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A Human Behavior Discrimination Method based on Motion Trajectory Measurement for Indoor Guiding Services

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Abstract. As a research on service engineering, a method to discriminate whether a person entering a space is a visitor or a staff was developed for guiding services in indoor environment. The motion trajectory of target is measured by background image subtraction and coordinate transformation, and the positional and orientational change per unit time (v and θ) of the trajectory is calculated. The motion index is defined by $v \cos\theta$, the value of which is characterized effectively to discriminate the target. The experiment setup was implemented using a sensor node with an artificial retina camera. The positional error of measurement was 350[mm] at the 6[m] distant position from the camera. The distribution of the motion index mean was obtained and approximated by Gaussian distribution. The probabilities of visitors and staffs were calculated by a statistical approach. As a result of experiment, it is shown that 90% of the target was successfully recognized.

Keywords. Human behavior discrimination, motion trajectory, motion index, image processing, statistical approach, artificial retina camera

1. Introduction

Towards the post mass production paradigm, the service engineering challenges to systematization of service synthesis to generate added value in artifact design and utilization[1]. We have been discussing on the function required for the artificial systems and the methodology to realize services, regarding the artificial systems as media to transmit services from service producers to users.

In order to deliver suitable services, it is required to recognize what kind of services the users demand and in what kind of states the users are. In this research, assuming that such information must appear in the behaviors of the users, recognition and discrimination of the users for guiding services is discussed based on the measurement of users' behavior.

Human motion detection and recognition are subjected to concentrated research [2]-[7]. In CMU, VSAM (Video Surveillance and Monitoring) has been developed as a system in which motion of humans or vehicles is detected and recorded by the cameras deployed in outdoor environment[8][9].

Measurement of human behavior by the sensors equiped in the environment has been discussed in the research of Robotic Room[10], Intelligent Space[11], etc. Recognition of human behavioral patterns has also been discussed based on using position and posture of human body[12]. A system for detecting dubious persons was also developed[13]. However, for recognition of users to whom suitable services should be delivered, it is still required to descriminate the users or their states depending on services, based on the model of users' behaviors representing the relation between users' states and users' behaviors.

In this paper, aiming at development of a guiding and navigation service system to visitors in indoor environment, discrimination of persons who are walking into the entrance in a indoor space is investigated to recognize whether the persons are visitors or not, because it is desired to deliver the guidance service only to the visitors, and to avoid a nuisance to the staffs who know the environment very well already.

This paper proposes an motion index utilizing the velocity and orientational change of the motion trajectory of a target person walking into the entrance, which is a characteristic variable to descriminate the persons effectively, and presents a moethod for the trajectory measurement by image processing and a statistical method for the descrimination based on the motion index mean. A compact sensor node device equiped with an artificial retina camera is used for the measurement toward the ubiquitous computing environment.

2. Method for Human Motion Trajectory Measurement and Discrimination

The motion trajectory of a person walking into the entrance is very important to discriminate whether he/she is a visitor or not, because the visitors may blunder around in the environment to find the way to the destination, while the staffs must go straightforward to the destination in comparably fast speed, who know the map of the environment very well. There have been reported some methods to measure and discriminate the trajectories of human motion by cameras set up in the environment[12][14], where statistical methods to discriminate the trajectories are employed. We pay more close attention to the characteristic properties in the trajectories, which are velocity and orientational change.

Our method for trajectory measurement uses the background subtraction to extract moving human from the image taken by a camera. Since the bottom part of the extracted image of human is the foot which must contact with floor, the position of the foot can be calculated by coordinate transformation from the coordinates of the bottom part of the subtracted image. By measuring the foot position continuously, the trajectory of human motion can be obtained as the time series of the foot position in the world frame.

In the analysis of the human behavior from the motion trajectory obtained by image processing, it should be noted that the duration of the trajectory is not constant and the starting point and end point of the motion are difficult to determine. To cope with this problem, we focused on the motion feature on each unit time. The velocity of each trajectory segment and the angle of two connecting trajectory segments, namely change of orientation, were employed as featuring parameters which are effective to discriminate a person walking into the entrance and to recognize if he/she is a visitor or a staff (not a visitor). In this paper, we call a person *visitor*, who visits the place at the first time and to whom the guidance information is desired to deliver, and *staff*, who knows the place very well and to whom the guidance information should not be delivered. Namely, since staffs have the knowledge on the map and the path to their destination, they must walk straightforward to the destination, which means the velocity is expected to be large and the orientational change to be small. On the contrary, since the visitors do not have enough knowledge on them, they must blunder around at the entrance, and the velocity is expected to be small and the orientatinal change to be large.

