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Vision-Based Autonomous Human Tracking Mobile Robot

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Abstract

Tracking moving objects is one of the most important but problematic features of motion analysis and understanding. In order to effectively interact robots with people in close proximity, the systems must first be able to detect, track, and follow people. Following a human with a mobile robot arises in many different service robotic applications. This paper proposes to build an autonomous human tracking mobile robot which can solve the occlusion problem during tracking. The robot can make human tracking efficiently by analysing the information obtained from a camera which is equipped on the top of the robot. The system performs human detection by using Histogram of Oriented Gradient (HOG) and Support Vector Machine (SVM) algorithms and then uses HSV (Hue Saturation Value) color system for detecting stranger. If the detected human is stranger, robot will make tracking. During the process, the robot needs to track the stranger without missing. So, Kalman filter is used to solve this problem. Kalman filter can estimate the target human when the human is occluded with walls or something. This paper describes the processing results and experimental results of a mobile robot which will track unmarked human efficiently and handle the occlusion using vision sensor and Kalman filter.

Keywords: camera; human tracking; HOG; HSV; Kalman filter; SVM.

1. Introduction

Tracking system is interesting for a number of robotic applications such as obstacle detection, automatic path planning, and surveillances. Human tracking is one of fundamental issues for human-robot interaction.

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To perform such a task, the robot needs not only to detect and track the target human but also to avoid obstacles in the cluttered environment. Most human tracking systems or mobile robots have been designed to operate in indoor and outdoor environments. When a human tracking algorithm is implemented in an outdoor environment, sensors will be exposed to more noise than indoor, and the human target can be occluded or temporarily lost. In such unstructured environments, human tracking is a difficult task. Human tracking approaches have been developed with most based on visual tracking and other approaches such as laser range finder-based human tracking, 3-D sensor tracking, RGB-D sensor tracking, and camera and laser fusion tracking. For a mobile robot that performs autonomously, the communication between the human and the robot is the most important factor. The main difficulty in this kind of work is that the detection of the target is a sensitive thing to carry out. To perform this task accurately, robot needs a mechanism that enables it to visualize the human and act accordingly [1]. The robot must be intelligent enough to track the human in the environment. When the autonomous mobile robot moves, it depends on vision system to detect the objects. So vision system is one of the key technologies for intelligent robot. Any object tracking technique must solve the temporal correspondence problem that is the task of matching the target object in successive frames. Usually, the tracking process starts with detecting the initial instance of the moving object, then identifying that image object repeatedly in subsequent frame sequence. Human tracking is often a difficult process, due to factors such as sudden object motion, object occlusions and camera motion [2]. The complete system is based on the use of both camera and ultrasonic sensor, which is to know the distance of the human and obstacles in the environment. To improve tracking performance, many researchers have been applied on the recognizable parts of the human body. Lee and his colleagues [3] and Arras and his colleagues [4] proposed a human tracking algorithm by scanning two legs, and Glas and his colleagues [5] scanned the torso part of a human. In this research, the robot makes its tracking performance by recognizing the cloth' colors of the human. So, the robot can make human tracking more quickly and accurately. Vision-based human detection, performed from a moving vehicle, is a difficult task because human are deformable obstacles. The robot will have to make to be clear the several different poses, wearing different clothes with different colors, and changing of their appearance to give more accurate data needed for human tracking. Therefore, Histograms of Oriented gradients (HOG) and the Support Vector Machine (SVM) are used to classify the objects whether human or not and color detection method is also used to improve the detection system for human tracking. This system is able to detect human and obstacles appearing in the scene.

