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# Development of Vision Based Person Following Module for Mobile Robots in RT-Middleware

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## 1. Introduction

Recently, the role a robot can play in a person's daily life has increased drastically over the years. There are many researches that aim to communicate and interact with human in a real environment. In order to achieve such purpose in a real environment, robots need the ability to see the person and adjust to the person's behavior. Such ability is an indispensable function for safety and security as well as carrying out tasks. The ability to automatically follow a person is a key enabling technology for mobile robots to effectively interact with the surrounding world. If a robot combines a communication function with speech-recognition, a grasping function with arms and a person following function, we believe that the robot can serve the person well (Fig.1). The robot must follow the person intelligently not only in a limited environment such as an indoor office but also in real world such as a crowded area outdoors. In order to continue following the person intelligently in an indoor/outdoor environment, the robot needs a robust adaptive control system under varying illuminations.

In this chapter, we describe the robust person following method based on disparity images and HSV color spaces from a color stereo camera and distance information from the laser range sensor. The proposed person following method applies for an inverted pendulum type robot, Segway RMP200 (Segway Japan, Ltd.) and a humanoid type service robot, enon (FUJITSU Ltd.). The validity of the proposed methods is confirmed through the person following experiments in an indoor/outdoor environment under varying illuminations.



Fig. 1. Overview of Person Following Mobile Robot Service

## 2. Person Following Mobile Robot

In order to follow a person, the first thing the robot must do is find the target person. Many researches using fixed camera images find the target person by using such characteristics as the face, human body shape, background subtraction, etc. (2006, Kwon et al., 2005, Negishi et al., 2004, Ohya & Munekata, 2002, Schlegel et al., 1998, Schulz et al., 2003, Sidenbladh et al., 1999). (The following problems, however, occur when the robot follows the target person by using a camera located on the robot, because both of the camera and the target person are moving.)

- 1) Background changing problem. The background is always changing because the camera is moving.
- 2) Occlusion problem. Camera images change according to distance between the robot and the target person.
- 3) Position problem. The image size of the target person is changeable.
- 4) Direction problem. The robot cannot see the target person's face at all times. Face tracking is not the best method in this case.
- 5) Multi person problem. Robot has to find the target person even if several people exit in the frame.
- 6) Brightness problem. The light condition, sunshine and shadow become a major problem when the robot moves between indoor/outdoor environments.
- 7) Real-time problem. Calculation cost is important for person following.

We proposed a robust person following method to solve such problems. The proposed method uses three information; the disparity images, HSV color spaces images from a color stereo camera, and the distance information from the laser range sensor. The proposed method does not depend on the image size, the target person's shape and face, but depends on the color histogram of the target person's clothes and the distance between target person and background. We also proposed the multi HS histogram sequential update method for a color extraction method to realize the person following in real surrounding.

## 3. Person's Area Detection Image Processing Method

### 3.1 HS Histogram Based Color Extraction Method

This section describes the target person detection method based on target color extraction image processing method. First, the target person's color images are registered by captured multi view point around the target person. Usually, clothing color is not the same throughout, print and color are not same on the front and back, or on the left and right side. If only one color of the person's clothes is registered, the robot cannot find the target person when the target person changes his/her walking direction. Fig.2 shows the template histogram created by a front image of the target person. The  $x$  axis indicates H value of HSV color space,  $y$  axis is S value of HSV color space,  $z$  axis is a normalized number of HS pixels. Fig.3 also shows the template histogram created by the back image of the target person. In this example, the front template has two peaks indicating blue and purple, and the back side temple has one peak indicating purple. These templates show that there are differences found in the colors found on the front and back side of the same person's clothes, even if same person.

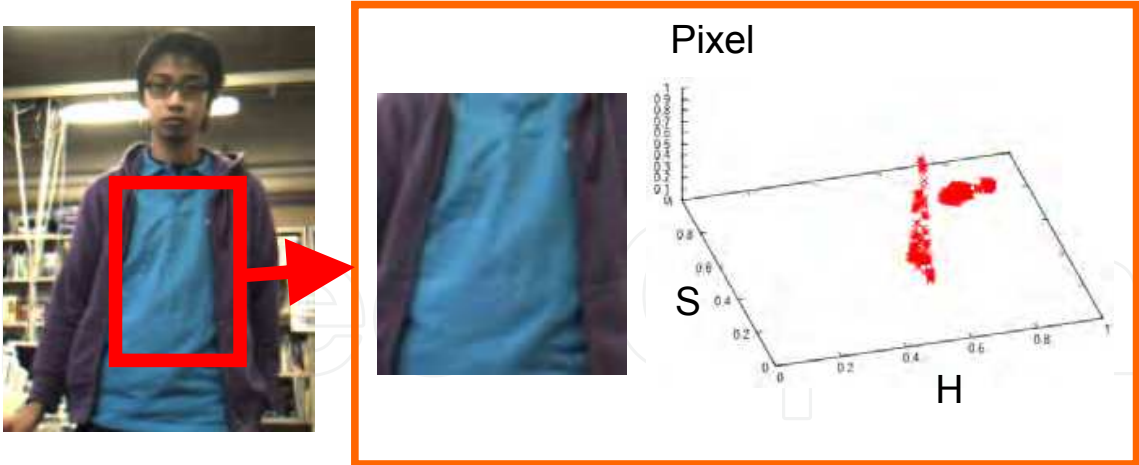


Fig. 2. Template Histogram (front side)