If the position of the person is obtained in time t_i as (x_i, y_i), the velocity of the person and his/her orientational change at time t_i are represented respectively as follows:

$$v_i = (x_{i+1}, y_{i+1})^T - (x_i, y_i)^T \quad (1)$$

$$\theta_i = \cos^{-1}((v_{i-1} \cdot v_i)/(|v_{i-1}||v_i|)) \quad (2)$$

Taking account that the motion difference between a staff and a visitor must appear in the velocity and orientational change of their trajectories, we define the motion index as $v\cos\theta$. The motion index mean X during time period n can be calculated as follows;

$$X = \frac{1}{n}\sum_{i=1}^{n} v_i \cos\theta_i \quad (3)$$

where n denotes attentive time steps in the motion trajectory. Figure 1 illustrates the motion index calculated from the partial trajectory of a walking person. As mentioned above, since the velocity of a visitor must be small and his/her orientational change must be large, the motion index mean value is expected to be small. On the contrary, the motion index mean value of a staff is expected to be large. Namely, the distribution (probability density function) of motion index mean of staffs is expected to be differentiable from that of visitors as shown in figure 2.

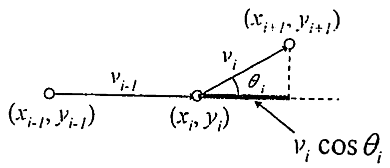


Figure 1. *Motion index calculated from the partial trajectory of a walking person*

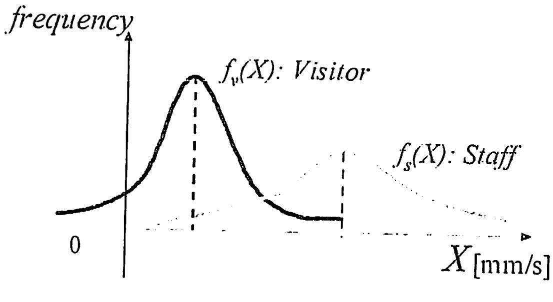


Figure 2. Probability density function $f_v(X)$ and $f_s(X)$

Suppose the distribution (probability density function) of X can be Gaussin distribution, the function can be represented as follows:

$$f_k(X) = \frac{1}{\sqrt{2\pi}\sigma_k} \exp\left\{\frac{-(X-\mu_k)^2}{2\sigma_k^2}\right\} \tag{4}$$

$k = v$ (for visitor) or s (for staff)

where μ_k and σ_k represent the mean value and the varience of the distribution.

If the probabilities of visitors $p(v)$ and staffs $p(s)$ are obtained as priori probabilities, the posteriori probabilities $p(v|X=x_i)$ and $p(s|X=x_i)$, which are probabilities that a person entering into the scene is a visitor and a staff, can be obtained as follows by Bayes' theorem:

$$p(k|X = x_i) = \frac{p(k)f_k(X = x_i)}{p(v)f_v(X = x_i) + p(s)f_s(X = x_i)} \tag{5}$$

$k = v$ (for visitor) or s (for staff)

By calculating and comparing the probabilities by (5), it is possible to descriminate the person as follows:

If $p(v|X = x_i) \geq p(s|X = x_i)$, then the entering person is a visitor

If $p(v|X = x_i) < p(s|X = x_i)$, then the entering person is a staff

3. Preparatory Experiments for Human Motion Trajectory Measurement

We developed an experimental setup and evaluated the error of position measurement of a person at the entrance by experiments. The setup of the experimental system is shown in figure 3.

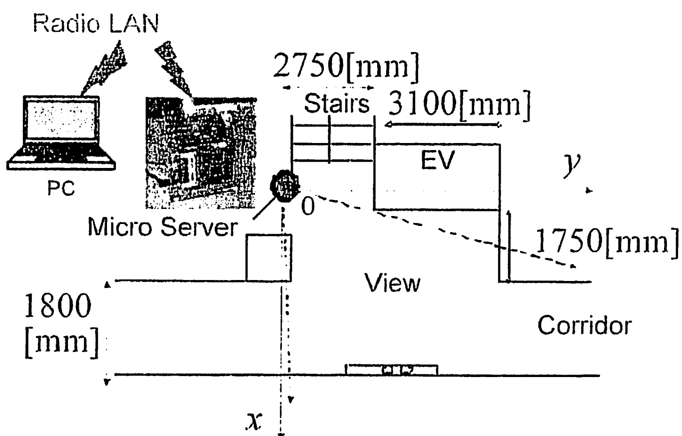


Figure 3. Setup of the experimental system

In this system, a compact sensor node device called μT-Engine (Mitsubishi Electric Corporation) equipped with an artificial retina camera was employed, and embedded at the location where the landing arena area in the fifth floor of a building of the Komaba Campus of the University of Tokyo can be monitored, which is the entrance of the our research center (RACE) for persons entering from an elevator or stairs. An example of the image captured by the camera is shown in figure 4.

