INDOOR SECURITY PATROLLING WITH INTRUDING PERSON DETECTION AND FOLLOWING CAPABILITIES BY VISION-BASED AUTONOMOUS VEHICLE NAVIGATION

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ABSTRACT

A vision-based vehicle system for security patrolling by human detection and tracking in indoor environments is proposed. A vehicle with wireless control and a web camera is used as a test bed. A camera calibration method is proposed first by use of an angular mapping technique which is based on the concept of spherical coordinate system. Next, a human detection and tracking a human is proposed, which use a color feature of the face and that of the rough shape of the human body to recognize human beings. To track a target person, a clothes region intersection method is proposed to predict the motion of the person. In addition, a vehicle escape function is proposed, which is designed for the vehicle to move away from offensive strangers by a technique of safe distance keeping. Good experimental results show the feasibility of the proposed methods for the application of indoor security patrolling.

1. INTRODUCTION

Autonomous vehicle guidance by computer vision has been used in numerous applications. For the application of indoor security patrolling, not only vehicle learning and navigation but also stranger intrusion detection and tracking are important research topics. Use of a *moving* autonomous vehicle equipped with a video camera is more “active” than the use of traditional *stationary* cameras fixed on house corners. On the other hand, detection and tracking of moving humans in changing backgrounds is challenging and demands complicated solutions.

In ordinary video surveillances, human detection focuses on analysis of moving objects by frame differencing and background establishment [1]. When moving cameras are used, the conventional techniques cannot be applied since the scenes taken by the camera are unstable. In the case of human detection by mobile cameras, many approaches have been proposed, like optical flow [2], dense stereo and motion measurements [3], or thermal infrared sensing [4]. Many features were used to recognize humans, such as skin color [5], motion [6], depth [7], contour, and texture [8], etc. Since it is difficult to recognize humans in images using only a single feature, many systems use multiple features to distinguish human beings from other objects. Some systems extract skin color to detect human body parts, and track each part by motions [9]. Some others detect moving parts first and analyze their shapes to detect humans [10]. Heisele & Wohier detect pedestrians by clustering of color image segmentation results and analyzing the cluster shapes to find human legs [11].

In this study, we develop a vision-based vehicle for indoor security patrolling, with the function of detection and tracking of intruding persons. The vehicle also has the capability of escaping from offensive strangers by keeping safe distances. If the distance between the vehicle and a person is shorter than a safe distance, the vehicle will go to the last position in its path.

2. SYSTEM CONFIGURATION AND CAMERA CALIBRATION BY VIEWING ANGLES

In this study, we use the Pioneer3, a rugged vehicle made by ActiveMedia Robotics Technologies Inc., as a test bed, on which an optional robotic arm is equipped, as shown in Figure 1. The tip of the arm is enabled to hold a digital web IP camera, AXIS210. We control the vehicle via wireless communication. Since the camera is the only sensor of the vehicle system and the techniques of human detection and tracking are based on visual perception, camera calibration and image analysis techniques are indispensable. Through imaging with a camera, 3D world coordinate systems are mapped into 2D image coordinate systems. However, there is ambiguity in the inverse mapping from 2D image coordinates to the 3D world coordinates. Each point in the image is the projection result of a light ray onto the image sensor. The light ray can be described by a longitude angle and a latitude angle of

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the ray in the 3D world space. To define the corresponding longitude and latitude angles (or simply called the *longitude* and *latitude* in the sequel) of each point in an image, we propose a technique of *angular-mapping* camera calibration in this study. The details are described next.

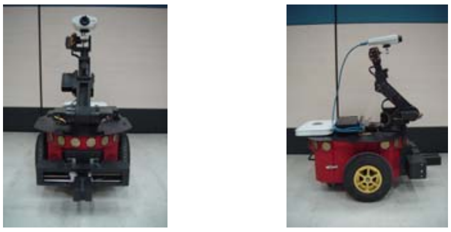


Figure 1. The vehicle Pioneer3 used in this study.