In this paper, the mobile robot makes human tracking in indoor environment. It detects human by using the Histograms of Oriented gradients (HOG) features and the Support Vector Machine (SVM) and then makes color detection by estimating the color on a person's cloth to be sure whether that person is stranger or not. If the robot detection shows that person is stranger, the robot will make tracking. During the process of human tracking, the robot tracks the stranger all the time not to be missed from its vision. The stranger can be occulded with something during tracking. To solve this problem, the system will track human by using Kalman filter. The Kalman filter (KF) has commonly been used for estimation and prediction of the target human position in succeeding frames. The tracking system is activated after a successful detection. With this approach, the robot can even follow a human who is hidden or occulded with something in the camera vision. This paper is organized as follows: Section (1) describes the introduction of the system. Section (2) describes about the related works for human tracking systems. Proposed system and overall flow chart are described in Section (3) and Section (4). Methods of human features detection with HOG system and stranger detecting by color detection algorithms are discussed in Section (5). In section (6), robot control system is described. Tests and results of human tracking system is shown in Section (7). About the discussion and conclusion of the system is described in the last section.

2. Related Work

Tracking people by the use of a mobile robot is an essential task for the coming generation of service and human-interaction robots. In the field of computer vision, the tracking of moving objects by mobile robot is a relatively hard problem. The most fundamental requirement to achieve stable motion detection from a mobile platform is to compensate the motion of a sensor. The computer vision community has proposed various methods to stabilize camera motions by tracking features [6, 7] and computing optical flow [8, 9]. These approaches focus on how to estimate the transformation between two image coordinate systems. Other approaches that extend these methods for motion tracking using a pan/tilt camera include those in [10]. However, in these cases the camera motion was limited to translation or rotation. When a camera is mounted on a mobile robot, the main motion of the camera is a forward backward movement, which makes the problem different from that of a pan/tilt camera. There is other research on tracking from a mobile platform with similar motions.

Person detection represents the process of identifying the presence of humans in video streams and differentiating them from non-human video objects. Human tracking identifies the instances of each detected person in the frames of the analysed movie. Detecting humans in images and videos constitutes a challenging task, being complicated by numerous factors, such as: variable people appearance, camera position, wide range of poses adopted by persons, variations in illumination, brightness, contrast levels or backgrounds, and person occlusions [11, 12]. Over the last decade the problem of detecting and tracking humans has received a considerable interest. Significant research has been devoted to detecting, locating and tracking people in digital images and videos, since numerous applications involve humans' locations and movements [13]. Many person identification and tracking techniques have been developed recently [14].

Most of the tracking methods focus on tracking humans in image sequences from a single camera view. In [15], each walking subject image was bounded by a rectangular box, and the centroid of the bounding box was used as the feature to track. By using the KF and the Optical Flow for the navigation of the mobile robot because it will predict next state from the previous state. Human tracking by mobile robots has been an area of intense research for years. Humans can be tracked by mobile robots using 3D or 2D data by any normal KF [16, 17], or using segmentation of the main target from the background [11, 12]. Other approaches are based on hierarchical KF [14] and quaternion [15]. Extended KF [16] and the interactive multiple model [17] have successfully been used for human tracking using mobile robots in the past. In [18], stereo vision and KFs are used to track and follow a single person using a mobile robot for short distances. But sudden deformation in the target motion can cause the failure of the predefined behaviour model of KF [13]. In [19], a robot equipped with two laser range sensors, one pointing forward and another backward, can track several people using a combination of particle filters and joint probabilistic data association.In this research, the system is presented a method of a human tracking robot based on human feature identification and clothes' colours detection by using a camera and ultrasonic sensors. Intelligent tracking of specified target is carried out by the use of vision sensor and Kalman filter. Kalman filter can solved the problem of target person missing which can be caused by occulded with walls or something in the environment while tracking.

3. Proposed System

The autonomous capability of mobile robots is a social and technological issue. Many potential applications add to the importance of human tracking technology. In this paper, the system proposes the detection and tracking schemes for human by the use of a camera. The mobile robot is moving in the indoor environment and detecting the human. Firstly, Mobile robot's camera captured the image sequences which are used as the input to the system. From the capturing images, the robot detects moving objects by Histograms of Oriented gradients (HOG) to be sure whether the object is human feature or not. After detecting the human features with HOG, the support vector machine (SVM) will classify whether the moving object is human or not. If the detected object is human, the robot will classify the stranger detection by using HSV colour system to track that human.

