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A Monocular Vision-based Specific Person Detection System for Mobile Robot Applications

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Abstract

The availability and low price of single camera makes them an attractive sensor to develop more sophisticated applications in the field of robotic system. Person detection and tracking systems are important capabilities for applications as a service robot in hospital environment. This work presents a simple method that able to visually detect and track specific person using a single camera based on hybridization method of image information. This method is applied to estimate the position and orientation of a moving target person in crowded hospital environment that can be a nurse or a doctor. The range between the target person and the mobile robot can be computed in real-time using a set of markers so that the robot can control its speed and direction to follow the target person as closely as possible. The experimental results show that proposed algorithm can detect target person under various conditions such as marker features, lighting and in complex backgrounds.

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1. Introduction

The problem of a specific person detection and tracking system has been studied by many researchers in literature. Most of research efforts on target detection and tracking system have been documented based-on vision methods. One of the important tasks of vision-based target detection is that the system should be able to detect and track the person in various environmental conditions and situations. Vision-based is an economical approach. But this method is very challenging for robust real-time person detection and tracking [8] due to uncontrolled lighting conditions, motion target in crowded environment and moving camera. This situation can cause the captured image loss information. The image information such as color and texture is very important for target identification. The most popular method on target detection and tracking is by using feature-based approach. However, most of them still focus on detecting of shape, motion of target and human skin color [5], [10], [17]. Fritsch et al. [7] have applied color segmentation of skin regions for face detection. Tsalatsanis et al. [16] have also used color-based approach to identify the target person. They applied region growing algorithm to detect the target person by using color information of wearing cloth. Satake and Muira [14] have been developed shape-based techniques for person detection. In recent years, stereo cameras are widely used for person detection and tracking by mobile robots [8], [9]. However, many of them have proposed the method for detecting multiple people but not a specific person [3], [13] and some of them use only a fixed camera. In addition, the major drawback of the systems mentioned above is that they are not capable of distinguishing the target person from the other people when they wear cloths of similar color or from other objects of similar color appearing in the vicinity of target person. A system of detecting a person by shape can also detect shapes not belonging to the specific person. In this paper, a novel system for specific person detection and tracking...
based on marker detection system has been proposed. This system can be used for service robot in hospital environment such as doctor assistant since the population of patient is increasing whereas the required number of nurses is always inadequate. The efficiency of marker-based person detection and tracking system can be evaluated by computing of its detection and tracking time performance in real-time. Two yellow color circular patches on doctor’s dress are used as a marker for target person identification. This system performs the image processing for noising object subtraction, marker identification, position and distance between the robot and target determination and then tracking a specific person. This paper is organized as follows: Section (2) describes briefly the system configuration. Section (3) introduces a hybridization of method combining color-based and shape marker technique for detection and tracking a specific person. In section (4), a motion control approach is present to keep the robot following the target. To test the performance of proposed method, some of the experimental results is shown in Section (5). Finally, conclusions are derived in Section (6).

2. Specific human following robot

2.1. Specifications

The target person following robot has a specially designed structure so that it can go into the limited space between hospital beds. The platform of robot is approximately 1m in height, 0.4m in width and 0.5m in length and can carry a weight of 25kg. The robot is mounted with two independently driven wheels so that it is able to move at a human speed and two additional wheels on the rear for maintaining the robot stability. A single camera is mounted on the top of robot to capture the image for target detection and tracking. Several ultrasonic sensors (Maxbotix LV EZ1) around robot body are used for obstacle avoidance. Lithiumion polymer (LiPo) batteries are used with its operation time is about one hour when fully charged.

2.2. System configuration

In this system configuration, two function parts have been constructed as shown in schematic diagram of system set-up in Figure 1. Figure 1a shows the Vision Part for detection and tracking the marker and Figure 1b shows the Motion Part for controlling the mobile robot to follow the Doctor. The captured image is sent to the Vision Part through an USB port. Various algorithms for processing of the monocular video image are included in Vision Part. In searching and localization of the marker, the Vision Part has two Modules: Detection Module and Tracking Module. The Detection Module needs the characteristics of marker including the color and shape information. A hybridization of method combining color features and edge information of marker is proposed to distinguish the marker from other noise objects. The background subtraction technique is performed to detect the foreground object.