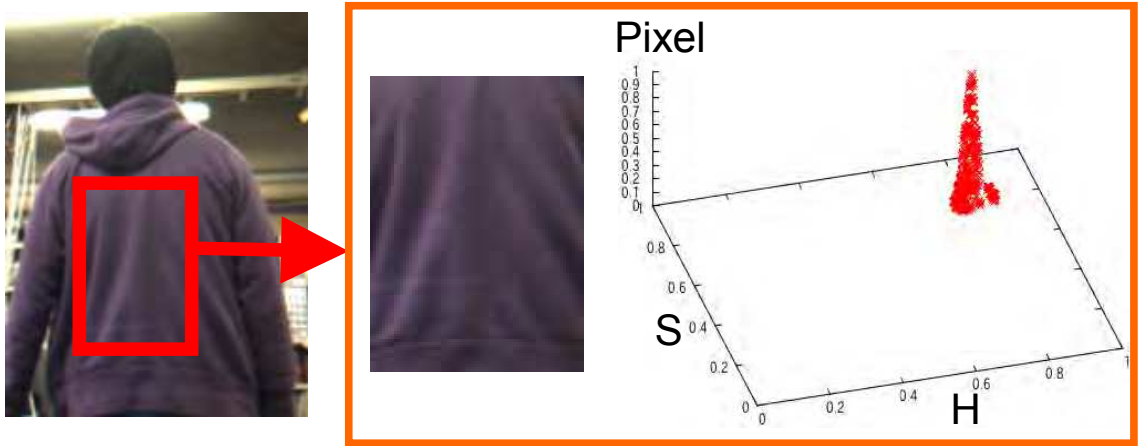


Fig. 3. Template Histogram (back side)

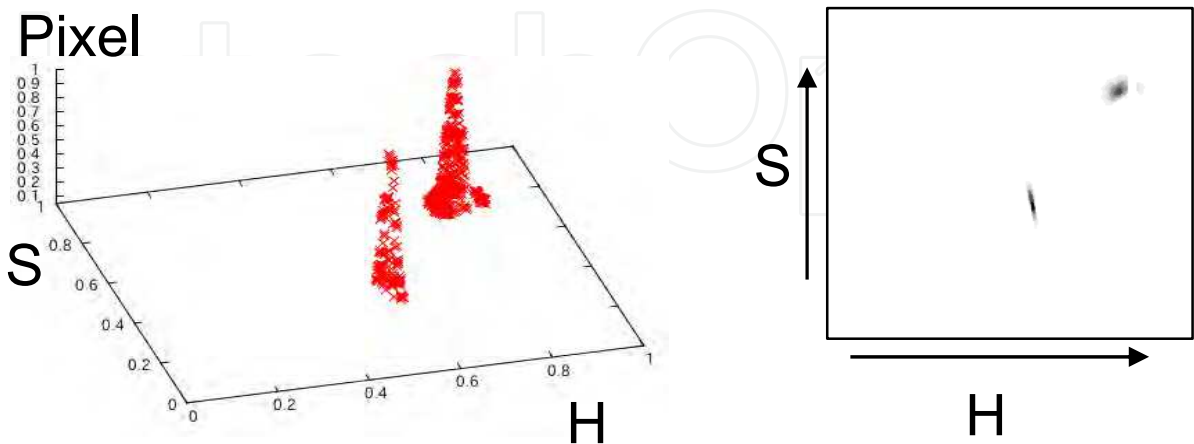


Fig. 4. Base Template Histogram

Fig.4 is a base template histogram connected by the front and back templates. The base template is also normalized by multi template histogram. Fig.4 (right) indicates the number of pixels as the brightness (0 to 1).

The next step is to cluster the base template histogram by using the Nearest Neighbor algorithm. The NN method is a method for classifying objects based on closest training examples in the feature space. The NN method was applied to the base template histogram, and the result is shown in Fig.5. There is no guarantee that a target person wears unique color clothes. The proposed method can extract multi colors by using the clustered histogram. In this example, the base template histogram divided into clusters. One of them indicates a blue color on target person's clothes, and the other a purple color. The advantages of using clustering of the base template histogram are that multi color templates are available and that some small color space and noise can be neglect.

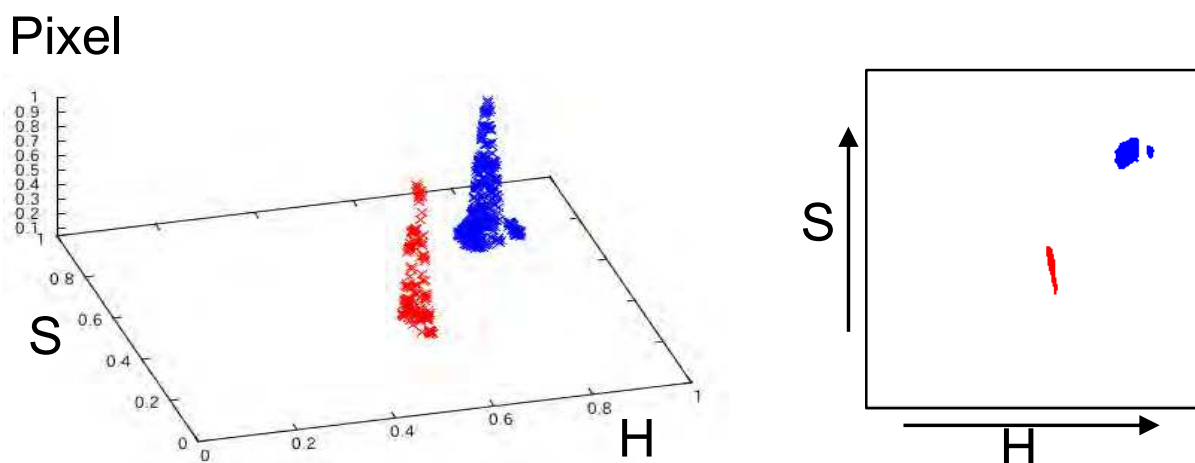


Fig. 5. Clustered Histogram by NN Method

### 3.2 Updating HS Histogram by Anisotropic Asymmetric Gaussian Distribution Model

The clustered histogram is not a Gaussian distribution and the HS histogram has an anisotropic characteristic. The S value is more changeable than the H value under varying illumination. The weight of each color cluster is calculated by using an anisotropic asymmetric Gaussian kernel function. The center cluster position  $(u, v)$  and the distribution value  $\sigma^2(\theta)$  are needed to define the anisotropic asymmetric Gaussian distribution in the H-S plane. The definition of the anisotropic asymmetric Gaussian distribution model (Umeda et al., 2006) is given by

$$W(h, s) \equiv W(r, \theta) = e^{-\frac{r^2}{2\sigma^2(\theta)}}, \quad (1)$$

where  $r$  is a distance from the center of a cluster to the outer perimeter of the cluster and  $\theta$  is an angle ( $0 < \theta < 2\pi$ ) of orientation around the center. The H-S rectangular coordinate system is transformed to  $r$ - $\theta$  polar coordinate system. Fig.6 shows the calculation result of the anisotropic asymmetric Gaussian distribution filter for weighting the HS histogram.