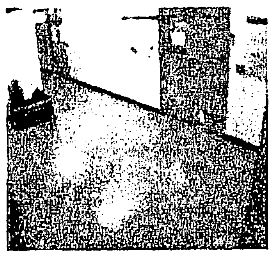


Figure 4. Image captured by the artificial retina camera of the sensor node device

The size of the image taken by the camera is 160[pixel] by 144[pixel]. We set the camera at the location as shown in the figure 5, and the resolution of the measurement is about 300[mm] for the vertical direction and about 70[mm] for the horizontal direction at the farthest position in the scene of the image (about 6.0[m] distance from the location of the camera on the floor).

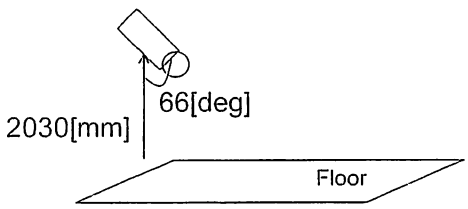


Figure 5. Location of the artificial retina camera

Next, the error of the position measurement was evaluated. Figure 6 shows the experimental results of the errors which were obtained by comparison between the position measured by our system and the position measured by a motion capture device (SV-Tracker, Ohyoh Keisoku Kenkyusho, Accuracy: 50[mm]). As shown in the figure, the error of position measurement at the distance of 6[m] apart from the location of the camera was about 350[mm]. This result is considered allowable for human behavior discrimination, assuming the system displays the guidance information to a walking person at a location near the person, and makes the person notice the guidance information, while the velocity of human is about 0.86[m/s] in indoor environment which was obtained in our experiments.

The preparatory experiments to measure the trajectories of the visitors and staffs, and the calculation of motion index mean were carried out by the experimental system. The numbers of samples for the preparatory experiments are 15 for visitors and 110 for staffs. We observed the persons walking into the entrance from the elevator or stairs, and judged manually whether they are visitors (strangers who visited the research center at the first time), or staffs (professors, students, secretaries, and clerks of the center).

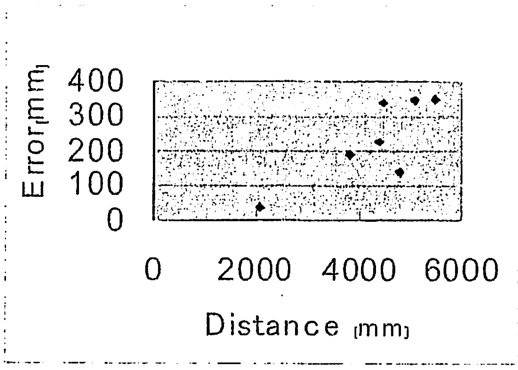
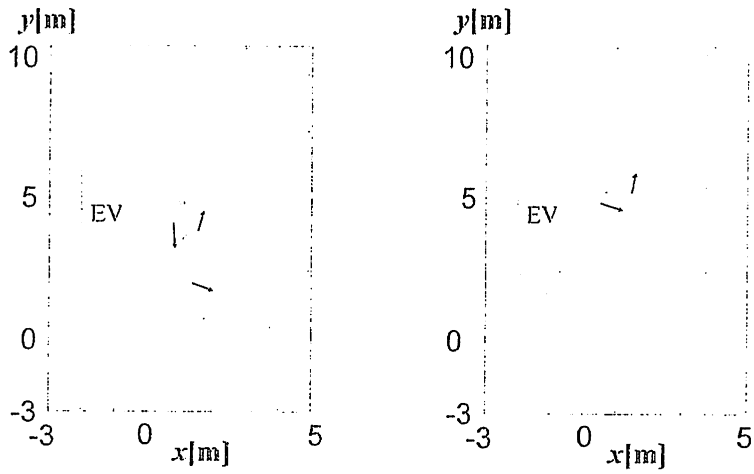
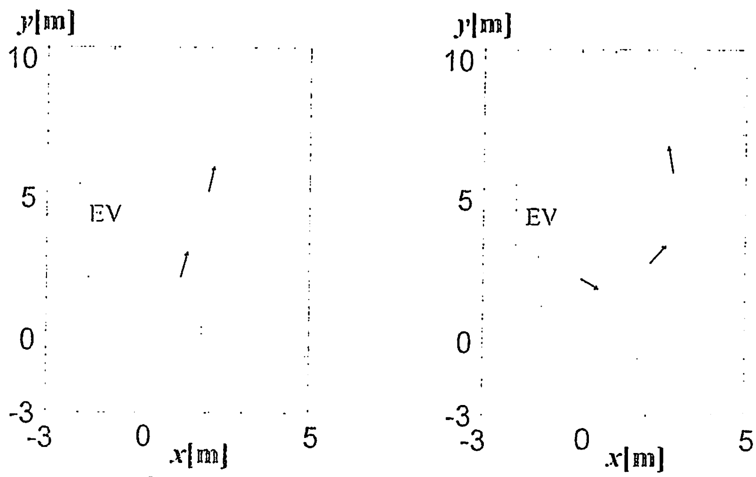


