VOL. 20, NO. 2-3, 2021, 7-12
www.elektrika.utm.my
ISSN 0128-4428

ELEKTRIKA
Journal of Electrical Engineering

Multiple Detections Application for Indoor Tracking Using PIR Sensor and Kalman Filter

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Abstract: Recently, human tracking in multiple indoor environments is getting broadly in demand to enhance security surveillance. Traditional passive video surveillance shown that it has working ineffectively nowadays because the number of cameras has exceeded the ability of operators to monitor them. In this paper, we proposed methods of detecting human presence using Pyroelectric Infrared (PIR) Motion Sensor and tracking people in multiple indoor locations using Kalman filter-based estimation. The proposed method is implemented to analyze the movement of people within the prescribed area and the result will be presented in footprint mapping of the said area. This will further enhanced building security surveillance especially at the sensitive or restricted areas. Experiments for single target tracking in several areas are carried out to verify the application of the developed system. As the results, the maximum error for tracking trajectory reduced from 0.28m to 0.19m and average error for tracking trajectory also reduced from 0.10m to 0.07m after using Kalman filter estimation algorithm.

Keywords: Human tracking, Kalman Filter, PIR Motion Sensor.

Article History: received 25 May 2021; accepted 12 June 2021; published 15 October 2021

1. INTRODUCTION

In recent years, the research for human detection and tracking in surveillance system has rapidly increased as this system is crucial for variety of applications. It has a wide range of applications, including remote personnel identification, access control in special area, detection of abnormal behaviour, and interactive surveillance using multiple cameras in different areas [1]. The ability to detect and track accurately the objects of interest (OI) - primarily humans – in real time is a prodigious importance in the fields of security and surveillance [2]. For that reasons, this novel tracking system using Pyroelectric Infrared (PIR) motion sensor is seen as a useful tool for the users to identify the presence and track the movement of the people in their monitoring area. This system also able to put an awareness to the operator when detecting any suspicious behaviour or breaching of restricted area.

In real world, surveillance system faced a challenging problem to detect the present of human and distinguish them from unrelated object and background. The object segmentation such as lighting changes, shadows, camouflage in color, and dynamic background has associated to the difficulty to recognize the object [3]. By using this PIR motion sensor, it would solve the problem to identify the presence of human in that area as this PIR sensor detect the heat of human body in its range. Then, another challenge when it comes to tracking the object of interest (OI) in a dynamic environment, this object tends to appear and disappear at certain locations. These locations might relate to doors, garages, partitions, room dividers, tunnels and even on the edges of the camera [4]. The target also tends to lose when it moves to another room or different area. Therefore, the development of tracking system using Kalman filter will give more advantageous and increase the efficiency of surveillance system.

The organizational structure of this paper is as follows: Section 2 describe the related work of the PIR sensor for object detection and Kalman Filter application for tracking system. Section 3 and 4 presents the design of the system and the algorithms used for tracking system. Section 5 presents the simulation experiment and mapping model of the tracking system in an indoor environment. Conclusions and suggestions for future research are presented in Section 6.

2. RELATED WORK

PIR Design for Object Detection

For performing PIR limitation, Ma [6] proposed a cognitive signal conditioning by reconfigure PIR circuit and design a sensor mask to get higher signal-to-noise ratios (SNRs) and recognition performance. The gain and filter bandwidth of the PIR sensor can be automatically adjusted according to the working condition after reconfigure program system on chip. PIR sensor masks can be optimized by training complex neural networks using large thermal imaging datasets to optimize feature extraction for specific targets.

The PIR detection module (PDM) system proposed by

Lai [5] consists of two PIR modules installed on the ceiling to form a non-terminal inferior positioning system. By using a suitable reference structure, the space used for object detection is divided into several discrete cells. The proposed system shows that the system achieves the objective as simpler system design and higher estimation precision.

Gami [7] configured PIR sensors as well as signal processing and machine learning algorithms to estimate the presence, direction and distance of human motion in the corridor. It used integrated PIR sensor with machine learning and computer vision methods for analog pattern recognition and motion classification to monitor occupational analysis on specific floors of the building.

Moreover, Ma [8] also proposed three methods using PIR detection systems, which can actively detect static thermal targets suitable for various purposes. First, the sensor can be used to detect nearby static or moving thermal objects by automatically controlling the rotation of the servo motor. Second, it is equipped with a sensor for low-complexity posture recognition. Third, it can be worn on the wrist to recognize surrounding objects, which is particularly useful for blind people. The also developed a random sample structure for the active PIR system and established a statistical feature space for identifying human scenes.

