Adaptive Sensing System for Human Detecting with Dynamic Disposition

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***Abstract*— In this paper, we propose a novel human detecting system using several stationary and moving laser range finders(LRF). The occluded area where the stationary sensors cannot measure will be covered by the actively moving sensor. The occlusion is perceived by overlaying visible area of the stationary sensors. The moving sensor will move to the target position where the sensor can measure the occluded area. Finally, the measured information of all sensors will be merged for data fusion. The experimental results show the effectiveness of the system.**

I. Introduction

HUMAN tracking is very adaptive to various applications, for example indoor security systems and also adjustment of air-conditioned control systems in building, optimizing the flow of people walking in environment and marketing in shopping mall, to realize a world where human and robots can coexist. In the field of computer vision, detecting and tracking moving objects such as human have been widely discussed. Although most proposed methods depend on outer environment such as lighting condition and usually demand computational power. Moreover the use of camera in public environments is becoming difficult because of protection of personal information. Whereas more recent works using LRF instead of camera, for example [1]-[5]. Prassler *et al* [1] used occupancy grids and linear extrapolation of occupancy maps to estimate trajectories. Zhao *et al*[2] proposed a human walking model-based Kalman-filter with multiple LRFs implemented to track the walking pedestrian. Lee *et al*[3] also proposed human tracking and counting system using multiple LRFs. In [2] LRFs are placed at ground level, on the other hand the sensors are placed at waist level in [3]. Montemerlo *et al*[4] also uses LRF from a mobile robot for people tracking and simultaneous robot localization by using conditional particle filters. Carballo *et al*[5] also set multiple LRFs on a mobile robot to move with detecting and following person. They propose double layered approach which the LRFs is placed at both knee level and chest level. The fusion of the extracted features from both layers defines a 3D volume enclosing every person detected. These human tracking methods depend on the way they scan the environment which can be classified as one of two different approaches: having fixed sensors in the environment and having sensors on mobile platforms.

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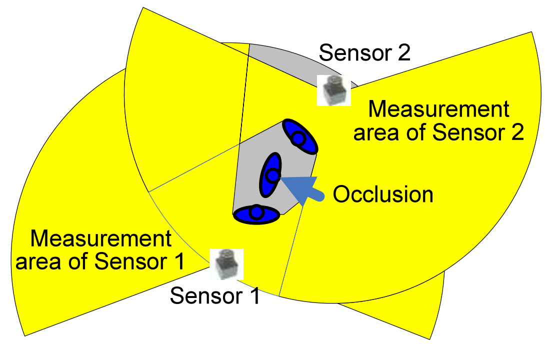
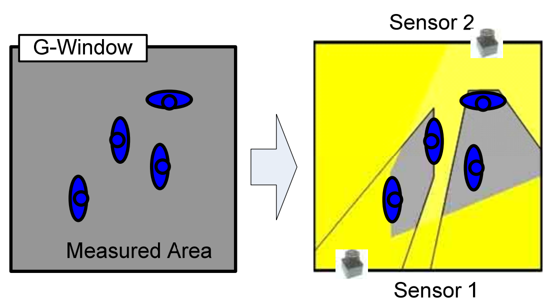


Fig.1 Occlusion(Yellow: Visible area, Grey, Invisible area)



(a) Environment (b) LRF Data Fusion

Fig.2 Visible and Invisible Area in G-Window
(Yellow: Visible area, Grey: Invisible area)

As described as above, a lot of work of human tracking is been done, though there are few works which use both approaches simultaneously. Tracking with fixed sensors can detect distance to objects accurately, but have as weakness the occurrence of invisible areas for their inflexible positioning. On the other hands mobile sensors are dynamic in their disposition to avoid invisible area. In this paper we describe an adaptive human detecting system with dynamic disposition for effective human tracking. The dynamic disposition is realized by fusion of fixed and mobile LRFs. This function provides a novel solution for occlusion problem, which means that objects hidden by other objects or structures are lost from LRF. Many works solved this problem by probabilistic methods such as the above mentioned. The organization of this paper is as follows: we explain a method to detect invisible area where occlusion may occur and to decide mobile sensor's destination in Section II. Path planning algorithm is discussed in Section III. In Section IV, system development and experiments will be shown to demonstrate the effectiveness of the developed system. Finally conclusions are presented in Section V.

