers. Therefore, the development

Fig. 1. Theoretical structure of Obrid-Sensor

of sensing systems that can reduce the burden in watching over in a long time is expected⁽²⁾. Though the system using camera images is given as one example of the sensing system. The system has some problems, such as high installation cost, and privacy violation possibilities in some private places in daily life⁽³⁾. In order to solve the problems, we developed the Obrid-Sensor that can watch over care-receivers without violating privacy in daily life. The system was developed to detect motions and status of a single subject. It could not correspond multiple people or the occlusion with the obstacle. Multiple the Obrid-Sensors are also needed to estimate the horizontal and depth position of the subject simultaneously⁽⁴⁻⁶⁾. In this research, we introduce the method to estimate the horizontal and depth position, and occlusion with abstract by using an Obrid-Sensor and a Kalman filter⁽⁷⁻⁸⁾.

2. Orbid-Sensor

2.1 Theoretical Structure

The Obrid-Sensor consists of a line sensor and a cylindrical lens. The cylindrical lens is one of a planoconvex lens. The line sensor is an optical sensor set light receiving elements in a low. It is generally used as the products such as a scanner or a barcode reader. The cylindrical lens collects incident lights. The theoretical structure of the Obrid-Sensor is shown in Fig. 1(a). The top view of Fig. 1(a) and the side view of Fig. 1(a) are respectively shown in Fig. 1(b) and Fig. 1(c). The horizontal lights from each points R , C , L of the subject space enter to the corresponding points S^R , S^C , S^L on the line sensor through the center of the cylindrical lens. As shown in Fig. 1(c), the cylindrical lens does not have the effect of the lens because of the shape of flat glass. Thus, the lights from each point C^+ to C^- of the subject space enter one point S^C on the line sensor. Therefore, the lights from the subject space are integrated, the brightness corresponds to the integral value.

2.2 Feature Acquisition Method

The proposed method uses the background subtraction method⁽⁹⁾ to estimate feature value. The method extracts the object that did not exist in the previous frame by comparing the current image and the previous image. The image captured by camera for the confirmation in the detection range of the Obrid-Sensor is shown in Fig. 2(a). The brightness distribution waveform observed by the Obrid-Sensor is shown in Fig. 2(b). Firstly, when the subject does not exist in the detection range, the Obrid-Sensor obtains the brightness distribution waveform that means the background. Secondly, when the subject exists in the detection range, the Obrid-Sensor obtains the brightness distribution waveform that means the foreground. By taking a difference of the two waveforms, the brightness distribution waveform that means the feature value of the subject is obtained. In this research, in order to explore the feature values of the multiple subjects, the proposed method uses the maximum value of the difference waveform. Then, it may be difficult to explore the ideal maximum value due to the dark current noise from the Obrid-Sensor. Thus, the maximum value is calculated after performing the moving average processing to the difference waveform by the equation (1).

$$L'_i = \frac{1}{n} \sum_{j=0}^n L_{i-2+j} \quad (2 \leq i \leq N-2) \quad (1)$$

(a) Camera image

(b) Brightness distribution waveform

Fig. 2. Background subtraction method

The L_i is the brightness value at the pixel number i . The L'_i is the brightness value after the moving average at pixel number i . The N is the number of the pixels of the line sensor. The proposed method calculates the incline g_i at pixel number i for the difference waveform provided from the equation (1) by the equation (2).

$$g_i = \frac{Diff_{i+m} - Diff_{i-m}}{m} \quad (2 \leq i \leq N-2) \quad (2)$$

The proposed method defines m as the step to calculate the incline g_i . The $Diff_i$ is the brightness value of pixel number i in the difference waveform. The pixel numbers of maximum value and minimum value calculated the moving average are made into one set. The middle pixel number is defined as the horizontal position P_h . Therefore, this method can explore the feature values of multiple subjects robustly against dark current noise.

3. Methodology

3.1 Depth Distance Measurement Method

The positional relationship between the Obrid-Sensor and the subject is shown in Fig. 3. The D is the distance between the subject and the Obrid-Sensor is determined by

the equation (3) from Fig. 3. In this figure, the θ_h is a horizontal detective angle of the Obrid-Sensor,

$$D = \frac{W_{XY}}{2} \times \frac{1}{\tan \frac{\theta_h}{2}} \quad (3)$$

The length W_{XY} of the line XY depends on the position of the subject. Therefore, to calculate the depth distance, it is necessary to compare the width w_c of the subject with the actual width l of the subject. The W_{XY} is expressed by equation (4).

$$W_{XY} = \frac{1}{w_c} \times P \quad (4)$$

The P is the total number of pixels of the Obrid-Sensor. The real depth distance and measurement result is different by installation conditions because the Subject is not observed from the front of the Obrid-Sensor. The relationship between the depth distance and the measurement distance is shown in Fig. 4. The Obrid-Sensor has a depression angle. In this case, the Obrid-Sensor looks down on the subject. Therefore, the depth distance that the nearest part of the body of the subject from the Obrid-Sensor is observed. The depth position is expressed by equation (5). The θ , L , H and h respectively mean the depression angle, the distance from the sensor to the subject, the distance from the ground to the sensor and the height of the subject.

