5 Universal Terminals

5-1 Outdoor Environment Recognition and Semi- Autonomous Mobile Vehicle for Supporting Mobility of the Elderly and Disabled People

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Elderly and disabled people with impaired vision, hearing, and mobility often find it difficult to get around because their physical impairment mean that they partially lack the three elemental abilities necessary for mobility, i.e., recognition of the environment, actuation through their legs, and ready access to information for navigation. We developed Robotic Communication Terminals (RCT) as a system to support these three elemental abilities comprehensively for mobility outdoors. General road observation system and semi-autonomous outdoor mobile vehicle (Intelligent City Walker, ICW) are some components of the RCT. General road observation system detects various types of moving objects for all times and weathers by a camera mounted about 5 meters above the ground alongside a road. ICW, which is based on commercial electric scooter and equipped with variable sensors and interfaces, can avoid obstacles semi-autonomously. We also performed field experiments on public roads by cooperating these terminals.

Keywords
Mobility support, Intelligent Transportation Systems, Computer vision, Intelligent mobile robot, Barrier-Free

1 Introduction

For human beings, freedom of movement is an essential part of living independently and comfortably. However, at present, elderly and disabled people — with impaired vision, hearing, or movement in the lower extremities — still suffer difficulty in some or all of the three elemental aspects of mobility: recognition of one's environment, actuation of movement by the legs, and ready access to information required for navigation. Consequently, these individuals are required to expend a great deal of effort simply to move about independently.

Against this background, we have proposed and promoted the Robotic Communication Terminals (RCT) Project involving a system supporting the three elemental abilities of recognition, actuation, and information access.

RCT consists of various components, including a system for surveying general roads and detecting and recognizing moving objects, an intelligent outdoor mobile vehicle, various information devices intended for the disabled, and the Mobility Support Geographic Information System (GIS). The components operate in coordination and provide efficient support for pedestrian mobility — mainly of the elderly and disabled — in outdoor environments.

Diverse research activities have taken place in Europe with the aim of supporting the elderly and disabled including TIDE, the VAHM Project (France), the Bremen autonomous "Rolland" wheelchair, the "Maid" wheelchair, and the SIAMO Project (Spain). However, most of these devices are intended for indoor use[1].

A number of research activities are also underway targeting mobility support in outdoor urban and residential areas, including research and development by Kotani and Mori, et al. of the Robotic Travel Aid (RoTA), designed to replace a guide dog. This system stores various image characteristics along the intended route in advance and recognizes various boundaries as it moves along the road: the road itself, walls, steps, and landmarks[2].

RCT is not a single system but instead is designed to provide comprehensive support for pedestrians by combining a number of component systems.

In this paper, Section **2** describes the concept underlying RCT and its characteristic features. With respect to the RCT components, Section **3** describes the details of the general road observation system (including the Environment-Embedded Terminal, or EET), and Section **4** describes the details of a semi-autonomous outdoor mobile vehicle (the Intelligent City Walker, or ICW). Section **5** describes field experiments in a real-world environment, performed by combining these system elements.

2 Robotic Communication Terminals (RCT)

The goal of the Robotic Communication Terminals (RCT) Project is to provide comprehensive support for outdoor pedestrians, particularly the elderly and disabled, in the three elemental abilities required for mobility: recognition of the environment, actuation through the legs, and ready access to information for navigation (Fig. 1)[3][4].

RCT embodies the following features:

- Provides support for a wide range of users according to the type and degree of impairment.
- For each of the three elemental abilities — recognition, actuation, and information access — provides comprehensive means of addressing problems through conversation with the user and by sharing roles among the devices.
- Connects the real world, the Internet, and the user and provides an environment in which the user can access information anywhere and at anytime through a unified process.

RCT consists of the components indicated below (Fig. 2).

These components communicate and collaborate with each other, helping the user to move through urban areas safely and freely