II. DETECTING AND CANCELLATION OF OCCLUSITON

A. Strategy

As described in previous section, the occlusion problem (Fig.1) is common in the field of human detection and tracking, because occlusion causes decline of sensing accuracy. To avoid occlusion many works use probabilistic methods for example Extended Kalman Filter and Particle Filter and so on. These methods judge whether an object is in the invisible area[1] by tracking, using the object's data while it is visible from LRF. However they are unsuitable to environments where humans usually go standing such as elevator halls and lobbies, because those methods request that the person is always moving as precondition. As another solution, to increase the number of LRF is also proposed[2]. The idea is: the more the number of LRFs, the less the invisible area. However it means that the cost to structure the system also increases.

Our main idea is that an adaptive and dynamic disposition of sensors is indispensable to cancel fundamentally the invisible area which may cause the occlusion. Therefore we propose such method as follows.

--First, multiple fixed sensors ordinarily measure the environment.

--Second, mobile sensors move and measure inside the invisible area when fixed sensors detect the possibility of occlusion.

In next subsections and section, concrete algorithms for realizing this idea are discussed.

B. Detecting Occlusion Candidate Area

To detect invisible area early and certainly is very important to reduce the possibility of occlusion. For that purpose, we propose a detecting method as below.

Firstly, we created a model of the environment including geometrical information with non-specific reduced scale and also sensor position and represent it as a GUI window named "G-Window", as shown in Fig.2. In the example case drawn in Fig.2(b), two LRFs and four humans exist in G-Window. Then each sensor's visible area is formed as a polygon composed by sensor's position and measured points is colored with yellow. It also means that non-colored areas are invisible, and they can be detected easily by image processing techniques like labeling.

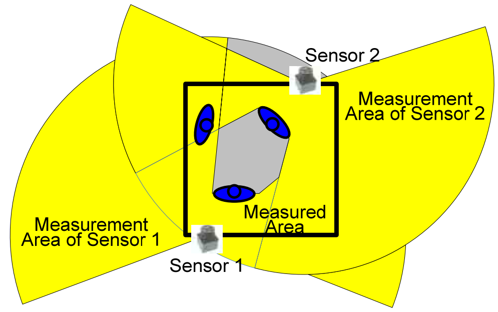
The invisible area can be classified as two types:

-- Essential invisible area such as inside of object itself

-- Space hidden by objects

Occlusion may occur inside of the second type which must be detected. Static structures in environment, which are part of the first type can be recognized by stored map data. Moving objects, which are also part of the first type, can be recognized by their size of invisible area. For invisible areas where occlusion may occur, the size of each area must be bigger than human size. Thus we search for such invisible areas as candidate occlusion areas. Each area's size is calculated by its number of pixels: firstly general human size is decided from real data, then the size of each area is compared with the human size. Finally candidate occlusion areas are detected.

[1] The term "invisible area" is used in this work to refer to the area where no data from LRF can be acquired in the sensor range.



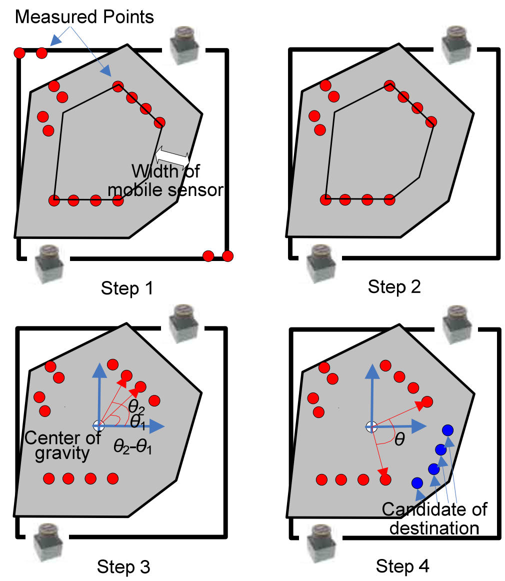


Fig.3 Process to find candidate of destination

C. Destination of Mobile Sensor

To reduce detected invisible areas, a mobile sensor moves to a place where the sensor can measure inside of the invisible area. Thus the destination of mobile robot is determined as follows (refer to Fig.3).

--First, detected invisible areas are dilated with the same size as the width of the mobile sensor's platform.

--Second, measured points which are not inside of the dilated area are filtered out.