$$L = \frac{2D + h \cos \theta - 2H \sin \theta}{2 - \sin \theta} \quad (\text{if } h - (2H - L) \tan \theta \geq 0)$$

$$L = \frac{2D - h \cos \theta + 2H \sin \theta}{2 + \sin \theta} \quad (\text{if } h - (2H - L) \tan \theta < 0)$$
(5)

3.2 Threshold Acquisition Method

In order to measure the depth distance from the Obrid-Sensor, it is necessary to measure the width of w_c from the brightness values larger than threshold Th to remove dark current noise in the difference waveform. However, the waveform includes the shadow of the subject. Therefore, it is considered that part of the end waveform by the threshold Th_w that is shown by the equation (6).

Fig. 3. Positional relationship between Obrid-Sensor and subject

Fig. 4. Relationship between depth distance and measurement distance

$$Th_w = \left(1 - \frac{Diff_{max}}{L_{max}}\right) \times Diff_{max} \quad (6)$$

3.3 Kalman Filter

To estimate the position of the subject, the proposed method uses the Kalman filter. The Kalman filter makes the state space model by modeling the motion of the subject. The discrete-time equation that means the behavior of the system by using the model from the equation (7). The x_t is an estimation of the system. The system noise, the observation noise, and observation values are defined as w_t , v_t , and y_t . These values change automatically by processing inside the Kalman filter.

$$x_{t+1} = Fx_t + Gw_t \quad (7)$$

The matrix F is a model defined as a system matrix or a state transition matrix. The w_t is normal white noise defined as system noise. The G is a coefficient vector for transforming

w_t into a matrix. The observation equation to convert physical value to the observation value is shown in the equation (8).

$$y_t = Hx_t + dw_t + v_t \quad (8)$$

The matrix H is the observation coefficient vector, the v_t is a normal white noise defined as the observation noise. The d is system noise defined as the coefficient for the input. The accuracy of the Kalman filter largely depends on the created model. In this research, the acceleration and deceleration of the person are assumed slow. In addition, the frame rate of the Obrid-Sensor is fast enough. Hence, the proposed method supposes that the movement of the subject is constant velocity. Therefore, the F is shown like the equation (9). Each component of $X_t = [x_t, y_t, \dot{x}_t, \dot{y}_t]^T$ meaning the state variable is also defined as the P_h , depth distance, each of the time derivative. Assuming the uniform linear motion, the discrete time equation of state and the observation equation respectively become as follows the equation (10) and (11).

$$F = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (9)$$

$$X_{t+1} = FX_t + w_t \quad (10)$$

$$Z_t = HX_t + v_t \quad (11)$$

In this experiment, because of the time delay, the d is let be 0. The Z_t is an observation vector, w_t is a four-dimensional disturbance vector with an average value 0. The v_t is also four-dimensional observation noise with an average value 0. In order to apply the estimated value X_t to the observed value, we use the unit matrix as H . In addition, the G is let be the unit matrix in order to give independent noise to each component of X_t .

4. Evaluation Experiment

4.1 Conditions and Environment

In this experiment, the horizontal and depth position are

(a) Back and forth (b) Left and right
Fig. 5. Positional relationship of subject

Fig. 6. Positional relationship of subject with occlusion occurrence

Table 1. Detection angle of the Obrid-Sensor

	Theoretical value	Measured value
Horizontal detection angle [deg]	72.1	68.1
Upper direction detection angle [deg]	27.0	21.3
Downward detection angle [deg]	27.5	22.1

estimated by only one Obrid-Sensor simultaneously. Then, we evaluate the measurement results of the subjects' position by the proposed method. The results of occurring the occlusion are also confirmed whether the proposed method can estimate the horizontal position of the subjects. The Obrid-Sensor installed according to table 1. To estimate the horizontal position, the Obrid-Sensor installed in the position of left, right and center. The lighting of experimental environment was the fluorescent light. The illuminance of the experimental environment was 256 lx.

4.2 Methods

In this research, we prepare the eight subjects with different physical and clothes to compare with the actual position and the estimated position. The position of subject who moves by the pattern following Fig. 6 is estimated from observed waveform. In addition, in order to confirm whether

(a) Horizontal position

(b) Depth distance

Fig. 7. Forward and backward movement

the proposed method can estimate the subjects' position, the four pairs of two subjects are randomly made. The movements shown in Fig.6 are done five times. The Obrid-Sensor used in this experiment has dark current noise the value that is 22 on average and 28 on maximum randomly. Therefore, the threshold value for removing the error due to the subject's shadow is $T_h = 30$. Also, n and m used for the moving average of equation (1) and the gradient of equation (2) are $n = 5$, $m = 2$. In this experiment, the width of the subject used to measure the depth position is defined as described below. The width l of the shoulder of the subject turning to the front against the Obrid-Sensor is let be 450 mm, it is the average value of human shoulder. The width of the subject turning to the side is let be 210 mm⁽¹⁰⁾, it is the average value of human chest. The height h of the male subject is defined 170 cm, which is the average height of males. The height h of the female subject is 155 cm⁽¹¹⁾, which is the average height of females. The theoretical value and the installed angle of the Obrid-Sensor are set as shown in

(a) Horizontal position

(b) Depth distance

Fig. 8. Left and right movement

Fig. 9. Assumption of occlusion

Table 1.