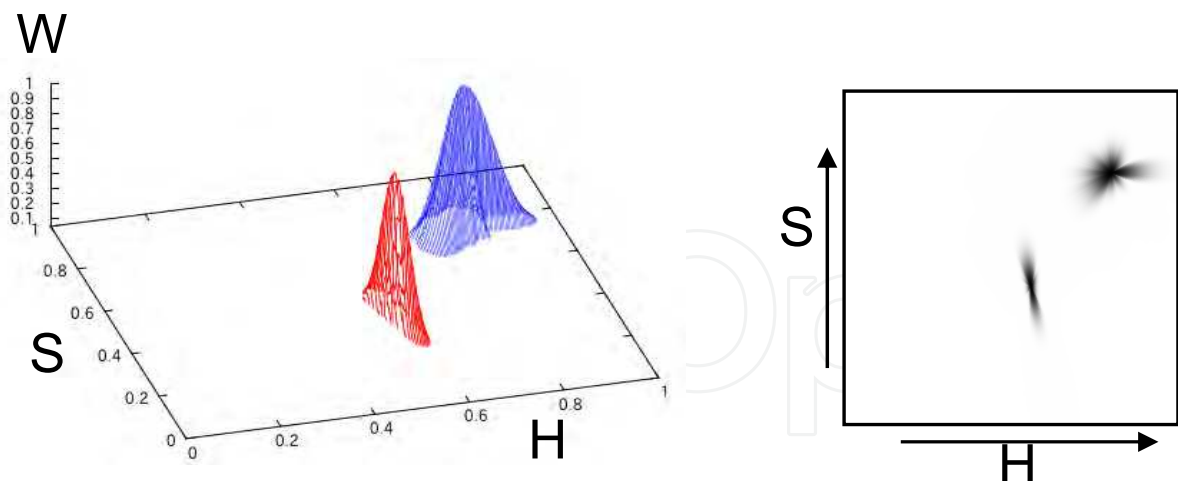


Fig. 6. Anisotropic Asymmetric Gaussian Distribution Filter for Weighting Histogram

In order to extract the target colors under varying illumination and cut noise, the weighted histogram has to update according to the lighting condition. The weighted histogram ( $H_w$ ) updates based on the target person's area.  $HS_{new}(t)$  is a current histogram acquired by the detected target person's area.  $H_w(t-1)$  is old histogram.  $W$  is weight calculated by equation 1.  $H_w(t)$  is calculated as follows:

$$Hw(t) = \frac{Hw(t-1) + W \times HS_{new}(t)}{\max(Hw(t-1) + W \times HS_{new}(t))} \tag{2}$$

3.3 Target Person Detection Processing Flow

The processing flow of the target person area determination method by using color, distance information and weighted histogram is shown in Fig.7.

- 1) Background Elimination: The background is eliminated by using the distance information from the stereo camera to reduce the color matching calculation cost. The area, which has the distance far from threshold value, is defined as the background area.
- 2) Color Extraction: The target person's color is extracted based on the weighted HS histogram.
- 3) Target Area Detection: The target person's area is detected based on the extracted pixels and a profiling process (Itoh et al., 2006). The profiling process is the position search method used maximum sum of  $x$  axis and  $y$  axis of the extracted pixels.
- 4) Histogram Update: The weighted histogram is updated based on the target person's area. In order to adjust to varying lighting condition, the weighted histogram is continuously to update using Equation (2).



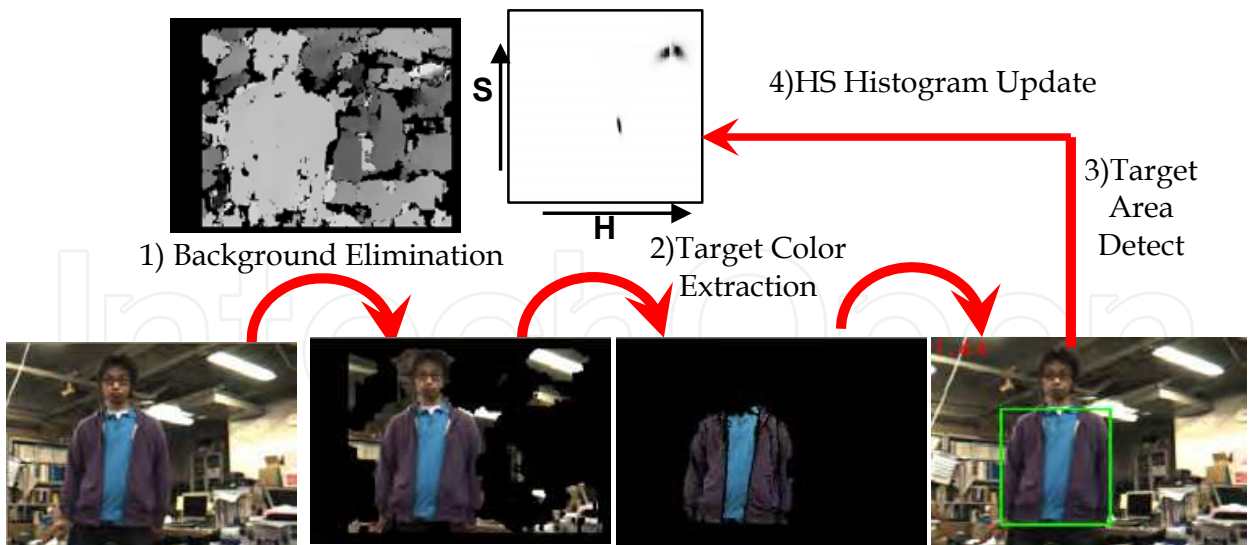


Fig. 7. Target Person Area Determination Process

3.4 Target Person’s Area Detection Experiment Results

Fig. 8 shows the target person’s area detection experiment results. In Fig.8, (a) are the target person’s area detection results, (b) the target color extraction results, (c)  $HS_{new}$  histogram of the detected target person’s area, and (d) are the updated weighted  $H_w(t)$  histogram. The bottom numbers in the results indicate processing time [second]. The green rectangles indicate the target person’s detected area. The lighting condition is changing; normal condition, becoming darker, becoming brighter and normal condition. As the results of time-series of (a), the target person could be tracked successfully in this experiment regardless of the size, shape, direction of target person and the varying illumination. It is understood that the histogram could be update according to the varying illumination. The background color, however, was not extracted, and only the target person could be tracked. This is the effect of the introduced anisotropic asymmetric Gaussian distribution filter. It estimated the changeable color range of the target person and the update process was actually performed only within the range.