2.1 Coordinate Systems

The coordinate systems, as shown in Figure 2 include an *image coordinate system* (ICS) described by image coordinates (u, v) and a *spherical coordinate system* (SCS) described by parameters (ρ, θ, φ). The latter is a 3D polar coordinate system which can be explained in terms of the 3D Cartesian coordinate system with coordinates (i, j, k). The ij-plane of the Cartesian system is parallel to the uv-plane in the ICS. The origin S of the SCS, which is also the origin of the Cartesian system, is the optical center of the camera. A point P at coordinates (i, j, k) in the Cartesian space is represented by a 3-tuple (ρ, θ, φ) in the SCS where ρ is the distance between the point P and the origin S; the longitude θ is the angle between the positive k-axis and the line from the origin S to the point P projected onto the ik-plane; and the latitude φ is the angle between the ik-plane and the line from the origin S to the point P.

2.2 Camera Calibration by Angular Mapping

From the mapping of the ICS to the world coordinate system, it is impossible to figure out the distance between eyepoint and the point P due to the inherent ambiguity of the light ray projection. However, the projection P' of P can be represented by the longitude θ and latitude φ of P in the real world, as shown in Figure 3. Because camera distortion exists both horizontally and vertically, a real world data acquisition method by angular-mapping camera calibration is proposed here to compute the longitude and latitude values of each point in the image. We attach a grid with m vertical lines and n horizontal lines on a wall which is perpendicular to the ground as shown in Figure 4. Then we have a real world point set $\boldsymbol{V}$ = $\{V_{00}, V_{01}, \ldots, V_{mn}\}$ where $V_{ij} = (\theta_{ij}, \varphi_{ij})$ is a pair of the longitude and latitude values in the SCS of the point V_{ij} at the intersection of the ith vertical line and the jth horizontal line as shown in Figure 5. The set $\boldsymbol{V}$ of intersection points is known in advance. And the corresponding point set $\boldsymbol{P}$ = $\{P_{00}, P_{01}, \ldots, P_{mn}\}$ appearing in the image may be identified manually, where $P_{ij} = (u_{ij}, v_{ij})$ is a point in the ICS corresponding to point V_{ij}.

We have known the longitude and the latitude values of the yellow points in Figure 5(a) by mapping $\boldsymbol{V}$ into $\boldsymbol{P}$. We use an interpolation method to compute the longitude and the latitude values of the other pixels in the image. More specifically, given a pixel I in the image, which falls in a region with four corner points P_{ij}, $P_{(i+1)j}$, $P_{i(j+1)}$, and $P_{(i+1)(j+1)}$ of $\boldsymbol{P}$ whose coordinates in the SCS are known, we utilize the image distances between I and the four lines formed by P_{ij}, $P_{(i+1)j}$, $P_{i(j+1)}$, and $P_{(i+1)(j+1)}$ as weights to compute the relative coordinates in the SCS of I in the interpolation as shown in Figure 5(b). Using the calibration by the angular mapping method mentioned in this section, we can get the longitude and the latitude values of each pixel in the image. And the information is important to compute the distance between an object and the vehicle by image analysis.

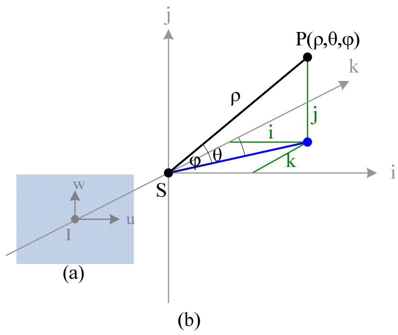


Figure 2. Coordinate systems used (a) Image coordinate system. (b) Spherical coordinate system.

3. HUMAN DETECTION AND TRACKING BY IMAGE ANALYSIS FOR INDOOR SECURITY PATROLLING

When the vehicle tracks a target person, the person is detected by the face. The detail will be described in Section 3.1. If nothing is detected, we try to confirm the decision further by detecting the existence of a human body using moving regions in the image. We propose a shift-tolerant blockwise frame differencing technique to detect moving regions. The detail will be described in Section 3.2. In Section 3.3, we present a method to extract clothes regions in images after an intruding person is detected. To track a target person, we propose a clothes region intersection method to predict the motion of the person in Section 3.4.