Fig 1. Schematic diagram of system set-up. (a) Vision Part of marker detection and tracking system. (b) The algorithm of Motion Control Module.
Once the marker is detected, the system enters to Tracking Module. In the Tracking Module, the position of marker within the image is determined and the range of the marker from camera is computed. The information from the Tracking Module (distance and direction) is sent to Motion Part through an USB port. At the Motion Part, two independent differential drive motors are controlled to move the mobile robot appropriately towards the target. An onboard notebook PC (X2 Dual-Core, 2.0 GHz) performs the processes of both Marker Detection and Tracking. The Motion Control Module employs a 89V51RD2 microcontroller as the processor for determining the control for drive motors.

### 3. Monocular vision-based detection and tracking

#### 3.1. Marker-based detection

This paper focuses on the monocular vision-based marker detection and tracking system for application on person following mobile robot in hospital environment. Marker-based detection is one of the most popular methods and widely used in augmented reality (AR) applications [19] for motion tracking and pose estimation. Marker-based detection is a method where cameras are applied to detect the movement of targets. The most popular approaches within computer vision for target person detection are usually to select the most suitable feature parameters of a specified part of the input image such as the shape, color, aspect ratio, velocity etc. In order to detect and track the target person, the marker model has to be created. The proposed marker model includes the marker feature parameters, such as the color and shape to discriminate the target of detection from other confusing objects. A marker model is coded with the pattern of two circular yellow colors stickers as shown in Figure 2. The diameter of circulars yellow color is selected as 28mm each and separated by a distance of 40mm between centers. The marker is printed or fitted on the dress/coat of the target person.

#### 3.2. Color-based detection

Tracking objects based on color is one of the quickest and easiest methods. The speed of this technique makes it very attractive for near-real-time applications but due to its simplicity many issues exist that can cause the tracking to fail. In this research, color segmentation is done by choosing suitable thresholds range for marker detection. The input image with size 640x480 pixel is captured and filtered with a 5x5 Gaussian filter to reduce speckles of high frequency noise. Then the OpenCV package [1] is used to convert color space from RGB to HSV. The HSV is chosen for its ability to accommodate the variable lighting conditions. Next, the image segmentation is proposed to extract the regions of interest in order to remove all colors except the color of marker model (yellow). There are many kinds of techniques in literature for image segmentation [11]. But the most popular technique is by using Color Threshold approach [18]. The Color Threshold approach is widely used to remove parts of image that fall within a specified color range for foreground detection. This technique will check every pixel of the input image to allow only the values above a certain range to be realized based on the selected value of threshold. In this image segmentation, only the hue channel is used because it represents the value of color. The range threshold values, $H_{low}$ and $H_{high}$, for hue channel based segmentation are adopted. As a result, the threshold module will generate a binary image (mask) where the foreground color is white and the background color is black. Binary image means that each pixel is stored as a single bit (0 or 1) and this is important for limiting the computational speed of image processing. The characteristic function of detected foreground in binary image is defined as:

$$ I_M(i,j) = \begin{cases} 1 & \text{for foreground} \\ 0 & \text{for background} \end{cases} \quad (1) $$

where $I_M(i,j)$ is the binary image with pixel position $(i,j)$. An example of color segmentation obtained using the above detection method is shown in Figure 3.
3.3. Circular shape detection

Target tracking based on marker detection is not reliable if only one feature parameter is used. For example, especially in dynamic environment, there have may be the same colour objects with the target which can cause tracking to fail. In other words, further identification of the target marker such as motion and shape is necessary. Shape-based detection is often used as a further feature parameter for target tracking. Shape-based detection is basically to isolate the edges of objects in input images. This approach is fast processing speed because it need only monochrome image as input data for object detection. Monochrome image means that each pixel is stored as a single bit (0 or 1) and it is important to limit the computational speed of image processing. This method is also not independent of human behaviour. In other word, the target object can be static or moving. Various edge detection approaches have been applied for detecting the shape in object images. One of the most common image processing used is Canny edge detector [6]. The Canny edge detection algorithm is basically to detect edges in a very robust manner of the greyscales image. The circular patterns within an image can be easily recognized after the processing of shapes. In this stage, the Circular Hough Transform (CHT) is utilized to find two yellow circles of marker. The CHT has been accepted as a very powerful tool for the detection of parametric curves in images [12]. The CHT can be described as a transformation of a set of feature points in the image space into a set of accumulated votes in the parameter space [4], [15]. As the person moves, the dimensions of marker change. It is, hence, necessary to identify the circular marker against other noise objects by developing an algorithm. The equation of a circle can be described as:

\[(x - x_0)^2 + (y - y_0)^2 = r^2\]  \hspace{1cm} (2)

where \((x_0, y_0)\) is the center of the circle in a \((x, y)\) space and \(r\) is the radius of circle. To determine a circle, it is necessary to accumulate votes in the three dimensional parameter spaces \((x_0, y_0, r)\) that can be described with the parametric equations:

\[x = x_0 + r \cos \theta\]  \hspace{1cm} (3)
\[y = y_0 + r \sin \theta\]  \hspace{1cm} (4)

where \(\theta\) is the angle subtended at the center by a pixel on the circumference.
3.4. Marker recognition

Once the circles the image planes are found, the marker recognition is implemented. Sometimes, more false circles may be detected. To identify the correct circles, several aspects should be considered. An algorithm for the marker identification with three criteria is proposed. These criteria consist of radius of circle $r_i$, where $i \in \{1,2\}$, distance between two centers of circles as $Dx_M$ and distance between two centers of circles as $Dy_M$ in y-axis. Referring to Figure 4, $Dx_M$ can be measured by using the Euclidean Distance as:

$$Dx_M = x_2 - x_1$$  \hspace{1cm} (5)

$$Dy_M = y_2 - y_1$$  \hspace{1cm} (6)

$$Dt_M = \sqrt{(Dx_M)^2 + (Dy_M)^2}$$  \hspace{1cm} (7)

where $Dx_M$ is the distance between two centers of circles in x-axis; Circle 1 is at $(x_1,y_1)$ and circle 2 is at $(x_2,y_2)$ as shown in Figure 4. A space of $(x,y) = (640x480)$ pixels is considered. Circle 2 is assumed to be far away from the origin compared to circle 1. Assuming that the circles are placed along x-axis so that $y_1 \approx y_2$ with $Dy_M \approx 0$. Their values are then bounded as given by the inequalities:

$$ r_m \leq r_i \leq r_m \hspace{1cm} (8)$$

$$Dt_{min} \leq Dt_M \leq Dt_{max} \hspace{1cm} (9)$$

$$|Dy_M| \leq Dy_{min} \hspace{1cm} (10)$$

where

$r_m$: Minimum value of radius;

$r_m$: Maximum value of radius;

$r_i$: Radius of circle;

$Dx_{min}$: Minimum distance between two centers of circles in x-axis;

$Dx_{max}$: Maximum distance between two centers of circles in x-axis;

$Dy_{min}$: Minimum distance between two centers of circles in y-axis;

$Dy_M$: Distance between two centers of circles in y-axis;

It is visualized that $r_i$ and $Dx_M$ are positive; $Dy_M$ can be of positive or negative values. Figure 5 shows an example of shape segmentation obtained using the above detection method and the placement of marker within the specified $(x,y)$ space.

3.5. Distance and position estimation

The robot orientation and the distance from robot to the targeted object are often used as feature parameters for tracking. This method has also suggested by [4]. They measured the distance from the target object to robot by using laser which can track the target continuously when there are no obstacles in the tracking path. Kwon et al. [9] calculate the distance from the robot to a target object by using two uncalibrated independently moving cameras. Stereo cameras are also popular for tracking [14], [16], but this method requires complex computation. In this system, a simple method by using only a single

![Fig. 5. Marker detection. (a) Edge image of circle recognition. (b) Marker is placed within (640x480) pixel area.](image-url)
camera for tracking the marker have been proposed. This method mainly depends on the varying \( D_{tM} \), the distance in pixels between two centers of circles in the marker as the robot moving towards the target. The direction of robot motion depends on the positional information of the moving marker as an input from the Detection Module. This position is determined by calculating the center of mass \((X_M, Y_M)\) of the marker as:

\[
\begin{align*}
X_M &= x_t + \frac{Dx_M}{2} \\
Y_M &= y_t + \frac{Dy_M}{2}
\end{align*}
\] (12)

The distance between two centers is needed to calculate the distance of marker from robot. A relationship is proposed to calculate the distance of marker from the robot (also referred to as the range) as follows:

\[
Z_r = \frac{C}{D_{tM}}
\] (14)

where \( Z_r \) is the range and \( C \) is measured in the linear portion of “Range Vs \( D_{tM} \)” plot. However, a look-up table on range against \( D_{tM} \) can be generated by series of experiments. This table can be a reference to determine the range when \( D_{tM} \) (in pixels) is measured.