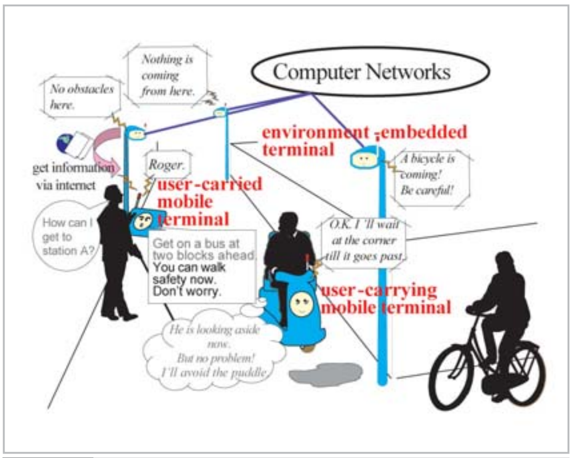

Fig.1 Robotic Communication Terminals (RCT) Project

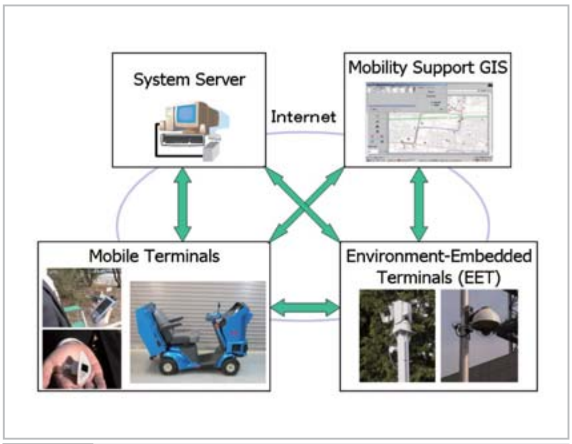

Fig.2 Components of RCT

and to arrive at his or her intended destination more easily. The terminals also provide connection to the Internet and allow the user to access a variety of useful information.

The Environment-Embedded Terminal (EET) consists of a camera mounted several meters above the ground along a road or in a station (lower right in Fig. 2), a recognition system that assesses road conditions and the trajectories of moving objects based on images taken by the camera, and a communication unit that provides communication with the mobile terminals[5]-[7].

We will discuss the recognition system later.

There are currently three sets of EETs at the National Institute of Information and Communications Technology (NICT) facility in Koganei, Tokyo; one set in Kamakura, Kanagawa; two sets on the campus of Chubu University in Kasugai, Aichi; and four sets in the Knowledge Creating Communication Research Center in Seikacho, Kyoto.

The user-carried mobile terminal is an intelligent navigation system on a wearable or hand-held computer carried by elderly or disabled subjects. This terminal communicates with an EET or map server and presents the user with information on ambient conditions and routes.

For the user-carried mobile terminal, we use the Compact Battery-less Information Terminal (CoBIT)[8][9]. The CoBIT receives a signal issued by a laser or a superdirective LED and converts this signal to electric power using a photoelectric conversion element in the receiver. This power is modulated based on the waveform of the sound; the receiver can thus receive vibrations (i.e., sound data) without requiring a power unit. Manufacturers today offer earbud, oscillator, and bone-conduction headphone receivers (upper and lower left in Fig. 2).

PDA-type user-carried mobile terminals are also available that can access a map server and display sign language animation providing guidance with respect to a given location.

The user-carrying mobile terminal referred to as the Intelligent City Walker (ICW) is a semi-autonomous outdoor mobile vehicle based on a commercially available electric scooter equipped with various sensors for avoiding obstacles and recognizing the environment, a touch-panel LCD monitor, and a processing unit (right-hand side of lower left of Fig. 2). In addition to the functions of a user-carried mobile terminal, the ICW provides driving assistance, including automatic avoidance of obstacles detected by sensors mounted on the user-carrying mobile terminal and by EETs[10][11].

We will discuss the details of these functions later.

The Mobility Support Geographic Information System (GIS) focuses on providing pedestrians with information that is more useful than that found in conventional maps (upper right, Fig. 2). Mobility Support GIS provides information not only on vehicular roads but also on narrow paths and footways. The information provided includes road width, inclination, and the presence or absence of steps. This system is also linked to a range of available data on barriers and can suggest the most suitable route according to the type and degree of impairment[12][13].

Three types of Mobility Support GIS are currently established, one for each of three areas: the approximately 11-square-kilometer area around Koganei; the area around Higashiyama, Kyoto; and the area around Akihabara, Tokyo. Part of the system is open to the public via the Internet as a test system.

The system server (upper left of Fig. 2) knows the IP addresses of the terminals and the GIS system and the positions of the terminals in the real world. When the mobile terminals and the EET interact as described in Section **5**, the system server mediates the devices. For example, the system server searches the EET watching the area in which a mobile terminal is moving and presents the IP address of the EET to the mobile terminal.

3 General road observation system

3.1 Overview of general road observation system

We are developing a system aimed at recognizing objects moving on a general road, for use as an Environment-Embedded Terminal (EET).

The hardware of this system consists of a camera for observing a road or other area (lower right of Fig. 2) and a PC terminal for processing the images acquired by the camera.

The camera is mounted several meters above the road and its angle can be controlled. Generally the device is assumed for applications in which the conditions of a relatively small area are monitored, such as a small road in a residential area or a railroad yard.