Fig. 8. Results of Target Person Detection Image Processing

4. Target Person Tracking by Laser Range Finder

4.1 Robust Target Person Tracking by LRF

A normal camera has a narrow dynamic range, the black out effect or the white out effect are caused when the robot moves from indoor to outdoor and vice versa, or moves against the sun, even if the proposed HS histogram sequential updating color extraction method is applied. The proposed method does not adjust to such a major illumination change. Thus, we also proposed the robust target tracking method by using the Laser Range Finder (LRF: UTM-30LX, HOKUYO CO., LTD.). In this method, the target person is detected by the



proposed stereo camera based method. The LRF is a laser range sensor, which can be used in an outdoor environment. LRF is not greatly influenced by the lighting condition.

#### 4.2 LRF Target Tracking Method

The Nearest Neighbor Clustering method based on the input data from LRF (Hashimoto et al., 2006, Ishihara et al., 2002, Kawata et al., 2005, Okusako et al., 2006, Lindstrom & Eklundh, 2001) applies to the LRF target tracking method. The LRF can be used stably and can adjust to such varying lighting conditions of the camera system such as a black out or a white out caused by sunlight. The LRF target tracking method is that the cluster of distance data around the robot is calculated by the Nearest Neighbor Clustering method and the target person's cluster is searched and tracked based on a shape of cluster and a Euclidean distance between each cluster. The process flow is described as follows:

- (1) Converting distance data from the LRF to 2-dimensional coordinate data (Fig.9 (a)).
- (2) Clustering by NN method (Fig.9 (b)).
- (3) Numbering only human size clusters and calculating center of each target person candidate's clusters (Fig.9 (c)).
- (4) Tracking the target person's cluster that is the nearest position of the target person's area calculated by the proposed camera based method or that is the nearest position of the pervious target person's cluster.

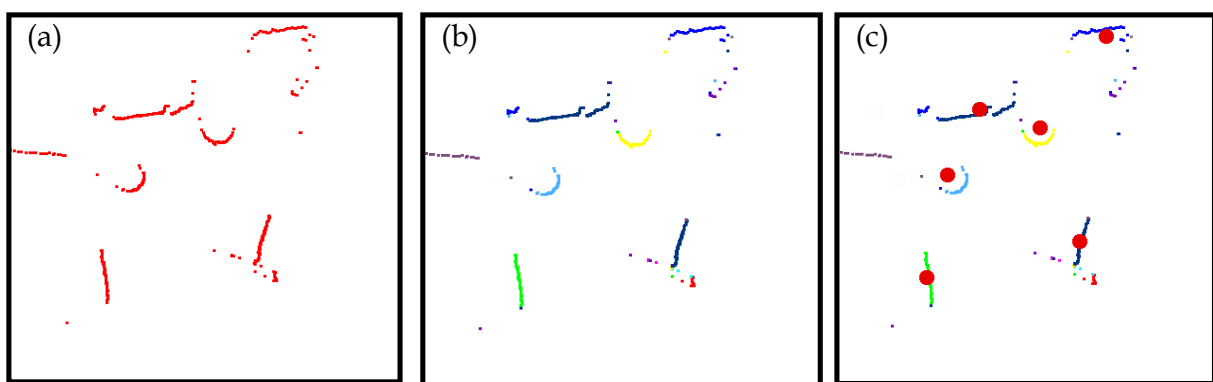


Fig. 9. Results of Target Person Detection Image Processing: (a) Input Data (b) Results of Clustering (c) Center of Each Class

#### 5. Target Person's Position Determination

The target person's position is determined based on the result of the proposed target person's area detection method and the proposed LRF target tracking method. In order to adapt to the changing image size and shape of the target person, the proposed target person's area detection method uses the color information as the target person's identification. The proposed LRF target tracking method calculates the target cluster position based on the size of 2-dimensional cross section shape and the time-series data. Although the camera based method has some trouble adjusting to rapid lighting condition change, the camera based method can re-detect when some occlusions occurred and the target is lost. Although the LRF target tracking method was trouble tracking the target person when some occlusions occurred and cannot determine the target person by using only LRF data, the LRF target tracking method can adjust to rapid changing lighting

condition. The target person’s position is determined by integrated the result of the target person’s area and the result of the LRF target tracking method to adjust to occlusion and changing lighting condition.

5.1 Integration of Camera Information and LRF Distance Information

The target person’s area and the target person’s cluster position should be the same when the robot moves in a stable environment. Fig.10 shows the integrated camera and LRF results. The outputs of both methods are the same. However, in real environment, the lighting condition is unstable and some occlusions occur by obstacles and other people. Sometimes the robot cannot detect the target person’s area and the robot cannot track the target person’s cluster. Although the camera system can track the target person as well as detect the target person, the camera system has a major problem (white/black out, against the sunlight) when the robot moves from indoors to outdoors and vice verse. The LRF target tracking method is not effect by sunlight and can be used in an outdoor environment. However, the target person cannot be detected by only using the LRF method. Another method is needed to detect the target person’s initial position when the robot has lost the target person. Thus, the integration of the two difference method can compensate the potential weakness. At first, the target person’s area is detected by using the camera based method. Then, the target person’s position is tracked by the LRF based method based on the camera based method result. Although the output from the LRF based method is used as the robot command input, the HS histogram continues to update according to the lighting condition. When the LRF based method has lost the target person’s position by occlusion or other reason, the camera based method re-detects the target person’s area by using the updating HS histogram method.