4. Motion control

Once the robot position on the image plane is estimated, then, the system enters into the Motion Control Module in Motion Part. At this stage, the image plane is segmented into 3 acting regions as shown in Figure 6a. Region 2 makes the robot move toward the target, while regions 1 and 3 make the robot turns on left and right, respectively. For example, if the position of marker is not at the region 2, the system makes the robot turns on its vertical axis appropriately to bring the center of mass at the center of image plane. The turning direction depends on the value of steering angle of robot \( \phi \). If the value of \( \phi \) is positive, the robot will turn in clockwise; otherwise the robot will turn anticlockwise. The robot’s steering angle \( \phi \) can be measured by the following equation:

\[
\phi = \beta - \frac{\rho}{2}
\] (15)

where \( \rho = 75^\circ \) is angle field of view of camera and \( \beta \) is relative angel according to center of mass in x-axis in image plane.

\[
\beta = X_{tM} \times \tau
\] (16)

where,

\[
\tau = \frac{75^\circ}{640\ \text{pixel}} = 0.1771 \ \text{pixel}
\] (17)

Then, the distance between robot and detected marker can be obtained by

\[
Z_m = \frac{Z_r}{\cos \phi} = \frac{Z_r}{\cos \left(0.1171 \times X_M - \frac{\rho}{2}\right)}
\] (18)

Since the distance is determined, then the robot is made to move towards the target person. The velocity of robot will be calculated using data derived from the monocular vision system. This velocity is varies from 0 to 1.4 ms\(^{-1}\) while average human walking speed is 1.3 ms\(^{-1}\) [2]. The human walking speed is decided to use at distance 1.4m to keep the robot tracks the target continuously and to avoid collision. This precaution is valid if the center of mass of marker fall at the center of image plane in region 2.
4.1. Motion path planning

In order to smoothly motion and changing direction of the mobile robot, a dynamic constraint such as driving velocities of both wheels should be considered in the design of the path planning algorithm. The robot with two difference driving wheels first turns on its vertical axis at the center of motion, denoted by $C$. This center is located at the midpoint between the right and left driving wheels. After the robot turns at steering angle $\phi$, then the robot moves in a straight line toward the target like path $B$ as shown in Figure 6b. Assuming that the robot moves on the planar surface without slipping, the tangential velocity of robot $v$ and $\omega$ angular velocity at center $C$ can be written as:

\[ v = \frac{v_R + v_L}{2} \times k \]  
\[ \omega = \frac{v_R - v_L}{d} \]  

where $v_R$ and $v_L$ is tangential velocity of the right and left wheels, respectively, $d$ is the distance between two wheels and $k = Z_m/140$ is a distance factor relatively to velocity. The tangential velocity of each wheel can be obtained as following relations:

\[ v_R = r \omega_R \]  
\[ v_L = r \omega_L \]

where $\omega_R$ and $\omega_L$ denote the angular velocities of the right and left wheels, respectively, and $r$ is the radius of the wheels. The velocity of robot is adjusted according to the relative distance between the robot and the target. For example, if the calculated distance is more than 1.4m, the velocity of robot will increase. Otherwise, it will decrease. However, for safety operation, the distance of moving robot is decided should not less than 0.7m from the target. In other word, the robot will stop if it calculated distance is less than 0.7m. The motion path planning like $B$ can moves the mobile robot toward the target accurately. However, since the turning rate of robot orientation is relatively slow, the target tends to go out of the field of view and the robot movement is not smooth. This planning path is only suitable if the target is static at the moment or during the robot searches the target when it loss. On the other hand, the circular trajectory like path $A$ from the current position to the target is proposed. In this case, the velocity of each wheel is adjusted to move the robot at velocity $v$ as follows:

\[ v_R = \mu \sin(\rho - \beta) \]  
\[ v_L = \mu \sin(\beta) \]
where \( \mu \) is the maximum speed of each wheel. These velocities rely on the steering angle \( \beta \). If it \( \rho/2 \) is less than the left wheel velocity \( v_L \) will decrease and the right wheel velocity \( v_R \) will increase. That means the robot turns on left. Otherwise, the robot turns on right. If the steering angle \( \beta = \rho/2 \), the robot will moves straight toward the target. If the center of mass of marker \( X_M \) in x-axis fall at the center of image plane in region 2 and the calculated distance is 1.4m, then the speed of moving robot is 1.3 ms\(^{-1}\). In this case, the steering angle \( \beta = \rho/2 \) then, \( v_R = v_L = 1.3 \text{ ms}^{-1} \). From Eq. (23), \( \mu = 2.14 \text{ ms}^{-1} \). Finally, the velocity of mobile robot can be expressed as:

\[
v = \frac{\mu Z_m}{280} \left[ \sin \rho \cos \beta + \sin \beta (1 - \cos \rho) \right]
\]  