--Third, the center of gravity of the invisible area is calculated, then the angles formed by neighboring measured points and the center of gravity is computed for all the pair of points.

--Fourth, if an angle for one pair of points is bigger than certain value, the place between those points is registered as candidate destination.

With this method, multiple candidates may be found. In such case, the nearest destination will be chosen as described in next section. Furthermore, processing is done using only

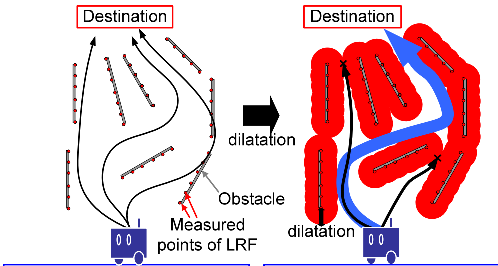


Fig4 Process of dilatation and determination of path

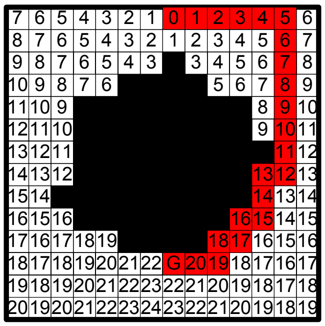
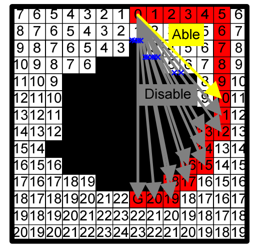
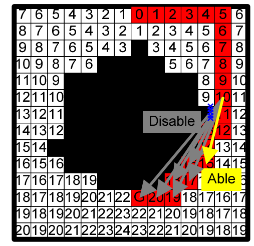


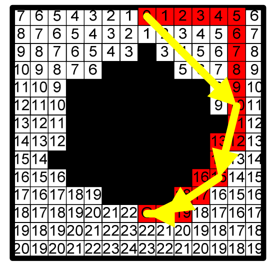
Fig.5 Path planning with distance-transform method



(a) First step



(b) Second step


(c) Final result of path(Yellow Line)
Fig.6 Optimization process of path

fixed sensors, because the size of the invisible area which is detected by the mobile sensor will change after the sensor's movement.

III. Path Planning and Tracing of Mobile Sensor

A. Path Planning

We adopted the distance-transform method(DT), which is suitable for our G-Window, as a rough path planning method of mobile sensor. Firstly detected obstacles which are not related with invisible area are also expanded according to the width of the mobile platform for avoiding narrow paths as shown in Fig.4. Then G-Window is divided into square grids as drawn in Fig.5. A grid which includes the present mobile sensor's position is numbered '0', then other grids with no obstacles are numbered according to their distance from '0' grid. The remaining grids which include obstacle or invisible area are colored in black. Finally, the grid which includes candidate destination and also has the smallest number is registered as final destination. In Fig.5, the grid labeled as 'G' is the final destination. Rough path from 'G' to '0' is determined by tracing the grids with smaller numbers.

The obtained rough path is not the shortest and need to be optimized. For example in Fig.5, the shortest path from '0' to '10' is tracing '0'->'2'->…'8'->'10'. The optimization method is drawn in Fig.6. First of all, whether the straight path is possible from '0' to 'G' is confirmed (Fig.6(a)). If a black grid (which includes something) exists on the straight path, it is not appropriate. The same operation is repeated with changing the destination whose number is smaller until available straight path is found. After obtaining first destination, same processing is repeated for finding second destination(Fig.6(b)). Finally the shortest path from '0' to 'G' is obtained (Fig.6(c)).

B. Path Tracing

After finishing path planning, mobile sensor starts to move by tracing the path. Then the mobile sensor stops and turns to the invisible area and senses inside when it reaches destination.

All processing which was explained above is repeated every 200[msec], so destination and path may change when target invisible area goes away or obstacle position changes. In such case, mobile sensor goes to another destination or returns its original position or stops as below.

--Stop case: new destination is not determined yet.

--Return case: target candidate occlusion area goes away and there is no other invisible area.

IV. Experiment

A. Experimental System

Two experiments were done to confirm the validity of the proposed method. In this subsection, the structure of experimental system is explained.

We used Hokuyo URG-04LX[6][7] as LRF, whose specification is shown in Table.1 and "Speego" which is a mobile robot based on YAMABICO[8]. Its specification is shown in Table.2. The mobile sensor is set to Speego with a metal frame and its height is 800[mm] as shown in Fig.7.