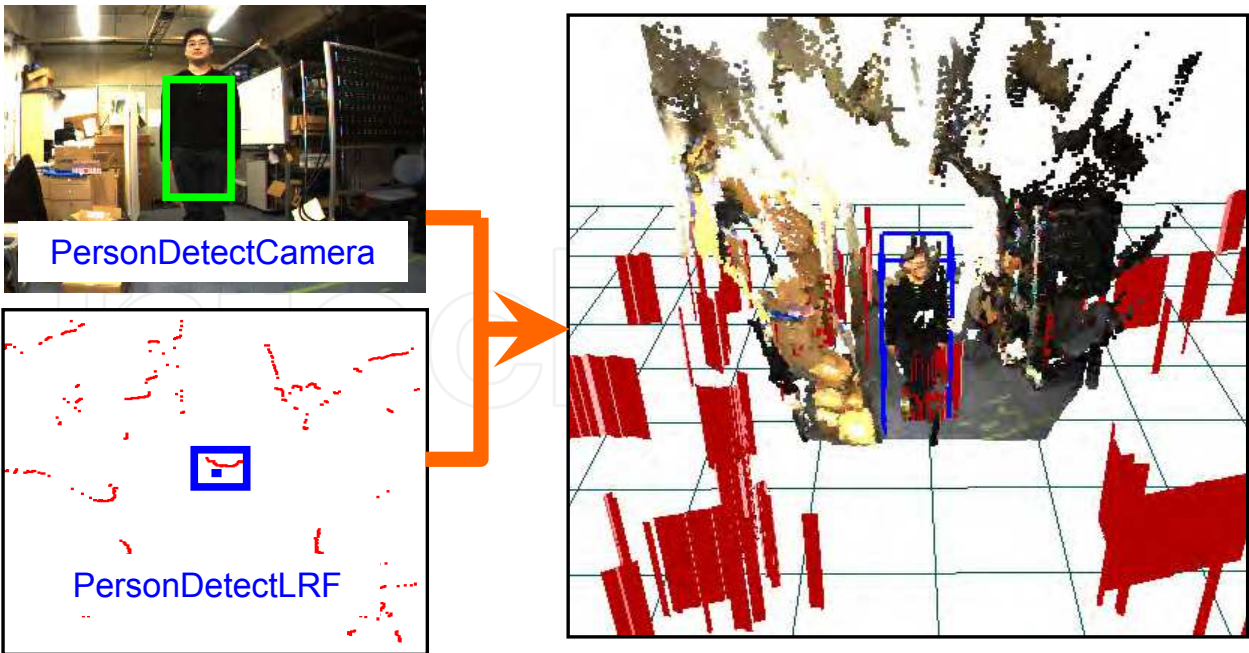


Fig. 10. Integration of Target Person’s Position Calculated by the Image Method and the LRF Method

6. Indoor/Outdoor Target Person Following Experiment

6.1 Evaluation of Target Person Following Method

The snapshots of the indoor target person following experiment are shown in Fig. 11. The robot can follow the target person in an indoor environment. The inverted pendulum type robot, Segway RMP200 (Segway Japan, Ltd.), is used as the robot platform. The robot has a color stereo camera (STOC: Videre Co. Ltd.) located on a two-axis (pan/tilt) motion control device (Biclops PT: TRAC Labs Inc.). A LRF (UTM-30LX: HOKYOU Co. Ltd.) is also located on the robot. All devices are controlled by one laptop computer. Fig.12 shows the trajectories of the target person and the robot calculated by the robot's odometer. The robot keeps a distance from the target person within 3 meter during the target person following. The target person following ability of the robot in simple environment is verified through this experiment.