(25)

5. Experiment results

In order to test the proposed system, the performance on three main experiments is measured: i) Detection and comparison the effectiveness of the selected color of marker in various lighting conditions, ii) Evaluation the performance of detection algorithm because of human behavior such as human walking speed and angle of rotation and iii) Evaluation the performance of robot to track and follow the target person. The marker-based person tracking algorithm is tested on a mobile robot where the webcam camera (Logitech C600) is mounted on the top of robot at a height of 1m from ground. The experiment demonstrates the effort of the detection algorithm that distinguishes the marker from the background, even if other objects with similar colors appear in the image scene. This experiment also shows the ability of detection algorithm to keep track of the marker in various lighting conditions. The first experiment is conducted with eight difference color of marker model to study the detection rate in varying light intensities. As well known, lighting conditions is one of the most challenging problems in vision-based for object tracking. The marker is placed 100 cm perpendicular to camera. Dimmers are used as devices to vary the brightness of a light where it can be measured by using lux meter. The image will captured in varying light intensities and then sent to Vision Module for marker detection. Table 1 shows the effectiveness of marker detection rate (%) in varying light intensities. From this result, it clearly shows that yellow color can perform better detection rate than other color.

The second experiment is conducted to study the effectiveness of changing in appearance because of person following behavior for marker detection. This study is focused on two motion patterns such as rotation and motion blur. The first test is conducted to evaluate the ability of our system to detect the marker in various rotation angles. Figure 7 demonstrates the result of detection rate in various rotation angles. This result is shown that the system perform accurately within an angle range of \( \pm 25^\circ \) where the detection rate is more than 80%. The maximum and minimum angle that the marker can be detected is \( \pm 45^\circ \). The next experimental study is to evaluate the performance of our detection algorithm for motion blur of

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input image. Motion blur is frequently caused by the relative motion between the camera and the objects in a scene. For example, the target person (marker) suddenly walks very fast or turns at the corner quickly will produce the motion blur of input image. In this experiment, the marker is mounted on the actuator linear sliding to precisely control its speed. Figure 8 shows the result of this experiment with seven different speed settings while the average human speed is 1.3 ms\(^{-1}\). As shown in Figure 8, the method can effectively detect the target with an average correct rate of 92.6%.

The third experiment is conducted to evaluate the performance of proposed method to follow a specific person in cluttered and dynamic indoor lab environment. It involves the robot moving across the lab space with difference in lighting conditions and dynamic background. The target person walks in the inside of an unstructured environment room. The robot performs following the target person at the distance of 1.4m where he/she moves the narrow inside the lab in the various directions. Figure 9 shows the tracking result in real time of person following test in the indoor environment. The upper and the lower graph show the distance between robot and target person and position of detected marker, respectively, while the robot follows the person. From this result, the average distance between robot and the target person is 133.4 cm. That means the robot keep moves in safety distance to the target. In addition, the average position of marker in monocular view of robot is 269 pixels, i.e. the robot always keep track target. Part \(a\) in Figure 9 shown that the tracking graph remained steady. At this situation, the robot loss the target and it try to searching the marker. In searching and localization of the marker, the previous distance and position before it loss will be recorded. When it found the target again, the new distance and position is measured and the speed to the target is recalculated. At part \(a\), the robot stop while the target person is not move. From this experiment, it was confirmed that the robot can follow a person smoothly who moves quickly and randomly.

6. Conclusions

In this paper a method of detection and tracking a specific person based on colored marker by using a single camera has been presented. The implemented system uses a hybridization of methods combining color features and shape information to distinguish a marker from other noise objects. The experimental results show that the proposed method of person detection demonstrating the high performance and low false positive rate. The system proves especially effective at detecting and tracking the target in real time such as various lighting conditions, human behavior and dynamic environment.
Fig. 9. Distances and position estimation from the robot to the target during it follows the person.

References