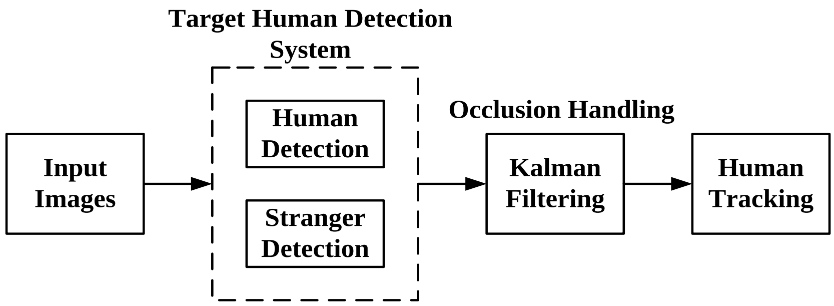


Figure 1: System block diagram

In color detection, it detects the upper color of cloth (White) and lower color of cloth (Dark Blue) of the detected human. If the detected human's colors are not upper white color and lower dark blue color, the robot will follow that human. So, the robot will make human tracking who is not wearing the school uniform. The proposed algorithm works by estimating the color on a human's cloth so that the robot can decide that human is strangers or students. After detecting the stranger, the mobile robot tracks the target human person around in the structured indoor environment. Along tracking, the robot performs the tracking system by using Kalman filter calculation data. Kalman filter is used for the pose estimation of the target person because it will predict next state from the previous state. To predict the stranger's pose, the system needs to know the distance between robot and the target person which can be got from the human detection system. So, the robot can track the target person even when the target person is out of vision in the environment. The system block diagram of vision-based human tracking robot is shown in Figure 1. The proposed scheme is successfully verified in real time environments.

4. System Flowchart

In this system flow chart, the mobile robot captures the images around in its surrounding and then human detection will make with HOG and SVM from these images. If the detected object is a human, the system will make stranger detection by using clothing colour detection algorithm. When the detected human is a stranger, the system will calculate the heading angle of the stranger will get from the human detection system. After that, the system make Kalman filtering to reduce the pose estimation errors during human tracking. Kalman filter is used to know the position of the target person. This filter will predict next state from the previous state and also need to get the measurement values from the detected human box. After the prediction step, the system makes updating step for pose estimation. Then, these calculated data are sent to the control board to make steering control for mobile robot. Finally, the robot will make human tracking. The flow chart of the proposed system is shown in Figure 2.