3.1 Human Detection by Faces

The rough sketch of a face can be represented by an elliptical shape with the skin color. Thus, we can detect a human face in the image by searching a skin-colored ellipse. We first segment out skin regions in the image and then fit shapes to them. If a skin color region is close to an ellipse in shape, it is decided that a face is detected. The detail is described in the following.

A. Skin Region Segmentation by Color Classification

We choose the YC_bC_r model to be the color space for detecting the skin color in images. Previous studies have found that pixels belonging to skin regions exhibit similar C_b and C_r values [12]. The distribution of skin color in the C_b-C_r plane is found similar to an oblique ellipse, as shown in Figure 6. In Lee and Yoo [13], a new statistical color model for skin detection with elliptical boundaries was suggested. Thus, we define an oblique ellipse in the C_b-C_r plane to be the skin color model in this study, and the parameters of the elliptical skin model are adjusted by experiments.

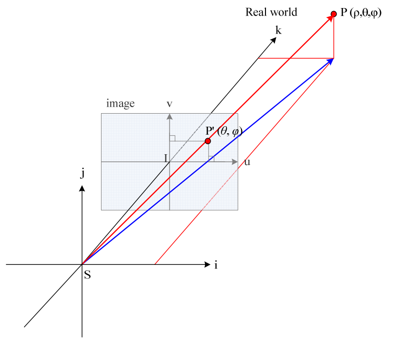


Figure 3. Image coordinates mapped into real world space.

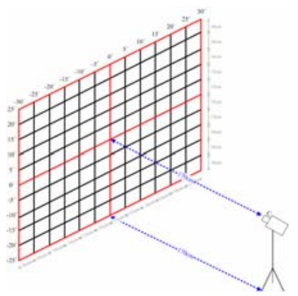
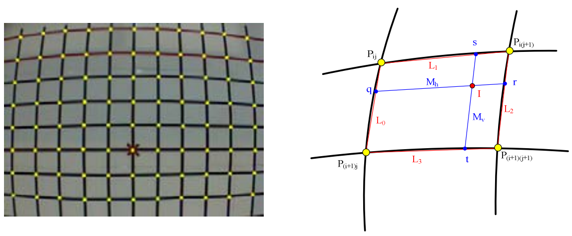


Figure 4. An illustration of attaching lines on the wall.



(a) (b)

Figure 5. A method of finding image coordinates of tessellated points in a grabbed image. (a) Tessellated points marked by yellow. (b) Illustration of interpolation where a region contains point *I* in ICS.

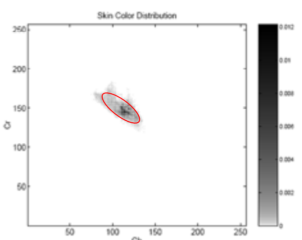


Figure 6. Distribution of skin color in C_b-C_r plane [12].

B. Detection of Human Face by Ellipse Shape Fitting

Since the shape of a human face is close to an ellipse, after segmenting the skin color regions out of an image, we determine if the region is similar to an ellipse. If so, we take it to be a human face. The proposed method is simple and different from usual methods like [14]. The method is described as an algorithm in the following.

Algorithm 1: *Face detection by recognition of ellipses.*

Input: A skin region set $\boldsymbol{R} = \{R_1, R_2, ..., R_n\}$.

Output: A face region R_{face}.

Step1. Get a new skin region set $\boldsymbol{R}'$ by filtering out regions too small or with wrong aspect ratio in $\boldsymbol{R}$.

Step2. Make a rectangular mask $rectangle_i$ and an elliptic mask $ellipse_i$ for each R_i in $\boldsymbol{R}'$.

Step3. For each region R_i in $\boldsymbol{R}'$, compute the number, in_i, of the pixels of region R_i within $ellipse_i$ and the number, out_i, of the pixels of region R_i within $rectangle_i$ and outside $ellipse_i$ by

$$in_i = number\ of\ pixels\ in\ R_i \cap ellipse_i;$$
$$out_i = number\ of\ pixels\ in\ R_i \cap (rectangle_i - ellipse_i)$$

Step4. Calculate a score S_i for each R_i in $\boldsymbol{R}'$ by $S_i = in_i - out_i$ and normalize S_i into the range of [0, 1].