4.3 Results and Discussion

The result of the forward and backward movement in the case of one subject is shown in Fig. 7. The result of the left and right movement is shown in Fig. 8. The result in the

case of occlusion is shown in Fig. 9. In these figures, the frame shown the observed value of 0 is the frame not obtaining the observed value. We confirmed the position of the subject is estimated around the previous frame by using the Kalman filter. Therefore, the position of the subject is estimated by one Obrid-sensor. About the whole results of the depth position measurement, the observed value in the case of moving forward and backward is larger than the theoretical value. The observed value in the case of the left and right movement is less than the theoretical value. As the cause of these error detections, it is thought that the width of observed feature is different from the theoretical value. In the experimental environment, the feature value was obtained lower than the supposition because the shadow disappeared by the fluorescent lights installed on all sides. In the results of the horizontal position measurement, the error detection that the observed value is 80 to 100 pixel often occurred. Two factors are considered as the main causes of detection error. The first one is that the feature values were obtained when the subjects move to the end of the detection range. The second is the shot noise that occurs with being proportional to the amount of light. Figure 9 shows that the proposed method can estimate the position of the subjects in the case the occlusion occurs. However, the proposed method estimated that the subjects were stationary when the occlusion occurs because the amount of the observed value change before the occurrence of the occlusion is small. The experimental results confirmed that the proposed method can detect the horizontal and depth movement by using one Obrid-Sensor. By using Kalman filter, the estimation of the person position is possible even if the observed value is not obtained.

5. Conclusions

In this research, we proposed the method to estimate the position of the subjects by estimating the horizontal and depth position simultaneously with a single Obrid-Sensor. By estimating the positional information obtained by the Obrid-Sensor by using Kalman filter, the subject's position measurement was verified. As shown in the experimental results, the proposed method can detect the horizontal and depth position of the subject with a single Obrid-Sensor. Meanwhile, the proposed method can track the positions of multiple subjects at the same time. By the proposed method, it is possible to estimate the position of the subjects with a single Obrid-Sensor using Kalman filter.

References

- (1) Cabinet Office Japan : “Annual Report on the Aging Society [Summary] 2018”, p. 2, 2018
- (2) Hirokazu Seki and Yoichi Hori : “Detection of Abnormal Action Using Image Sequence for Monitoring System of Aged People”, The transactions of the Institute of Electrical Engineers of Japan. D, A publication of Industry Applications Society, Vol.122, No.2, pp. 1-7, 2002
- (3) Sugihara Taro, Fujinami Tsutomu and Nakagawa Kenichi : “Effects of Cameras and Monitors on Caregivers' Work Stress in the Group Home”, The Institute of Electronics, Information and Communication Engineers, Vol.108(488), pp.73-78, 2009
- (4) Shota Nakashima, Shingo Aramaki, Kanya Tanaka, Shenglin Mu and Tatsuya Ichikawa : “Depth Measurement Method with Applying Stereo Vision to One-Dimensional Brightness Distribution Sensors”, the 4th International Conference on Informatics, Electronics & Vision, No.136, 2015
- (5) S. Aramaki, Y. Moriyoshi, S. Mu, K. Tanaka, and S. Nakashima : “Proposal of Fall Down Detection Method using Shape of Feature Quantity Obtained by Obrid-Sensor”, 2016 IEEE Region 10 Conference (TENCON) — Proc. the International Conference (Singapore) November, 2016
- (6) S. Nakashima, S. Mu, S. Okabe, K. Tanaka, Y. Wakasa, Y. Kitazono, and S. Serikawa : “Restroom Human Detection Using One-Dimensional Brightness Distribution Sensor”, Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing 2012, Studies in Computational Intelligence (Springer), Vol.492, pp.1–10, 2013
- (7) Chen Yee Ming, Tsai Chi-Li and Fang Ren-Wei : “TDOA/FDOA Mobile Target Localization and Tracking with Adaptive Extended Kalman Filter”, Vol.2017 No.ICCAIRO pp.202-206, 2017
- (8) Zhao Yubin, Li Xiaofan, Wang Yang and Xu Cheng-Zhong : “Biased Constrained Hybrid Kalman Filter for Range-Based Indoor Localization”, IEEE Sensors Journal , Vol.18 No.4 pp.1647-1655, 2018
- (9) E. Komagal and A. Vinodhini: “real time background subtraction techniques for detection of moving objects in video surveillance system”, in 2012 International Conference on Computing, Communication and Applications, pp. 1-5, 2012
- (10) National Institute of Bioscience and Human-Technology “A collection of human dimension data for design”, 1996 in Japanese
- (11) Ministry of Health, “Welfare Statistics Handbook”, 2018