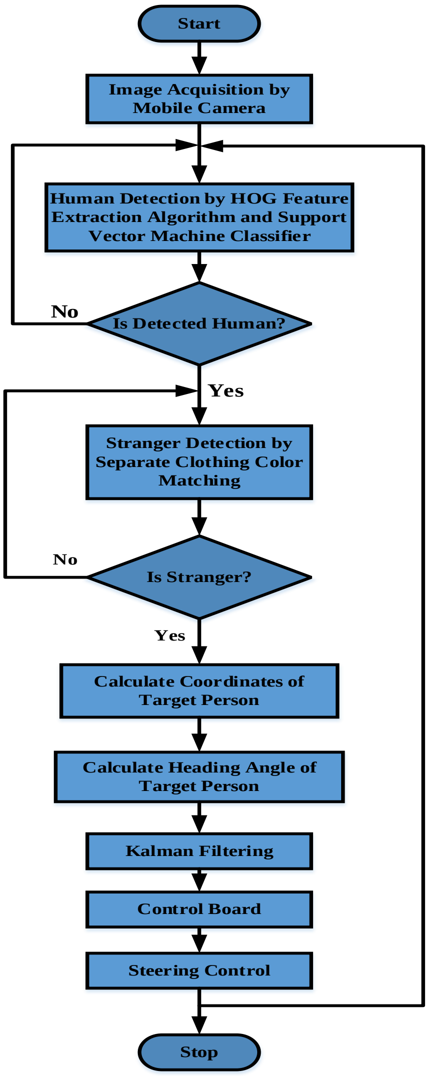


Figure 2: System flow chart

5. Human Detection System

Human detection is closely related to general object recognition techniques. It involves two steps- feature extraction and training a classifier as shown in Figure 3. Feature extraction is the main step of image understanding. Feature is a significant piece of information extracted from an image which provides more detail understanding of the image. After having all the moving objects labelled and segmented, the next step is to understand what the object is or in other words, to recognize them. The algorithm uses HOG features trained using linear Support Vector Machines (SVMs). The linear SVMs are trained on positive and negative training images.

Figure 3: Components of Human Detection System

5.1. Histogram of Oriented Gradients (HOG) descriptor

Histogram of Oriented Gradients (HOG) is a technique to extract features from an image. It is an algorithm that extract features from an image, which can be used to train object detection algorithms. It generalises properties of objects by rendering various conditions invariant in describing the feature. This means objects are represented by a single, global feature vector, instead of a collection of smaller, local features representing different parts of the object. The implementation of the descriptor can be achieved by dividing the image into a grid of small connected regions, called blocks, and for each block constructing a histogram of gradient directions for the pixels within the cell. The histograms are concatenated to represents the features. For improved accuracy, the local histograms are normalized by calculating a measure of the gradient across a block, and then using this value to normalize all pixels within the block. the magnitude and orientation of pixels can be calculated by using equation (1) and (2). Histogram of Oriented Gradients Overview is shown in Figure 4.

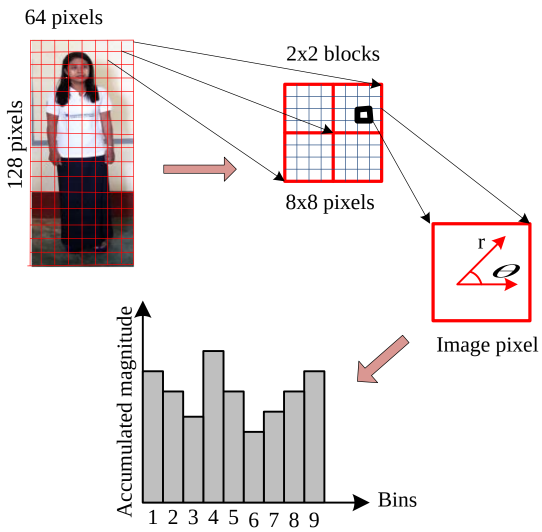


Figure 4: Histogram of Oriented Gradients Overview

$$\text{Magnitude} = |I_x| + |I_y| \quad (1)$$

$$\text{Angle} = \tan^{-1}\frac{I_y}{I_x} \qquad (2)$$

5.2. Support Vector Machines classifier

The Support Vector Machines classifier is a binary classifier algorithm that classifies the detected object features as human or not. This characterization is finally used with a linear Support Vector Machine classifier [13]. General architecture of SVM classifier is shown in Figure 5.

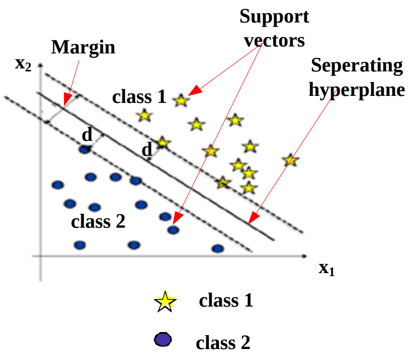


Figure 5: General architecture of SVM classifier

The recognition system is based on a supervised learning technique. A set of training image is used determining with and without human, and described by their HOG, to learn a decision function. When the SVM is trained for human, it will classify the moving objects features as human or not. In the verification step, the HOG feature vector is extracted from activity image frames and fed into the SVM classifier in recognition mode. Features with the highest confidence level are recognized as the correct human features. The confidence level is measured using the probabilistic output of the SVM classifier. The system processing results for human detection is shown in Figure.6. In Figure.6, the mobile robot detects the entire human in the environment. The detection results of HOG and SVM are shown with red color box.