Step5. Decide region R_i to be a face region R_{face} if the score S_i' of R_i is highest among all regions in $\boldsymbol{R}'$ and S_i' is higher than a pre-determined threshold h in the range of [0, 1].

3.2 Human Body Detection by Motion Analysis

When a person is too far from the vehicle, he/she cannot be detected by face detection. We thus propose alternatively a method of frame differencing and a method of human body recognition in the following.

A. Motion Detection by Shift-Tolerant Blockwise Frame Differencing

First, we define some terns for use in the proposed method. The image captured from the camera at the current moment, or equivalently, in the current navigation cycle is called the *current image.* The image captured at the last moment is called the *reference image*. A *searching window* is defined to consist of a square region of pixels, whose size is larger than the size of an image block.

Subtracting the current image from the reference one block by block is the proposed idea of blockwise frame differencing. If the difference between the target block in the current image and the candidate block at the same position in the reference image is smaller than a certain threshold t, then it is possible that no motion has taken place. If it is not, we find then the *best match block* for the target block within the searching window in the reference image. If the difference between the best match block and the target block is smaller than the threshold t, we decide that the target block is *stationary*; otherwise, *moving*. Repeating these steps for each block in the current image, we can get all the moving parts in the current image. The value of the threshold t is decided by experiments for different environments. The detail is described in the following algorithm.

Algorithm 2: *Shift-tolerant blockwise frame differencing.*

Input: current image I_c, reference image I_r, block size $s \times s$, and the size of a searching range w.

Output: a difference image I_d.

Step1. Segment I_c into a block set $\boldsymbol{B}_c = \{b_{ij}, i = 1, 2, ..., m, j = 1, 2, ..., n\}$ as shown in Figure 8. Also, segment I_d into a block set B_d in the same way.

Step2. Define the range of the searching window to be $(2w+s)\times(2w+s)$, as shown in Figure 9. Subtract each target block b_{ij} from the candidate block at the same position in the reference image. If the difference is smaller than a threshold t, regard the target block b_{ij} as *stationary* and go to Step 5. Otherwise, go to Step 3.

Step3. Find the best match block of the target block b_{ij} within the searching window in the reference image by subtracting the target block b_{ij} from each of the blocks within the searching window.

Step4. If the difference between the target block b_{ij} and the best match block is smaller than the threshold t, regard b_{ij} as *stationary*; else, *moving*.

Step5. Repeat Step 2 for each block in B_c to decide the state, *stationary* or *moving*, of it.

Step6. Get a complete frame difference image I_d by filling the *moving* blocks with white color and the *stationary* blocks with black color, as shown in Figure 10.

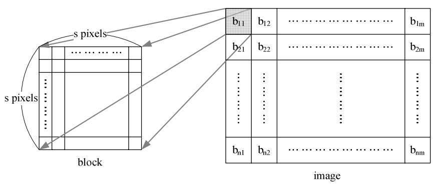


Figure 8. The image is segmented into blocks.

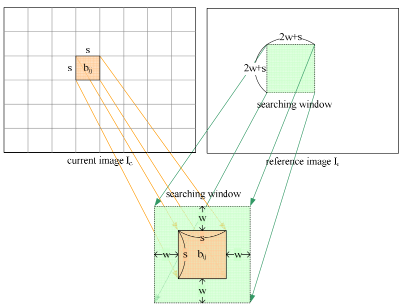


Figure 9. The searching window.

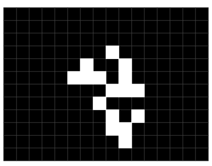


Figure 10. A result of blockwise frame differencing.

Algorithm 3: *Human body detection.*

Input: A moving region set $\boldsymbol{R} = \{R_1, R_2, ..., R_n\}$ with the width of each region R_i in $\boldsymbol{R}$ denoted by w_i and the height of R_i by h_i.

Output: A human body region R_{body}.

Step1. Get a new moving region set $\boldsymbol{R}'$ from $\boldsymbol{R}$ by filtering out regions too small or with wrong aspect ratios.

Step2. If $\boldsymbol{R}' = \varnothing$, it means that no human body is detected in the moving regions.