Kalman Filter Application for Tracking System

By applying the Kalman Filter, Lee [9] proposed a method of tracking multiple people spotted in a multi-camera system and automatically align the camera. The inter-camera alignment algorithm works based on rigid transformation, while the tracking algorithm is based on Kalman filter method and combines various human body positions through cyclic correlation and model update processes. The tracking method shows a successful result, being able to merge multiple observation positions of a single person and track the position without losing the identity of that person.

Nguyen [10] introduced a new method to track human targets under conditions that are greatly affected by the complexity of the environment. The RGB-D camera is used to acquire and define the Depth of Interest (DOI), which is used in conjunction with the CAM-shift algorithm in human tracking. The Kalman filter is used and implemented to help predict the direction of the target. This method can produce more accurate and effective tracking results and can also be used in real-time applications.

Yao [11] applied Kalman filter to estimate the position of the hand at the human-robot interface. The leap motion is fixed on the Cartesian platform and captures the movement of the user's hand. The Kalman Filter helps counter measurement errors found in the process of retrieving gesture due to sensor-specific noise. The natural human robot interface using the adaptive tracking method can effectively expand the operating space while ensuring high precision. Therefore, the operation is more intuitive and natural because the robot can directly reproduce the movement of the user's hand.

Also, Rana [12] proposed a Kalman filter-based algorithm for human motion estimation using Internet of Things (IoT) sensors. The IoT sensors are used in smart control center to track elderly people and monitor their movements and postures. The residual error and Kalman gain determine the process noise covariance. The measurement noise covariance is also calculated together with the previous error covariance and residual error. The results of numerical simulation show that the developed algorithm can accurately track human orientation using IoT sensors.

3. HUMAN DETECTION ALGORITHM

3.1 PIR Motion Sensor

Human tracking system using cameras have been widely used as a conventional method of monitoring human movement. However, it is well known that the visual method of processing image information from the camera has disadvantage of small viewing angle, image pixels and lighting effects [13].

Recently, PIR motion sensor has been seen as a new sensor for detecting the presence of a person in a particular area. PIR motion sensor can scan human presence more effectively compared to regular cameras.

Furthermore, we can passively detect motion of an object especially human from distance by using PIR motion sensor. Figure 1 shows the PIR motion sensor used in this research.

PIR sensors used to detect movement and primarily to detect if a person has moved in or out of the sensor's range. It is small, inexpensive, has lower power consumption and is easy to use. For these reasons, it can be found commonly in home appliances or gadgets.

Figure 1. PIR motion sensor

3.2 Object Detection by PIR Detection Module

To make object detection design easy, simple and stable, each PIR sensor is fixed in 5 rooms which are Entrance, Room A, Room B, Room C and Exit area. PIR sensor basically detect levels of infrared radiation. The PIR sensor able to scan and detect the presence of human because of body temperature.

The detection area of each PIR detection module is divided into 9 individual cells in the reference structure as shown in Figure 2. Each cell has an area of 0.5 x 0.5 m. The maximum sensing area for PIR sensor as shown in Figure 3.

According to PIR data sheet, the sensitivity range of the sensor is 100 degree wide, with 7m high from the center and 4m high from the edge [14]. Generally, the ceiling height of an apartment is about 2.5m to 3m. According to trigonometric function, if we assume that h=3, we get the hypotenuse of 3/*cos 50°* = 4.668m. Therefore, there are some areas that the sensor cannot detect.

To overcome this issue, we limit the hypotenuse at $h/\cos\theta < 4$ (width of detection area after being molded by reference structure). If h = 3 and $\cos\theta > 0.75$, then we get the boundary of detection area is $\theta \leq 41°$.

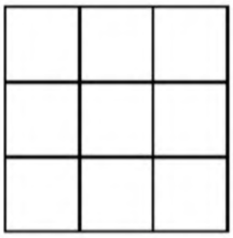

Figure 2. The discrete cell of each detection system

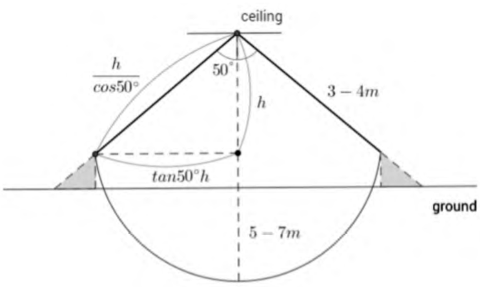

Figure 3. Maximum detection area for PIR sensor [14]

The aim of this design is to make PIR detection module to sense the presence of human within the reference structure area as in Figure 4. The coding of discrete cell is used to send data to the main computer once it identifies the presence of human within the reference structure location. In Figure 5, the detection area is divided by vertical lines based on the side view of PIR detection area. The angle θ and φ represent the outer and inner width respectively, which connected to the detection radius, r with the following equation.