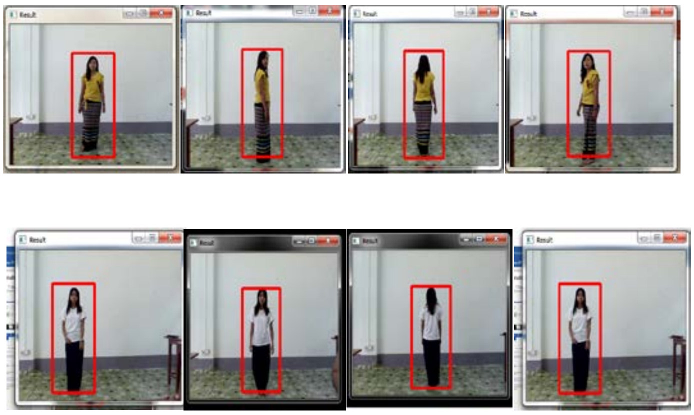


Figure 6: Processing results for Human detection system

5.3. Stranger Detection by Color Detecting

To make human tracking more accurately, the robot has to make accurate human detection so that it can correctly track the human who is not wearing the school uniform. Therefore, the robot detects the observed objects whether it is human features or not with HOG and SVM. If the object detection shows that the feature of the object is human feature, the system will make stranger detection by detecting cloth colors of human detection technique can be robust against non-stationary background.

Table 1: Color Detecting Ranges

	Upper cloth color (White)	Lower cloth color (Dark Blue)
R	0 ~ 0	100 ~ 179
G	0 ~ 0	100 ~ 255
B	0 ~ 255	35 ~ 50

For color detection, the system will firstly make classification. In classification system, the system classifies the detected image into three classes. The three classes are background, upper cloth color (white) and lower cloth color (dark blue). In this system, the background is neglected within colour detection. Depending on these classes, the system calculates the pixel values of image class. After cropping the parts of the human, the system will find the moments of the cropped area. If the detected color values are within predefined HSV color values and the calculated moment area is above the defined area (10000), it is considered that there is a target color in the mage. If it is not, the system will consider that there is no target color in the image After detecting the human with HSV, the robot will know the stranger person in the environment. And then the robot will make the tracking system. The HSV color range of detecting the stranger is shown in following table 1. The processing results of after converting HSV is shown in figure 7 and 8.

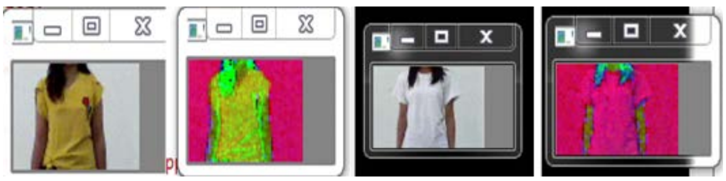


Figure 7: Processing results for Upper cloth's color detection using HSV

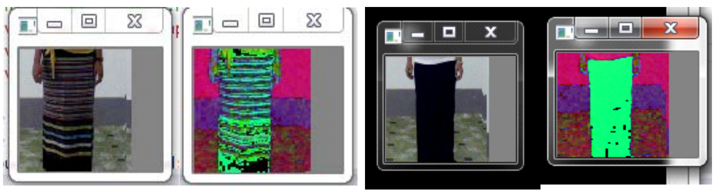


Figure 8: Processing resulots for Lower cloth's color detection using HSV

6. Robot Control System

The mobile robot is composed of the 4 DC motor with wheels, L298 motor driver, Raspberry pi model 3B, full HD resolution camera, Arduino mega board and two encoders. When the target human is detected, the raspberry pi module sends the two types of serial data. They are speed control data for the mobile robot and the direction data for the left or right turning of mobile robot. These two serial data are accepted by the Arduino mega board and this board drives the L298 motor driver to control the four motor for the speed and any direction for the mobile robot. When the target human is closed, the speed data is adjusted for the Arduino mega and Arduino board control the speed to reduce in mobile. when the target human is turn left or right, the direction data is changed to the left or right data for the mobile to track the target human. Figure 9 shows the robot control system.