Step3. Else, if $|\boldsymbol{R}'| = 1$ such that $\boldsymbol{R}' = \{R_i\}$, we decide that the moving region R_i is the human body region and set $R_{body} = R_i$.

Step4. Else, if $|\boldsymbol{R}'| \geq 2$, we decide the moving region R_j to be R_{body} if the product of w_j and h_j is the maximum among all products of w_i and h_i, where $R_i \in \boldsymbol{R}'$.

3.3 Extraction of Colors of Human Clothes

According to the detected face region, we know the width and height of the face region in the image. Accordingly, we can infer the width of the human shoulder and the distance from the face to the body. Since the image captured with the camera is a geometric ratio projection, after we detect the face region in the image, we can approximately infer the region of his/her clothes. We use the center of the clothes region to be the start point for region growing of the clothes region.

3.4 Human Tracking by Clothes Detection

To detect the location of the target person in the current navigation cycle by clothes, we use a clothes intersection region to predict the direction of the target person. The method only computes the directional variation of the target person. The detail of the proposed clothes region intersection is described in the following.

Algorithm 4: *Clothes region intersection.*

Input: Clothes image $I_{clothes}$, the initial region $R_{initial}$ which is the target clothes region.

Output: The current region $R_{current}$ of the person's clothes in the image.

Step1. Capture an image $I_{current}$.

Step2. Compute the difference between $I_{current}$ and $I_{clothes}$ pixel by pixel in the region of $R_{initial}$, and get an intersection $R_{intersect}$.

Step3. Conduct region growing in $R_{intersect}$ to get the desired clothes region $R_{current}$.

4. ESCAPE OF VEHICLE FROM STRANGERS

The mobility property of the vehicle makes corners in a house viewable from the camera. On the other hand, this property also makes the risk that the vehicle might be attacked or stolen by an intruding person. To avoid such cases, we design a mechanism for the vehicle to escape from strangers. The escape process has two stages: detection of dangerous situations and path planning for escape. We regard the vehicle to be safe if nobody appears in a pre-defined range of distances from the vehicle. Accordingly, we have to compute the distance between the vehicle and the person which is detected in the image. The detail is described next.

4.1 Principle of Escape

To decide what kind of situation in which the vehicle should escape, we define three states for the vehicle: *safe state*, *unsafe state*, and *buffer state*. As shown in Figure 11, imagine a circle with the vehicle as the center and a pre-defined distance r, the *safe distance*, as the radius. If a stranger is within the circle, we say that the vehicle is in an *unsafe state*; else, the vehicle is in a *buffer state* or a *safe state*. It means that if the distance between the vehicle and a person is smaller than the safe distance, we regard the vehicle to be in an *unsafe state*. Otherwise, we give a buffer between the *safe* and *unsafe states*. If a person stays in the buffer area, the vehicle will move neither forward nor backward.

If the vehicle is in an *unsafe state*, we command the vehicle to escape. However, only one camera is equipped on the vehicle and the camera has to "keep an eye on" the detected stranger, so no more camera can be used to observe the environment to escape. Thus, we instruct the vehicle to repeat the path the vehicle just moved before as a solution to this problem. That is, when the vehicle has to escape, it will be moved backward according to the recorded path. In this way, the camera can still be used to observe the stranger continually. When the target person is out of the safe distance, the vehicle will track the person again.

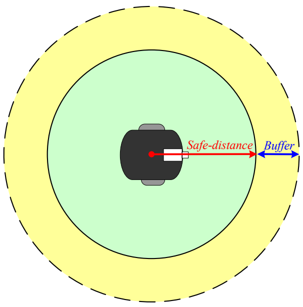


Figure 11. *Safe distance* for the vehicle.

4.2 Computing Distance from Vehicle to A Stranger

To determine if the state of the vehicle is safe or not, we compute the distance between a person and the vehicle by the face region and the clothes region of the person, respectively. However, we only have the angular information of the face from the image. We need the height of the face and the clothes to compute the distance. For this, we make a few assumptions in this study. We assume that the person is standing on the ground, the height of his/her face is between 20cm and 25cm and the height of his/her body part (not including the leg portion) is around 50cm to 60cm. The detail is described as an algorithm in the following.