Fig. 11. Snapshots of Target Following Test

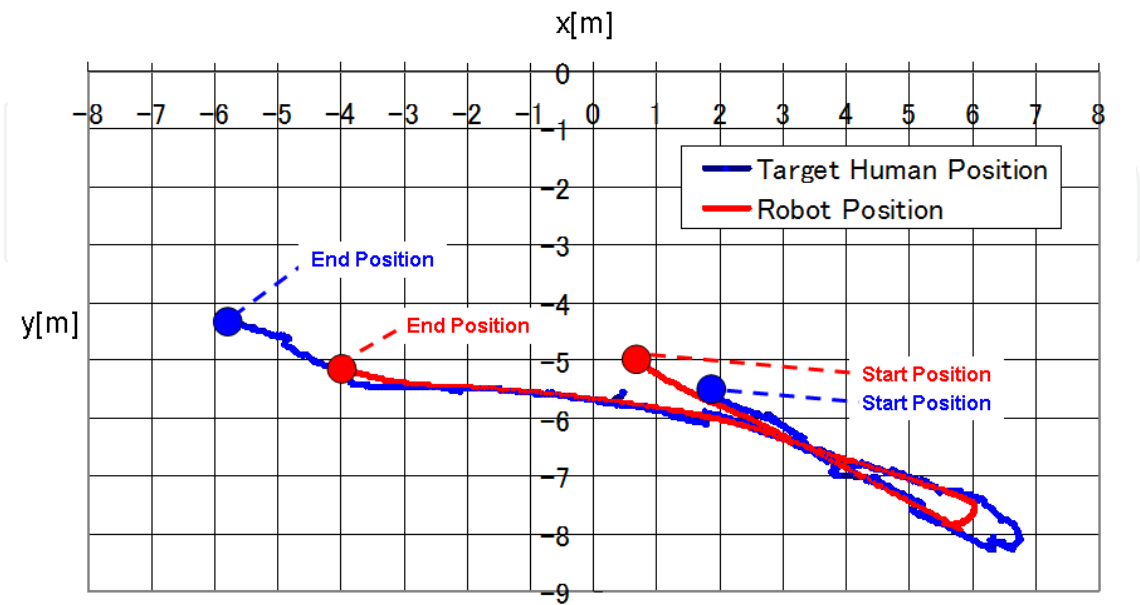


Fig. 12. The Target and the Robot Trajectory during the Target Following Test



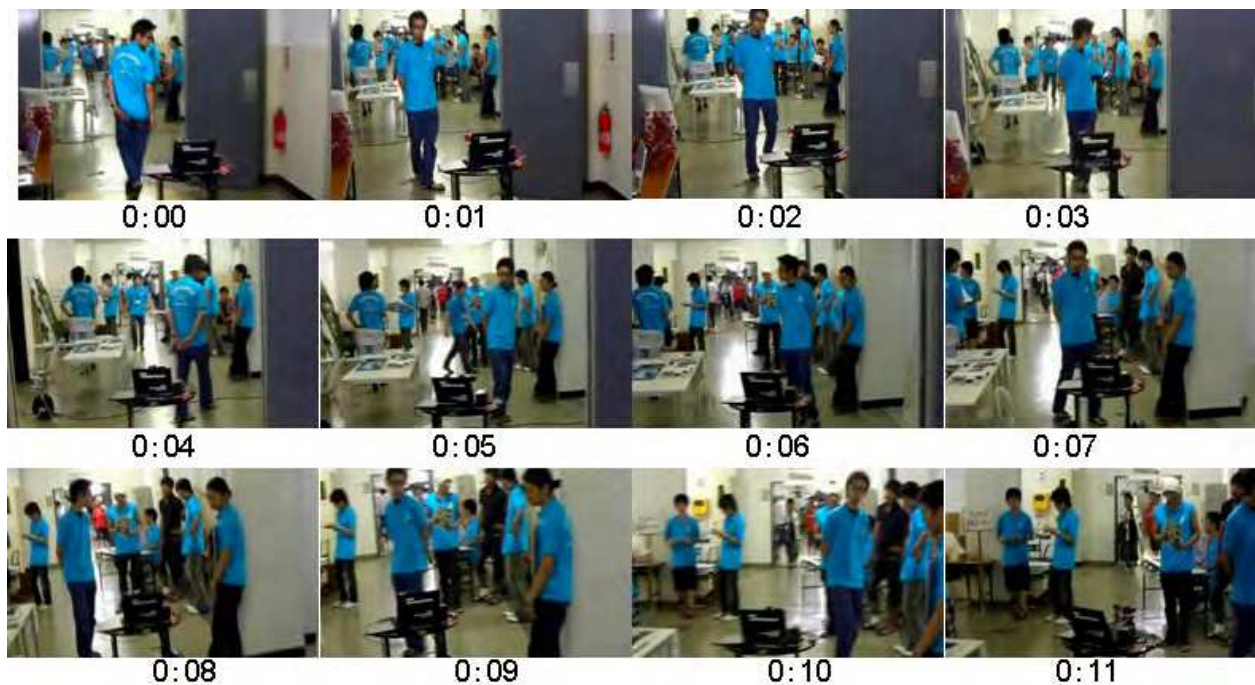


Fig. 13. Person Following Experiment (Indoor Environment)

## 6.2. Indoor to Outdoor Target Person Following Experiments

The previous experiment was performed in an indoor environment with a stable lighting condition. In this section, the experiments of target following is conducted in a more complicated environment, and the robustness of the proposed method are evaluated. Fig.13 shows the experiment result of an indoor environment with multi persons wearing the same color shirt. The space that the robot can move is limited and crowded with people. In such environment, the robot must not make a false recognition and the robot must adjust to the target person's movement. The proposed method uses the background subtraction based on the distance information of the stereo camera and also uses the time-series data. Therefore the robot can detect and track the target person in such a narrow space with other person wearing the same color shirt. The robot has the function to adjust to the target person's velocity. When the target person walks slowly in a crowded space, the robot tries to reduce the distance from the target person, and moves slowly according to the target person's walking velocity. Thus the robot achieves the target person following in such environment.

Fig. 14 shows the experiment results when the robot moves from indoor to outdoor. The major illumination change occurs when the robot moves from indoor to outdoor, even human is dazzled by the bright sunlight. The image device usually has a narrow dynamic range, and the stereo camera is hard to adjust to varying illumination compared to human eyes. However, the LRF is little effected by the sunlight because the LRF uses a laser to measure the distance around the sensor. Therefore the robot can track and follow the target person in such lighting conditions.