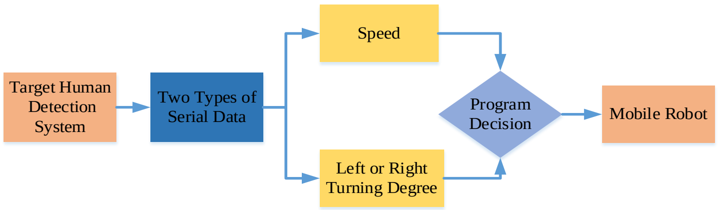


Figure 9: Robot control system

6.1. Position of target human in a coordinate frame fixed to a camera for tracking

The position of a human in the camera coordinate frame fixed to a camera is shown in Fig. 6. It is necessary to find a position of a human in the coordinate frame fixed to a camera in the case of a human tracking using the whole photo image captured by the camera.

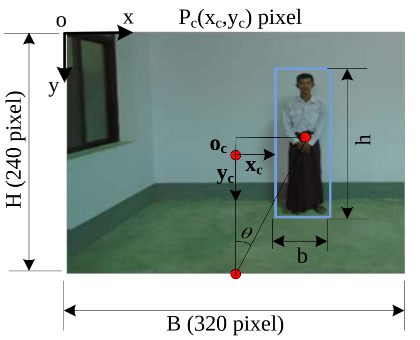


Figure 10: Position of a human in the camera coordinate frame fixed to a camera

The o_c-x_c,y_c coordinate frame denotes the camera coordinate frame fixed to the camera. The Pc (x_c , y_c) [pixel] denotes the position of the detected human of center. Where B is breadth [pixel] and H is height [pixel] of a whole photo image and h is the high and b is the breadth of the detection window. It is possible to calculate the coordinates (x_c , y_c) [pixel] and can calculate the P_c-$x_{c,}y_c$,[pixel] because the whole photo image is two-dimensional image. From this pixel differences the angle (ϴ) can be calculated by using triangulation method.

6.2. Kalman filter system

The Kalman filter is essentially a set of mathematical equations that implement a predictor-corrector type estimator that is optimal in the sense that it minimizes the estimated error covariance. The Kalman filter has been used extensively for tracking system. The Kalman filter estimates a process by using a form of feedback control: the filter estimates the process state at some time and then obtains feedback in the form of (noisy) measurements. As such, the equations for the Kalman filter fall into two groups: time update equations and measurement update equations.

The time update equations are responsible for projecting forward (in time) the current state and error covariance estimates to obtain the a priori estimates for the next time step. The measurement update equations are responsible for the feedback—i.e. for incorporating a new measurement into the a priori estimate to obtain an improved a posteriori estimate. The time update equations can also be thought of as predictor equations, while the measurement update equations can be thought of as corrector equations. Indeed, the final estimation algorithm resembles that of a predictor-corrector algorithm for solving numerical problems as shown below in Figure 11.

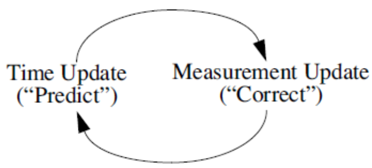


Figure 11: The Kalman filter cycle

In this human tracking system, the system estimates the position of the target human by calculating the data from HOG detection window with Kalman filter. The Kalman filter addresses the general problem of trying to estimate the state of a discrete-time controlled process that is governed by the linear stochastic difference equation

$$\hat{X}_{k|k-1} = A\hat{X}_{k-1|k-1} + Bu_k \qquad (3)$$

$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q \qquad (4)$$

The random variables represent the process and measurement noise (respectively). They are assumed to be independent (of each other), white, and with normal probability distributions

$$p(w) \sim N(0, Q)$$
$$p(v) \sim N(0, R) \tag{5}$$

In practice, the process noise covariance and measurement noise covariance matrices might change with each time step or measurement, however here they are assumed as constant.