To determine the number of sensors to use is a very important subject. At least two sensors, which are set opposite to each other, are needed to calculate the correct size of the invisible area. Thus we used two fixed sensors and one mobile sensor for purpose of confirming proposed system's effect, and the sensors was placed at same as the mobile sensor.

The structure of the proposed system is shown in Fig.8. One note PC has the role of getting environment information from fixed sensors which are connected with USB, determines the mobile sensor's path and indicates it to the mobile sensor using wireless LAN. Another note PC is on the mobile platform and receives its own path and control the mobile platform, then transmits the mobile sensor's data to the former note PC.

TABLE 1
SPECIFICATIONS OF URG-04LX

Range	0.02 – 5.6 m
Accuracy	±10 mm or ±1% of distance
Scan Angle	240 deg
Angle Resolution	0.352 deg
Optic source	Laser (λ=785nm)
Laser Safety Class	Class 1 (Eye safe)
Scan Rate	100 msec/scan
Dimension	50×50×70 mm
Weight	160 g
Environment	indoor

TABLE 2
SPECIFICATIONS OF "SPEEGO"

Dimension	312×245×282 mm
Weight	3 kg (exclude battery)
Max speed	120 cm/sec
Command System	SH Spur

B. Parameters

The length of one side of a pixel in G-Window was fixed as 15[mm]. A cross section of human was fixed as an are of 900[cm^2].

The threshold value for decision whether the mobile sensor can measure inside of a invisible area was set as 30[degrees]. The area except 15[degrees] on both sides was decided as destination. It means that destination of the mobile sensor is within 20[degrees] when the obstacle free angle was 50[degrees].

The invisible area and obstacle were dilated 250[mm] with circular structuring element. The value was determined by considering the form of Speego as circle whose radius is 200[mm] and 50[mm] as margin for sensor's error. The length of one side of a square grid for DT was fixed as 100[mm].

The experimental environment is shown in Fig.9. The measured area is set as a regular square with side length of 3[m]. The fixed sensors are set at the places as shown in the figure and at waist level. Initial position of the mobile sensor was established at left and upper vertex of the measured area.

Invisible areas outside the measured area were not considered. However all of the invisible areas and obstacles inside a regular square with side length of 6[m] were dilated for path planning, because the mobile robot may go through them.

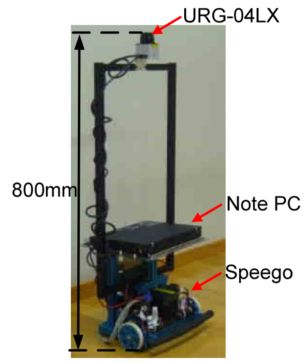


Fig.7 Mobile sensor system

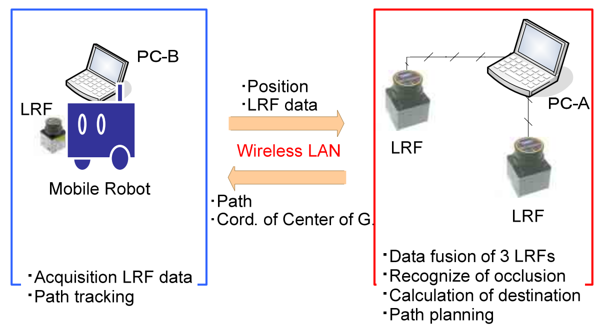


Fig.8 Structure of proposed system for this experiment

C. Display of Status

Fig.10 shows the status of measuring at one situation. There are 4 windows named as "Status+*number*" each.

In the left and upper window named "Status1", the area colored yellow expresses the visible area from two fixed sensors, the area colored grey is the visible area from the mobile sensor and the area colored black is the invisible area. Then the green points are measured points of fixed sensor 1, the red ones are from fixed sensor 2 and the blue ones are from the mobile sensor. Furthermore white circle is the position of mobile sensor and the white point on the circle is posture of the sensor.

In the left and lower window named "Status2", two fixed sensor's data are displayed. The area colored black and surrounded by squared grey line is candidate occlusion area and the number next to the grey line is size of the area.

In the right and lower window named "Status3", one candidate occlusion area whose size is the largest area is displayed. The area is fixed as target area.