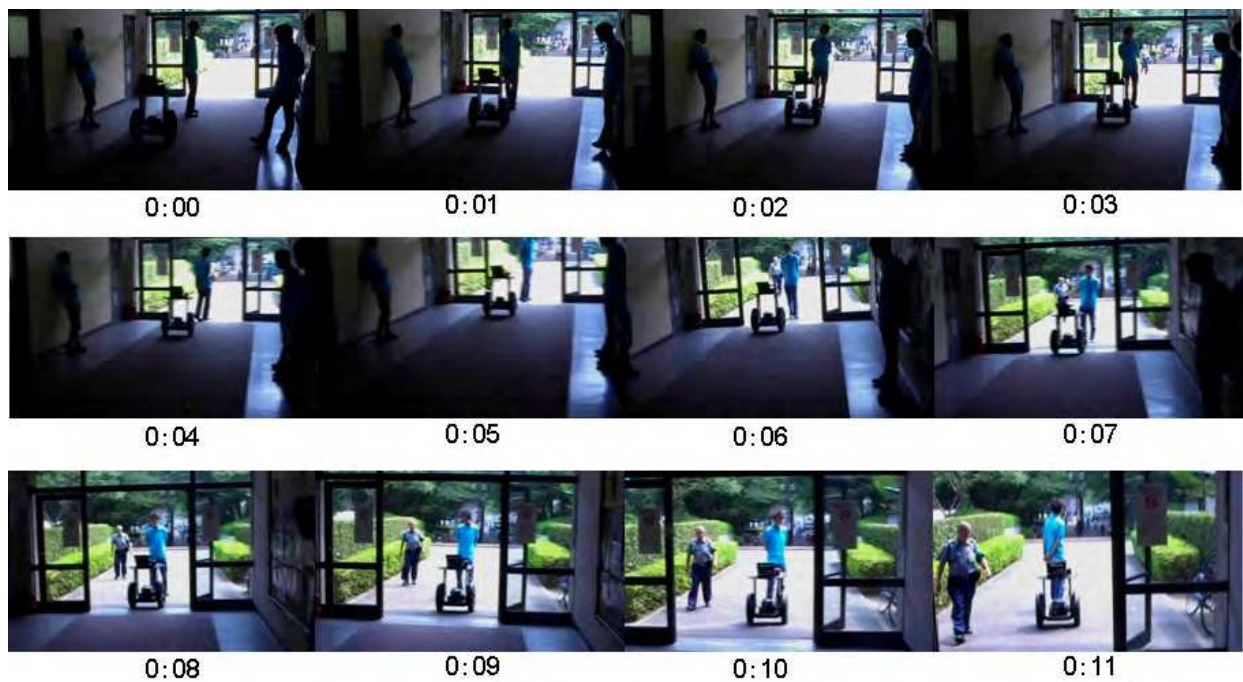


Fig. 14 Person Following Experiment (From Indoor to Outdoor)



Fig. 15. Person Following Experiment (Outdoor Environment)

Fig. 15 shows the person following experiment result when the robot moves in an outdoor environment. In comparison to the indoor environment, uneven surface, sunshine and shadow become serious problems in an outdoor environment. However, the robot also performs the target person following in an outdoor environment in where several people



wearing the same color shirt exist. The robot is used the two wheels inverted pendulum type robot and has the ability to move on uneven surfaces. The robot adjusts color changes according to varying illumination greater than indoor environments by updating the color histogram. As in the previous experiment, when the robot moves against the sun, the robot cannot detect the target person by using only the camera system. However, the robot can continuously perform the target following by using the LRF tracking system in conjunction with the camera system. The LRF system is effected only slightly by sunshine. There are several people wearing the same color shirt around the target person. The robot can separate the target person and the others by the distance information. The robot also uses the time-series location information to separate the target person from the crowd.

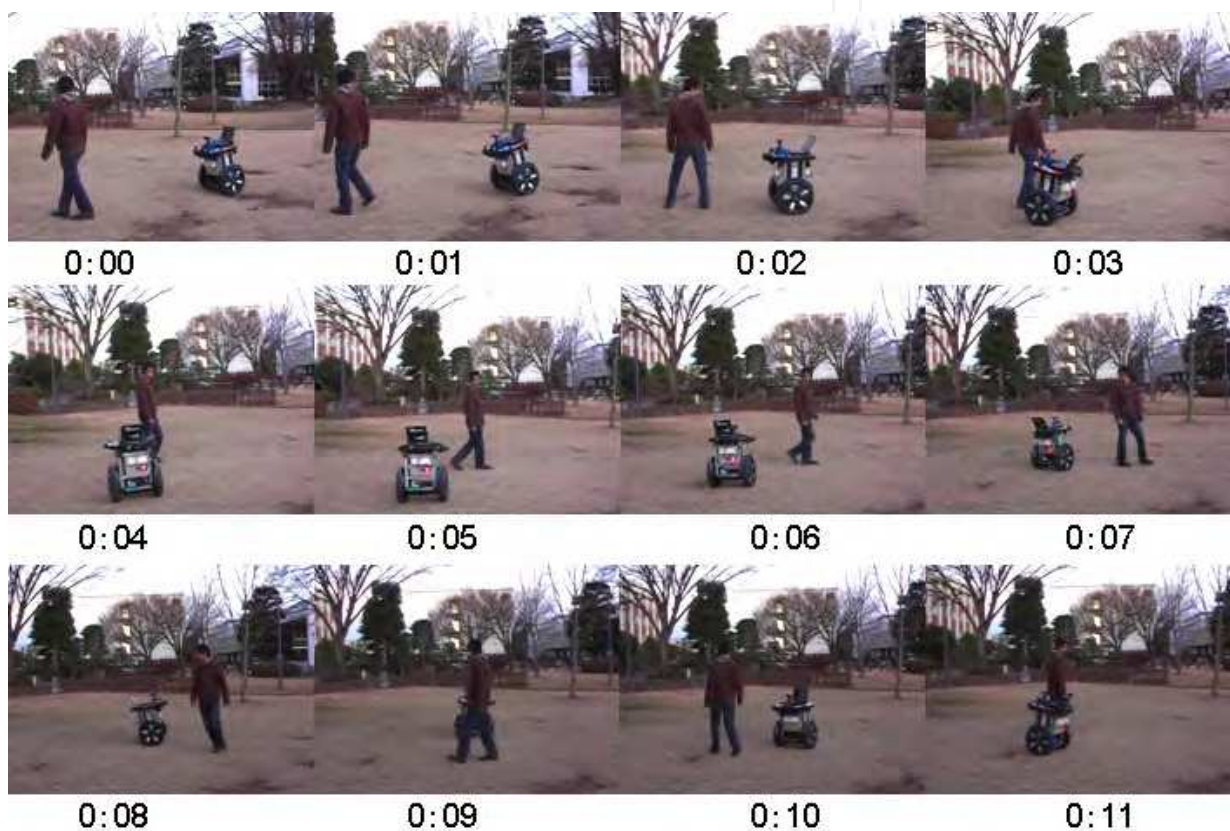


Fig.16. Person Following Experiment (Outdoor and Irregular Terrain Environment)

Fig.16 shows the experiment result when the robot moves on an outdoor irregular terrain. When the robot moves on a slope, the robot tries to keep a balance by tilting against slope because the robot is an inverted pendulum type robot. The tilt angle of the robot on an uneven terrain is larger than on an even terrain. In such case, the LRF located on the top of the robot rapidly tilts and the target tracking by the LRF will lose the target person. However, when the LRF target tracking method has lost the target person, the camera based method can re-detect the target person by the target person's color information. Therefore the target person following ability of the robot in real environment is verified through the experiment.