The matrix in the difference equation (1) relates the state at the previous time step to the state at the current step, in the absence of either a driving function or process noise. Note that in practice might change with each time step, but here it is assumed as constant. The matrix B relates the optional control input to the state x. The matrix in the measurement equation (2) relates the state to the measurement. In practice might change with each time step or measurement, but here it is assumed as constant.

The next step involves finding an equation that computes a posteriori state estimate as a linear combination of a priori estimate and a weighted difference between an actual measurement and a measurement prediction. The kalman gain can be calculated from the equation

$$J_k = \frac{P_{k|k-1}C^T}{(CP_{k|k-1}C^T + R)^{-1}} \tag{6}$$

The measurement update equations are

$$\hat{X}_{k|k} = \hat{X}_{k|k-1} + J_k(Y_k - C\hat{X}_{k|k-1}) \tag{7}$$

$$P_{k|k} = (I - J_k C)P_{k|k-1} \tag{8}$$

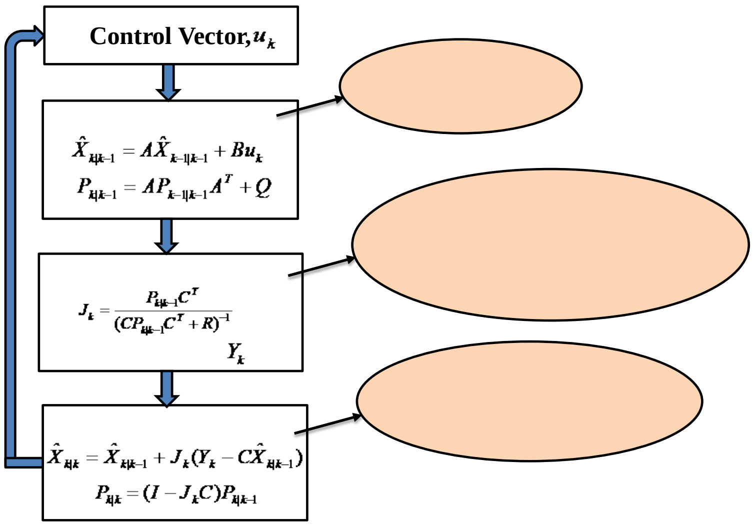


Figure 12: Flowchart of the Kalman filter used for human tracking system

The first step during the measurement update is to compute the Kalman gain. The next step is to actually measure the process and then to generate a posteriori state estimate by incorporating the measurement as in equation. The final step is to obtain a posteriori error covariance estimate via equation. Flowchart of the Kalman filter used for human tracking system is shown in Figure 12. After each time and measurement update pair, the process is repeated with the previous a posteriori estimates used to project or predict the new a priori estimates. After processing with Kalman filter, the system sends the processing results to Arduino Control board to drive the mobile robot without missing the target human. Processing results of target human tracking are shown in following figures. In figure 13, the system can detect the target human from its vision and in figure 14, the system can track the target person when the target person is in occluded condition.

Figure 13: Processing results for target person following with Kalman filter

Figure 14: Processing results for target human tracking in occluded condition using Kalman filter

7. Tests and Results of Human Tracking System

In human tracking system, the system detects all moving objects to know whether it is human or not by detecting with HOG and SVM.

This human detection works well if the whole body of a person is observed. The complete system is based on the use of both camera and ultrasonic sensors. After human feature detection on the observed objects with HOG, the system makes stranger detecting with HSV color detection.

The system makes color detection by comparing the HSV colour assign range with the detected human's upper and lower cloth colour range. After this all detections, the robot will make tracking system by doing with two functions: target human following and obstacle avoidance.