Figure 6. Error of position measurement



(a) Example 1 (b) Example 2

Figure 7. Examples of measured trajectories of visitors



(a) Example 1 (b) Example 2

Figure 8. Examples of measured trajectories of staffs

Typical measured motion trajectories of persons are shown in figure 7 and figure 8. Figure 9 and figure 10 show the distribution of the motion index mean of the visitors and staffs. The dots in the trajectories denote the location of the persons during motion at every 1[sec] sampling time.

As shown in the figures, the distributions of the X can be approximated by Gaussian distribution. The mean values μ_k and variances σ_k ($k = v$ (for visitor) or s (for staff)) of the distribution of X under the approximation were obtained as follows:

μ_v=2.37* 10^2[mm/s] σ_v=2.70*10^2[mm/s]

μ_s=1.14*10^3[mm/s] σ_s=6.56*10^2[mm/s]

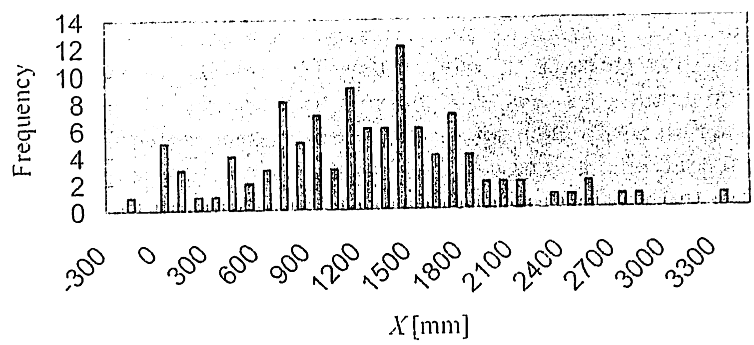


Figure 9. Distribution of X for visitors

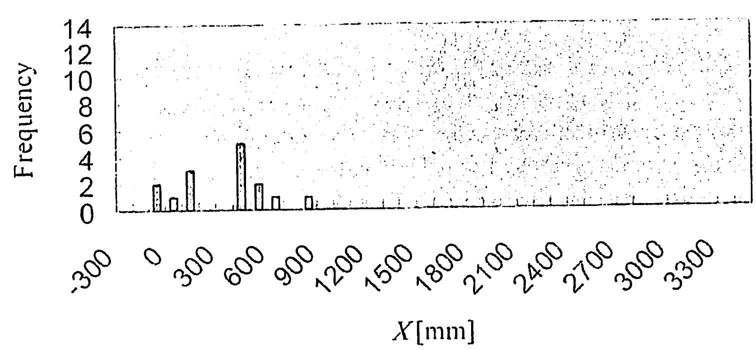


Figure 10. Distribution of X for staffs

We evaluated the appropriateness of the approximation of the distribution of X by the Gaussian distribution. The kurtosis and the skewness were -0.81 and -0.13 respectively in the case of visitors, and 0.41 and 0.29 respectively in the case of staffs. Though this means the distribution of visitors is more acute and left-sided than Gaussian distribution and the distribution of staffs is more obtuse and right-sided, it is concluded that these distribution can roughly be approximated by Gaussian distribution.

4. Verification Test for Human Behavior Discrimination

Since $f_v(X)$ and $f_s(X)$, the probability density functions of X for visitors and staffs, were obtained by the preparatory experiments as mentioned above, verification tests of the proposed method for human behavior discrimination were carried out. In the experiments, a priori probabilities of visitors and staffs were obtained as the ratios of the samples of the persons who came into the entrance during the preparatory experiments, which are $p(v)$=15/125 and $p(s)$=110/125.