$$r = \tan\theta\, h + \tan\varphi\, h \quad (1)$$

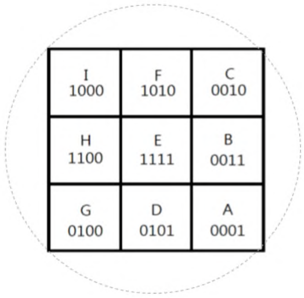

Figure 4. Reference area of PIR detection module

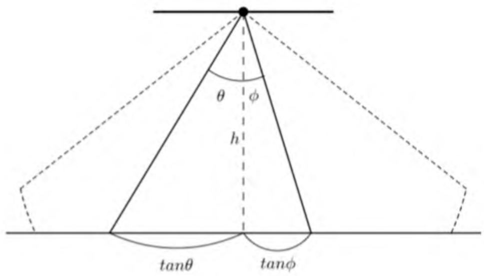

Figure 5. PIR sensor detection area (side view)

4. 4. TRACKING ALGORITHM

4.1 Human Modelling Using Kalman Filter

A discrete human body model is used, where it is treated as moving points on the ground. Then, the following human body model is applied in Kalman Filter to estimate the state of human object. The state vector x consists of the position and velocity of the center of human body as in

$$x^t = (p^t_x \quad p^t_y \quad v^t_x \quad v^t_y)^{\mathrm{T}}, \quad (2)$$

which the superscript t represents the index of the number of human objects in the tested area. The system model is designed as follows:

$$x^t(\mathrm{k}+1) = F^t x^t(k) + w^t(k+1), \quad (3)$$

Which w described as the modelling error and k represented the discrete time. Then, the state transition matrix is presented as follows:

$$F^t = \begin{bmatrix} 1 & 0 & \Delta T & 0 \\ 0 & 1 & 0 & \Delta T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (4)$$

While the measurement equation is given as

$$z^t(k+1) = H^t x^t(k+1) + \delta^t(k+1)\,, \qquad (5)$$

where δ described the measurement error. The observation matrix is presented as

$$H^t = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}. \qquad (6)$$

4.2 Tracking Method

The procedure for tracking is planned as following order. These entire steps will be repeated at each scan time to create tracking system. In this study, it is assumed that we are tracking people who walk in general motion, except for irregular movements.

Step 1 (Clustering Data): First, we need to extract the target person data from PIR sensor after it scanned the area and classified it into effective cluster to subtract from environmental data.

Step 2 (Finding Object Position): After that, as described above, the position of the target body model is entered by considering its exact body model location inside the reference structure.

Step 3 (Associating Object Possibility to Current Position): The target has been tracked until previous scanning are connected to current body possibilities. This is used to utilize the measurements for position estimation process. Here, we used a half breed scheme that includes a detection of minimum distance and validation region that can be expressed by the following equation.

$$\gamma \geq \upsilon'(k+1)S^{-1}(k+1)\upsilon(k+1) \qquad (7)$$

The innovation vector $\upsilon(k+1) = z^t - \hat{z}^t$ denotes the position error between the sensor measurement z^t and the state estimation prediction $\hat{z}^t$, which is computed by the filter. $S(k+1)$ is the covariance matrix for the innovation vector $\upsilon(k+1)$.

Step 4 (Update Objects States): The states of the target are update using Kalman filtering with sensor measurement to relate target body model with the measured position data given from the previous procedures. If object possibility has not been connected to the new scanning data for a while, it means occlusion state occur. If the occlusion time exceeds the given value, we consider it as disappearance and delete it. For checking whether the target enter the unauthorize area or not, the tracking map will show the whole movement of the target inside the facility.

5. 5. SIMULATION AND EXPERIMENT

5.1 System Configuration

Figure 6 shows the architecture of the proposed system which consist of five PIR sensors labelled with Sensor1, Sensor2, Sensor3, Sensor4 and Sensor5 fixed at Entrance, Room A, Room B, Room C and Exit area respectively. All these sensors are connected to the main computer for monitoring.

The tracking system start when main computer receives the input of human detection from Sensor1 at the Entrance area. After that person has been detected and tagged at the entrance, he will then be allowed to enter that area. Afterwards, the system will get alerted of his movement once he entered any rooms inside the security area. While doing this process, the system used Kalman Filter algorithm to predict the person's movement and update the tracking system.

This process will continue until that person is detected at the Exit and leave the security area. Then, the system will create the footprint mapping of that person inside the said area.