The PC terminal processes the images input from the camera. In addition, it communicates with the Mobility Support GIS and the mobile terminals to acquire positional information from mobile terminals and other components and to transmit the information relating to obstacles and dangers recognized by the general road observation system.

The system recognizes and obtains the trajectories of all moving objects in its field of view 24 hours a day, including automobiles, two-wheeled vehicles, and pedestrians, based on information acquired by a camera placed at approximately the height of a streetlight on a road that does not carry extremely large volumes of pedestrian or vehicle traffic. In general, variation in brightness poses a significant problem in detecting moving objects, and occlusion represents a significant challenge in tracking objects. We address the problem of detection using the normalized distance method described in the next subsection and tackle the tracking problem using a method proposed by Kamijo et al. based on the Spatio-Temporal Markov Random Field model[5][14].

3.2 Moving object detection based on normalized distance

In outdoor environments, the luminance of the image as a whole varies due to the movement of clouds and the camera characteristics, affecting recognition. Accordingly, this system adopts a method based on the concept of normalized distance proposed by Nagaya et al., a method that proves effective in counteracting the effects of mild variation in lighting[15].

Normalized distance is a characteristic quantity not easily influenced by changes in illuminance. This value is defined as the length of the vector composed of the pixel values in the area of interest, with the vector projected to a unit sphere. Using this normalized distance, this method separately assesses changes in the scene, background, structure, and illuminance in the area of interest. Based on the acquired information, the system detects the time period during which moving objects are present and updates the background.

Nagaya et al. use this method in a portion of an image, but we divide the entire image into small blocks and apply this process to each block, in a manner similar to that described by Matsuyama et al.[16]. However, unlike Matsuyama et al., our blocks are each eight pixels by eight pixels in size.

Nevertheless, the normalized distance calculated is significantly affected by noise when the luminance of the target environment is low. On the other hand, areas illuminated by a strong light source (such as the light of an automobile) lose texture as the luminance saturates, and it becomes difficult to obtain accurate normalized distances.

Accordingly, we classify nighttime illuminance into three categories: no lighting, weak lighting, and strong lighting. When there is no lighting, the system sums pixel values of images accumulated over an extended period to reduce noise. When there is some lighting, the system estimates the position of the light source[5]. These processes address some of the problems of nighttime illuminance.

3.3 Evaluating performance in detection and tracking of moving objects

To evaluate the effects of the above technique, we performed an experiment by placing cameras in the NICT Headquarters in Koganei, Tokyo, and on a building in Kamakura, Kanagawa. The cameras were mounted several meters above the ground and tilted at an angle so that the road in the direction of travel could be viewed over a length of 50 m to 80 m.

The images acquired by these cameras were classified into 23 types of situations according to the time (morning, midday, evening, twilight, night) and weather (clear, cloudy, rainy, after rain, and snowy). Three image sequences containing moving objects were extracted for each type of situation for each camera, totaling 125 sample image sequences. We processed the acquired images with the algorithm discussed above for purposes of this evaluation. Here, 61 percent of the moving objects in the samples were automobiles, 22 percent consisted of bicycles, and the remaining 17 percent consisted of pedestrians and small animals. The target area contained only a small amount of traffic, the maximum speed of the automobiles was approximately 60 km/h, and each of the vehicles was present in the camera's field of view for at least four seconds. Samples included sequences containing several automobiles in succession or passing.

Here, we set as our goal the detection and tracking of moving objects over a period of sufficient length to permit calculation of their respective trajectories. This structure was designed to enable the system to determine any risk of the mobile terminal's collision with moving objects, as in the experiment described later.

The results show that we were able to detect and track all moving objects in the daytime (morning, midday, evening, early twilight) over 70 percent of the period these objects were within the images (i.e., with the exception of the periods during which the objects were too far away to determine movement). At night, we could detect moving objects for over 30 percent of the period during which the objects were in view, except for in the case of two pedestrians. Even in these two failures, the pedestrians were detected for approximately 10 percent of this period.

4 Semi-autonomous outdoor mobile vehicle: the Intelligent City Walker (ICW)

4.1 ICW hardware

We are currently developing a semi-autonomous outdoor mobile vehicle, the Intelligent City Walker (or ICW; see Fig. 3), a user-carrying mobile terminal. The ICW was constructed by modifying a commercially available four-wheeled scooter (the Senior Car, from Suzuki Motor Corporation). The ICW has the following features.