In the right and upper window named "Status4", the target area which is dilated, measured points from fixed sensor inside of the area and candidate destination are displayed. The grey area is original target area and the blue area is the dilated area. The pink circles are destination candidates where the mobile sensor can measure inside the area. Finally the grey numbers are distance value from the present position of the mobile robot according to DT.

D. *First Experiment – Occlusion Cancellation*

As a first experiment, we evaluated the occlusion cancellation function. The scenario for this experiment is as below.

--First, there is nothing inside measured area.

--Second, a human enters and stops inside the area.

--Third, other three humans enter and stop and form occlusion where three of them surround one.

--Fourth, all go outside the area.

The mobile sensor kept stopping at the initial position until the second situation. In third situation, the fixed sensors detect the occlusion and mobile robot's path was planed, then the mobile sensor moves along the path to calculated destination. Finally the mobile sensor succeeded to find occluded human. After invisible area went away, the mobile sensor returned to his initial position in fourth situation. These behaviors are all what we expected.

Fig.11 shows two statuses of the third situation. The status shown in Fig.11(a) is before the mobile sensor starts. Status1 indicates that three humans were detected by fixed sensors and mobile sensor. Status2 indicates that the invisible area for fixed sensors was recognized as candidate occlusion for its size, and the area is detected in Status3. In Status4, destination and path of mobile sensor were decided. At this time the fact that there is no occluded human in the invisible area is remarkable.

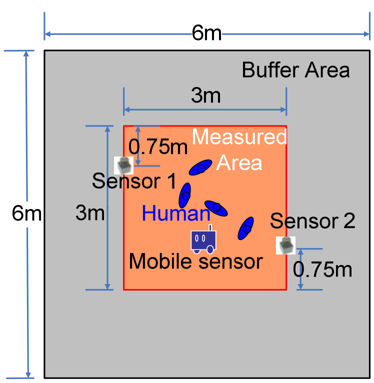


Fig.9 Experiment environment

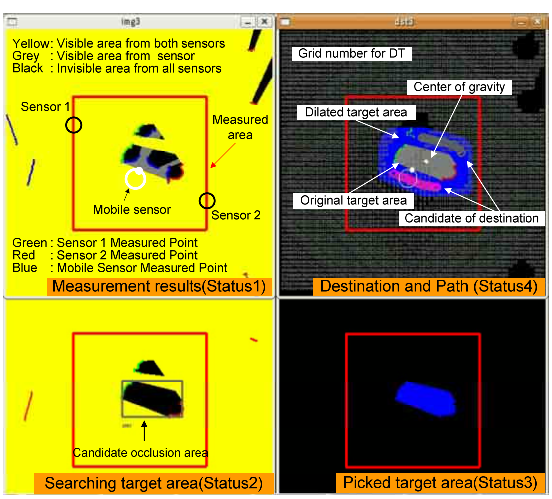


Fig.10 Example of experiment status

The status shown in Fig.11(b) is the mobile sensor measuring inside the detected invisible area from the destination point and finds one occluded human. This measurement continues until the size of the target invisible area is lower than the threshold. When the form or position of the target area changes, so the destination must be changed accordingly, continuous path planning determines them and the mobile sensor moves.

E. *Second Experiment – Dynamic Disposition*

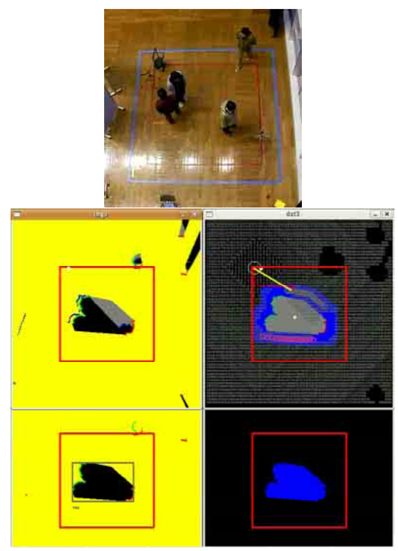
Secondly, we evaluated dynamic disposition function. The scenario for this is as follows:

--First, there is nothing inside measured area.