Algorithm 5: *Computing the distance from the vehicle to a person by the face region.*

Input: The detected face or clothes region R_{target} in an image, where R_{target} has two pairs of coordinates in the ICS: (u_{left}, v_{top}) and (u_{right}, v_{bottom}) which represent the boundary box of R_{target}. The length range of a human face or clothes region $[C_1, C_2]$.

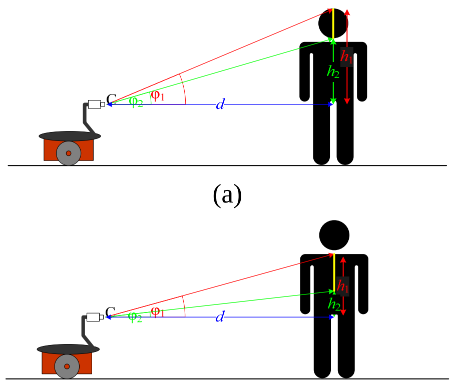
Output: The distance d_{pv} between the person and the vehicle.

Step1. Transform the coordinates $((u_{left} + u_{right})/2, v_{top})$ and $((u_{left} + u_{right})/2, v_{bottom})$ into the longitude and latitude values (θ_1, φ_1) and (θ_2, φ_2), respectively.

Step2. Referring to Figure 12 and assuming the distance of the person to be d, compute the value of $h_1 - h_2$ by $h_1 - h_2 = d\times(\tan\varphi_1 - \tan\varphi_2)$.

Step3. Since $C_1 \le h_1 - h_2 \le C_2$, rewrite the equation above as $C_1 \le d(\tan\varphi_1 - \tan\varphi_2) \le C_2$.

Step4. Compute the range $[D_1, D_2]$ of d by $D_i = C_i/(\tan\varphi_1 - \tan\varphi_2)$ where i = 1 and 2, and set $d_{pv} = (D_1 + D_2)/2$.



(a)

(b)

Figure 12. Illustration of distance between person and vehicle. (a) Distance computing using a face region. (b) Distance computing using a clothes region.

5. EXPERIMENTAL RESULTS

When the vehicle is in a detection mode, the system conducts face detection. If a face is detected in the image, the system will extract the clothes region for tracking and change the detection mode to the tracking mode, as shown in Figure 14. Else, if nothing is detected in the face detection mode, the system will conduct human body detection based on motion detection. If a human body is detected, the system will command the vehicle to move forward to the person, trying to get an image with a clear face region, and then finishes the current cycle, as shown in Figure 13. Otherwise, when the vehicle is in the tracking mode, which means the system already has the image of the clothes of the target person, the vehicle will track the target person using the intersection of the clothes image in each cycle. Until the system loses the target person, the system will change the tracking mode back to the detection mode. An experimental result is shown in Figure 15.

T=1

T=2

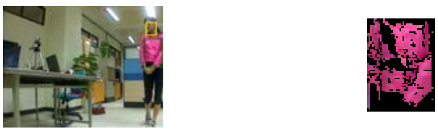
T=3

(a) (b) (c)

Figure 13. An experimental result of human body detection.(a) The input image. (b) The difference image. (c) The output image.

6. CONCLUSIONS

Several techniques and strategies have been proposed in this study and integrated into an autonomous vehicle system for security patrolling in the indoor environments with human detection and following capabilities. At first, a camera calibration by angular mapping using the concept of spherical coordinate system is proposed. Next, human detection and tracking techniques are proposed. A human face is detected by the use of color and shape features in images. Also proposed is a blockwise frame differencing method to extract moving objects in the image. After an intruding person is detected, the system will "remember" his/her clothes and track him/her. In addition, a vehicle escape method by safe distance keeping has been proposed. We designed a function for the vehicle to escape from offensive strangers by a technique of safe distance keeping. In the future, it is interesting to study the topics of improving the extraction of clothes, conducting clothes tracking by different features, and eliminating errors caused by the case where the clothes color is similar to the background.



(a) (b)

Figure 14. Clothes region detection. (a) A detected face region and the extracted cloth region by region growing. (b) The image of the extracted cloth.

t=1 *t*=2 *t*=3 *t*=4

Figure 15. An experimental result of human tracking using the intersection of the cloth images.

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