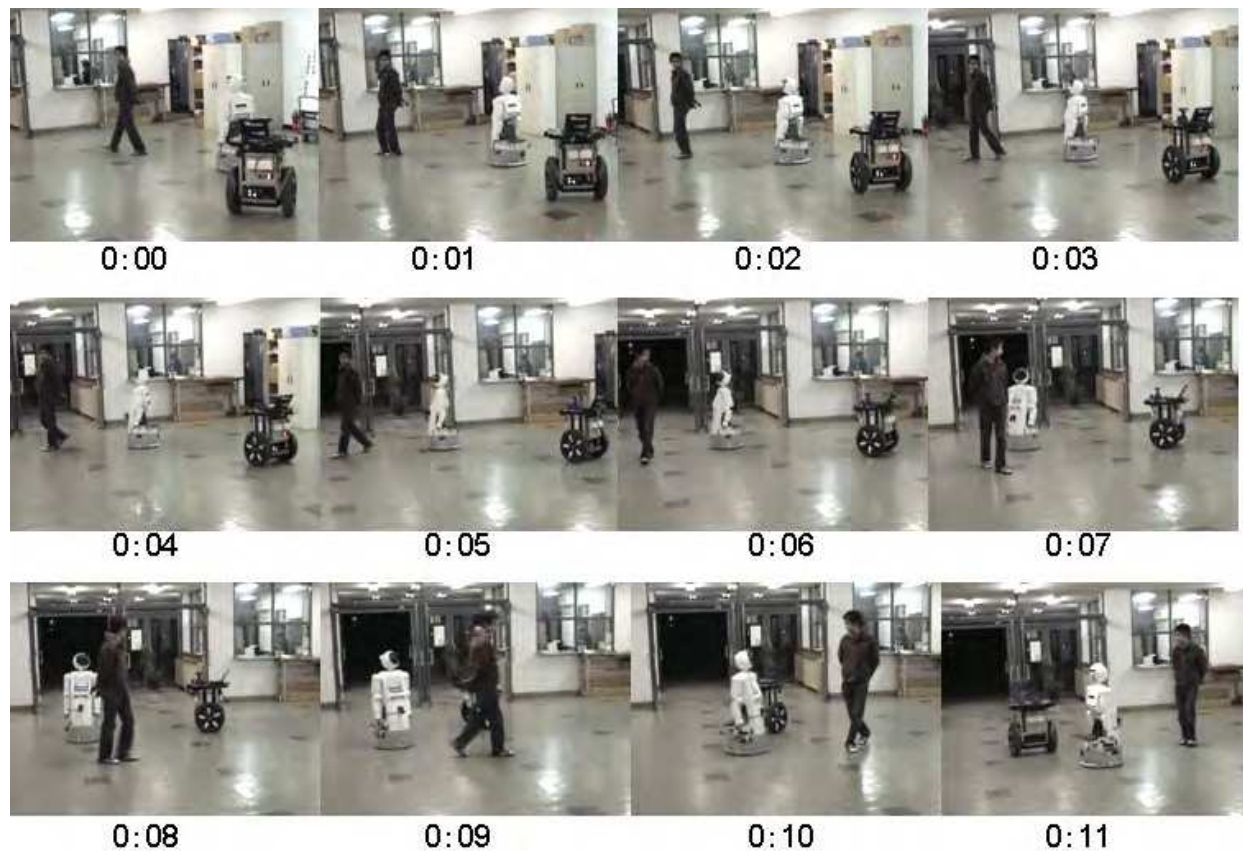


Fig. 17. Snapshots of Person-Robot Following Experiment

## 7. Target Robot Following Experiment

The proposed target person following method detects, tracks and follows the target person by using the target person's clothes color histogram and the target person's position history information. The method can be applied not only to human but also to other object, because the method does not use the temperature distribution of the target person by thermography or the shape of the target person for image processing. Additionally, the proposed methods can easily change hardware, because all the proposed methods are implemented using RT-Middleware (Ando, N. et al., 2005, Ikezoe, A. et al., 2006). Fig.17 shows the experiment result of a robot following another robot. Two different type of robots are used in this experiment. One is the Segway RMP 200, and the other enon (Kanade et al., 2006) a humanoid robot. Enon has two active wheels, two degree of freedom of his neck, a stereo camera (STOC) located on his face, and a LRF (UTM-30LX) located on his front. The proposed method is applied to these two robots. Enon attempted to follow the target person and Segway RMP attempted to follow enon. Thus there experimental result support that the proposed method can also be applied to cooperating operations between two or more robots.

## 8. Conclusion

In this chapter, we proposed the robust target person following method based on a color stereo camera and a laser range finder in a real environment. All proposed methods are implemented using RT-Middleware and therefore the hardware can be easily changed. The

proposed method is applied to two different types of robots, one is an inverted pendulum robot (Segway RMP), and the other is a humanoid robot (enon). The target person following experiments is conducted in an indoor/outdoor environment and on regular/irregular terrain. The robot can perform the target person following in such environment. The validity and utility of the proposed method is verified through these experiments. The target robot following experiment is also conducted to confirm the robustness of the proposed method. The experimental results support that the proposed method can also be applied to cooperating operation between two or more robots.

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## **Climbing and Walking Robots**

Edited by Behnam Miripour

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Nowadays robotics is one of the most dynamic fields of scientific researches. The shift of robotics researches from manufacturing to services applications is clear. During the last decades interest in studying climbing and walking robots has been increased. This increasing interest has been in many areas that most important ones of them are: mechanics, electronics, medical engineering, cybernetics, controls, and computers. Today's climbing and walking robots are a combination of manipulative, perceptive, communicative, and cognitive abilities and they are capable of performing many tasks in industrial and non- industrial environments. Surveillance, planetary exploration, emergence rescue operations, reconnaissance, petrochemical applications, construction, entertainment, personal services, intervention in severe environments, transportation, medical and etc are some applications from a very diverse application fields of climbing and walking robots. By great progress in this area of robotics it is anticipated that next generation climbing and walking robots will enhance lives and will change the way the human works, thinks and makes decisions. This book presents the state of the art achievements, recent developments, applications and future challenges of climbing and walking robots. These are presented in 24 chapters by authors throughout the world. The book serves as a reference especially for the researchers who are interested in mobile robots. It also is useful for industrial engineers and graduate students in advanced study.

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