(e)

(j)

Figure 14: The experimental results for human and stranger detection during human tracking

(d)

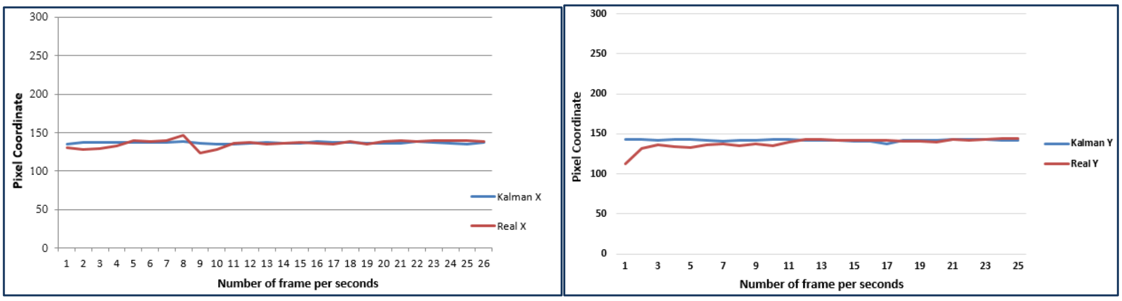
(h)

Figure 15: Target human tracking without missing in occluded condition

This system uses Kalman filter to be more efficient in tracking method. Kalman filter can perform well even when the target human occluded with something during its motion. The human tracking system using Kalman filter can give out more accurate results. The mobile robot detects the entire human in the environment. The mobile robot is moving and detecting the objects in the environment. When the robot found the stranger, it will note that human as target human and then make human tracking. The experimental results for human and stranger detection are shown in Figure 14.

When the robot knows the target human, it will follow that human. It can still follow the target human who turns to one side or occluded with something by estimating the target human state with Kalman filter. So, it can't miss the target human during tracking. The results of target human following and solving occluded conditions are shown in Figure 15.

The comparison chart for measurement pixel coordinate values and Kalman filter calculated values are shown in Figure 16 (a) and (b). In these figures, Kalman calculated coordinate values for human tracking system is stable with little variation and so the robot can track the stranger even when the stranger is out of view or occluded with something. Therefore, the system can reduce the position errors effectively during human tracking.



(a) (b)

Figure 16: Comparison result of Real and Kalman coordinate X and Y

8. Conclusion

A key requirement for robots is the ability to detect humans and interact with them. So, human detection and tracking are important capabilities for applications that desire to achieve human-robot interaction. An effective implementation of human tracking robot is illustrated in this research. In the case of human detection, it is necessary to perform an image processing on images captured by a camera.

In this research, the Histograms of Oriented gradients (HOG) features and the Support Vector Machine (SVM) were used in detecting a human. Then, the robot performs colour detection to be sure the human is not students. It perform stranger detection with HSV colour system by separate colour detection on the upper cloth colour (white) and lower cloth colour (dark blue) of the human’s clothes so the robot can detect the human with less error. If the stranger detection system was used with only one color, the system would get more error in stranger detection. This system showed that the use of color detection reduces the errors of the tracking system and can give more accurate results. In this paper, a novel tracking method is proposed, which is able to predict a target position very efficiently even if the target object turns suddenly during its motion. Tracking algorithm using kalman filter has been successfully tested on our mobile robot in real-time tracking of human in an indoor environment. This robot does not only have the detection capability but also the tracking and following ability as well.

9. Recommendations

The proposed algorithm is intended to use in indoor environment. This tacking robot can be used in outdoor environment by changing the robot mechanism and adding sensor technology. This human tracking robot is used as a security robot in this research. This research can be extended to work for various kinds of adverse condition. The system uses only vision and does not use depth data for detection. This system might be made even more robust and efficient by insertion of other sensors resulting in asynchronous and heterogeneous multiple sensory fusions.

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