The numbers of samples for the verification test are 10 for visitors and 45 for staffs, who came into the entrance in another day. The results are shown in Table 1. For the purpose of the guiding services, it is required to recognize the visitors correctly. The error ratio of the first kind in which the visitors were misrecognized as staffs was 10%, and the error of the second kind in which the staffs were misrecognized as visitors was 4.4%, while the recognition rates of staffs and visitors for the original learning data in the preparatory experiments were 96.4% and 80.0% respectively. From the result, it is verified that the proposed method is effective to discriminate a person walking into the entrance to be a visitor or a staff.

Table 1. Results verification test for human behavior discrimination

	Visitors	Staffs
Success	90.0%	95.6%
Failure	10.0%	4.4%

While the error ratios are required to be as low as possible for a better service system, the error of the first kind must be critical for reliable detection of visitors to guide. Figure 11 shows an example in which the visitor was misrecognized as a staff. As shown in this figure, the reason of the misrecognition is that the value of the motion index mean increased due to large velocity value in partial segments. To solve this problem, it must be effective to divide the motion trajectories into proper portions, calculate the motion index on not the whole trajectory but each portion, and evaluate the change of the motion index. Namely, the misrecognition ratios can be improved easily.

We also estimated the effect of the noises in the trajectory measurement on the human behavior discrimination. Taking an example of the case of figure 8 (a), in which the calculated motion index mean was $1.05*10^3$[mm/s], the reliability of the discrimination method was tested by adding white noises to the motion index mean value. Figure 12 shows the variation of the motion index mean value with various white noises in the limit of 200[mm], 300[mm], 400[mm], 500[mm], and figure 13 shows the variation of $p(v|X=x_i)$

with the white noises. As shown in the figure, even scattering of the motion index mean value and resulting probability of $p(v|X{=}x_i)$ depending on the white noises, the maximum change in the probability was only 0.25, which was observed in the case of maximum noise of 500[mm], and it was verified that the noise does not affect on the discrimination results. This shows the reliability and the robustness of the proposed methods for the motion trajectory measurement and the human behavior discrimination.

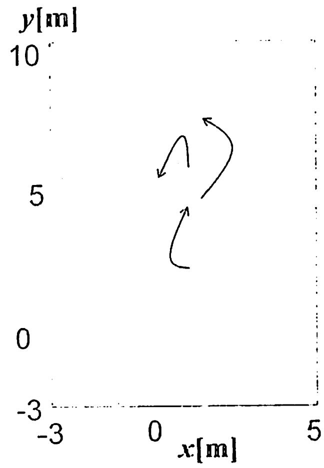


Figure 11. Example of misrecognized motion trajectory

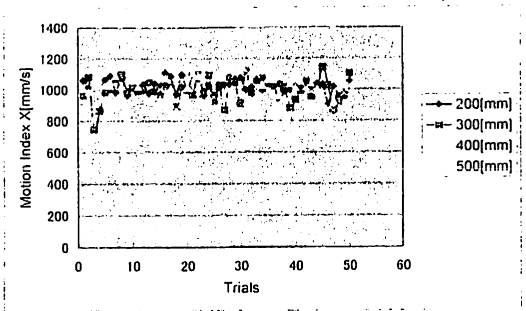


Figure 12. Variation of motion index mean with white noises

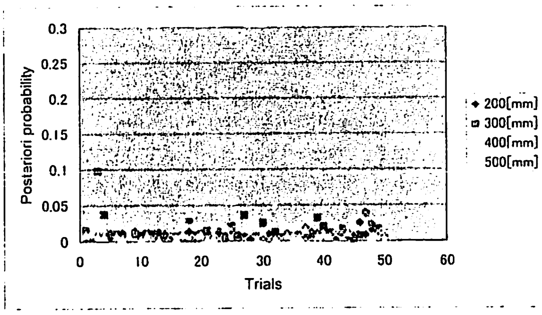


Figure 13. Variation of calculated probability with white noises

5. Conclusion

In this paper, taking an example of guiding service to visitors in indoor environment, methods to measure human motion trajectories using a sensor node device equiped with an artificial retina camera, and to descriminate persons walking into the entrance in indoor environment to recognize whether the persons are visitors or not were proposed. As a result of the experiments, effectiveness and robustness of the proposed method was verified.

This method is also considered applicable to security systems in which detection of dubious persons is required. The method proposed in this paper is limited to the case that a single person is included in the scene. It is planned in future to improve this method to cope with the case with multiple persons in the scene of the images, by labelling multiple targets in imege processing and probablistic correspondence even when occulusion occurs. The integration of information obtained by multiple cameras to cover wider area is also future work.

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