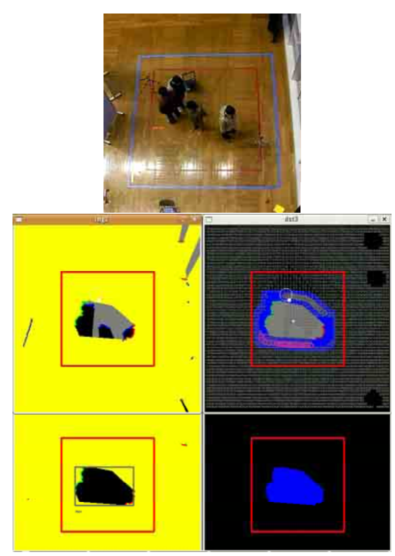
--Second, two humans enter and stop inside the area and form a candidate occlusion area.

--Third, another human enters and stops at present destination after mobile sensor starts

Fig.12 shows two remarkable statuses in this experiment.



(a) Target area is detected and path is decided



(b) Mobile sensor arrives at destination and measures inside of candidate occlusion area.

Fig.11 Experiment 1

As Fig.12(a) shows, the mobile sensor is moving to first destination at the second situation. However the destination and path are appropriately changed because the third human interrupts the mobile sensor as shown in Fig.12(b).

F. Discussion

In these experiments, the size of their environment was determined as 3[m] square by considering the detecting ability of the sensor and the number of the sensors. However the proposed system does not limit the size of environment by using other sensor which has higher ability or increasing the number of the sensor.

On the other hand, a fast mobile platform is required in order to promptly cancel the occlusion, however for safety reasons this becomes difficult in crowded environments.

Finally the center of gravity of invisible area may exist on the outside of the area if the form of the area is concave. The countermeasure for such situation must be considered.

V. CONCLUSIONS AND FUTURE WORKS

This paper presents an adaptive human detecting system with dynamic disposition. The proposed approach is to use both fixed and mobile LRFs for stable detection of human, that is, the mobile sensor complements the invisible area of fixed sensor.

For that purpose, methods to detect invisible area and plan the mobile sensor's path were proposed. Then effect of the methods was confirmed by experiments.

However, we think that the proposed system still has two big problems, which are safety control and speed of the mobile platform. Safety must be guaranteed while speed must be increased for more stable following of invisible area. Considering these problems is our future work.

Moreover "Counting people" or "Human tracking" at the following environments are considered as practical applications of the proposed system.

--First, Elevator hall : for adoptive elevator operation by measuring the number and flow of people.

--Second, Corridor near security zone : for detecting suspicious people.

It is also our future work to consider an effective implementation for the mobile platform and an optimal selection of sensors

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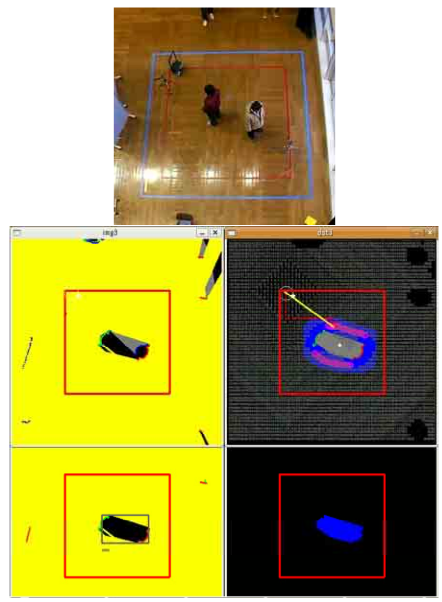
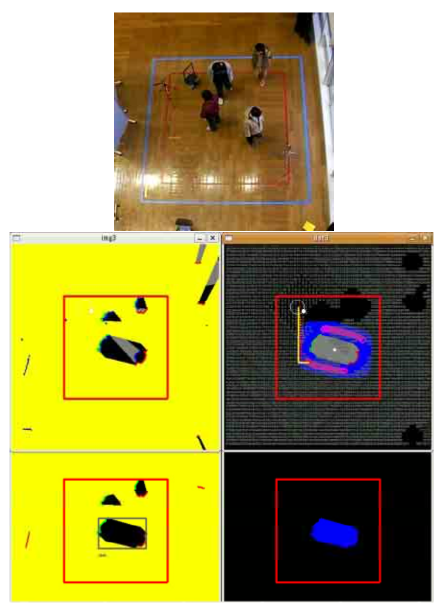


(a) Target area is detected and path is decided



(b) Path changes because a human enters previous destination.

Fig.12 Experiment 2