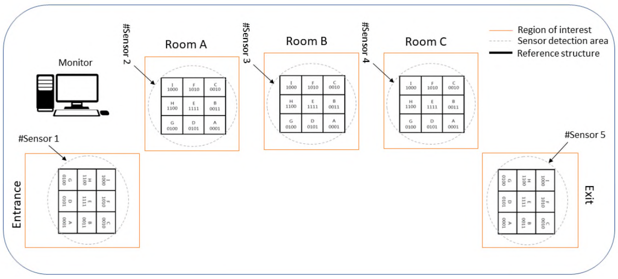

Figure 6. Architecture of proposed system

5.2 Experiment Results with Tracking System

The test bed for this system is replicated from small-scale security area consist of Entrance, Rooms A, B, C, D and Exit. Figure 7 shows the test bed for detection and tracking system.

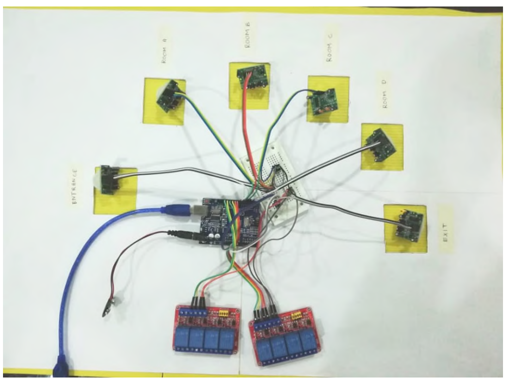

Figure 7. Test bed for tracking system

To evaluate the performance of the proposed system, the simulation for target tracking system is carried out in Figure 8. From this route, it can be explained that the target was first detected by the sensor at cell 'F' at the entrance. Then, he moved to cell 'G' at Room A and cell 'B' at Room B. Lastly, he went to cell 'E' at Room C before he was detected at cell 'B' at the Exit area.

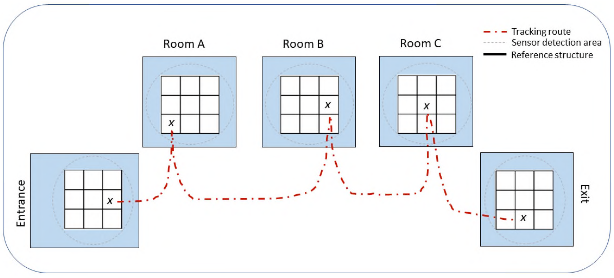

Figure 8. Target footprint mapping for tracking system

Inside the PIR sensor detection area, target moving with various speed and directions. The state variable is set to zero and adjusted by Kalman filter to assist in determining the target initial position and velocity. Figure 9 shows the trajectories of the target tracking before and after using Kalman filter. The maximum error between the trajectory after implementing Kalman filter and actual path was reduced from 0.28m to 0.19m. The average error also reduced from 0.10m to 0.07m.

This shows that the target tracking accuracy was improved after using Kalman filter. If the tracking map is more refined, the better accuracy can be achieved.

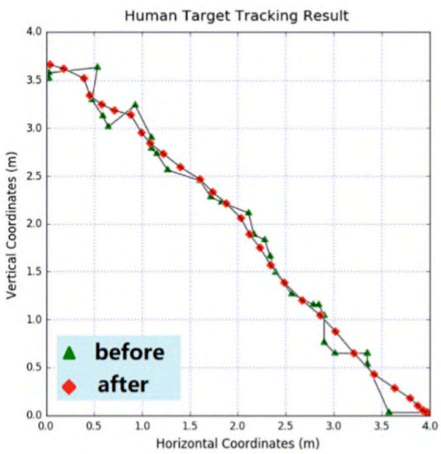

Figure 9. Target tracking trajectory by Kalman Filter

6. 6. CONCLUSION

In this paper, a novel method to detect and track people in multiple indoor location is proposed. PIR sensors were employed in each location to detect the presence of human object. Single-target model tracking system with Kalman filter algorithm is applied to track the movement inside the security area. The simulation experiments for detecting and tracking people are performed to verify the capability of the system for security surveillance application. The maximum error for tracking trajectory was reduced from 0.28m to 0.19m and average error for tracking trajectory also reduced from 0.10m to 0.07m after using Kalman filter. As for future works, continuous study on new method and algorithm to track multiple people at multiple location must be done to make the system viable for commercial purposes. The use of advanced identification and recognition system via security camera can be integrated in the future to enhance the functionality and effectiveness of the tracking system.

7. ACKNOWLEDGMENT

The authors gratefully acknowledged the contributions of research team members in Faculty of Electrical Engineering UTM.

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