- Intended for outdoor movement
- Normally moves in response to driver operations; manages control only in dangerous situations (semi-autonomous).
- Moves at low speed (6 km per hour at maximum)
- Intended for use in pedestrian spaces, not on vehicular roads

The ICW is equipped with seven sensor units, each consisting of a sonar sensor and an infrared sensor. The sensor units are placed at the front, back, left, and right of the vehicle. The device also features a trinocular camera mounted obliquely downward at the front of

Fig.3 Intelligent City Walker (ICW)

the vehicle. Using these sensors and cameras, the ICW acquires dynamic environmental information for a space of several meters surrounding the vehicle.

Table 1 shows the specifications of the ICW, including details of these sensors.

4.2 ICW presentation of information

The ICW collects the following three types of information:

- Dynamic environmental information for surroundings of several meters, acquired by the ICW itself
- Dynamic environmental information for the surrounding dozen to several tens of meters, acquired by the general road observation system
- Static wide-range environmental information provided by the Mobility Support GIS

The ICW presents the information to the user on the touch-panel LCD monitor (Fig. 4).

The touch panel LCD monitor installed on the ICW has three types of display modes as indicated below. Figure 4 shows screenshots of each mode on the right, from top to bottom.

- Sensor information mode (Displays speed, values of sonar and infrared sensors, and processing results for image sensors)
- Normal mode (Displays control panel, speed, present position, simplified map, and warning information)
- Map mode (Displays detailed map and can search routes)

The general road observation system transmits information on the presence of moving objects that may collide with the ICW. The ICW displays this information on the monitor and operates semi-autonomously as required — for example, stopping automatically. Through Mobility Support GIS, the device can also search for appropriate routes. The ICW communicates with the other components of the RCT system through wireless LAN.

In addition, the ICW internally processes the ambient environmental information that it collects with its own sensors and can present the results to the user via the monitor. The

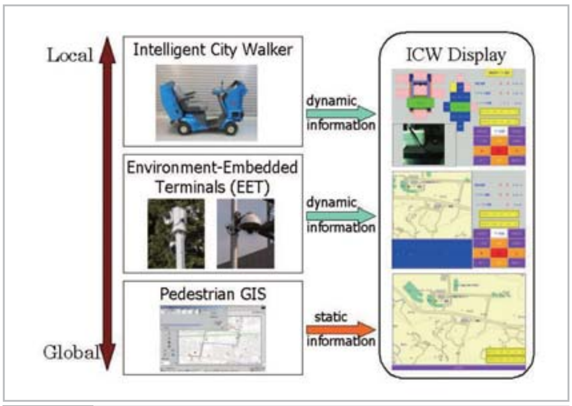

Fig.4 ICW Presentation of Information

Table 1 ICW specifications

External sensor	Sonar and infrared sensor unit × 7 Infrared LED laser sensor ×4 Semiconductor laser sensor × 1
Multi-lens camera	Trinocular camera × 1, binocular camera × 1
Positional sensor	GPS, electronic compass
Internal sensor	Gyroscope, steering wheel angle sensor, wheel rotation sensor
Interface	Touch panel LCD monitor Microphone, wireless LAN (802.11b)
Power supply	Transport for 2 1/2 hours with 30-minute charge
Processing unit	PC (Linux OS)×2

next and subsequent subsections describe the preparation of this environmental information.

4.3 Creation of environmental map by three-dimensional occupancy grid method

The occupancy grid method is an environment description method proposed by Elfes et al.[17] to obtain more robust ambient environmental information based on sensor information containing various types of noise. This method divides the space into grids and cells and describes the environment by attributing a probability to the presence of an object in each grid cell. In most past studies, the probability calculation was generally based on information input by sonar sensors and the cells were two-dimensional. However, this study focuses particular attention to surface unevenness, using a three-dimensional grid that divides the space particularly finely in the vertical direction, enabling the unit to distinguish:

- Stairs (to be avoided) and slopes (ignored; the vehicle proceeds)
- General curbs on the walkway (high steps: to be avoided) and sectioned curbs to allow entry of vehicles and pedestrians (low steps: ignored; the vehicle proceeds).

The size of the present grid is 4 cm high and 8 cm wide and deep. The number of grid cells in each direction is 64, 128, and 128, respectively.

The grid is created based on the three-dimensional coordinates corresponding to each pixel, which are calculated based on images acquired by the trinocular or binocular camera.

Figure 5 shows a visualization of the grid. When the upper image in Fig. 5 was obtained, the ICW camera was positioned in the right corner of the lower image. The lower image shows that the stairs, trees, and poles at the far end are correctly recognized. The demonstration field experiment, which we will describe later, also showed that the system was able to acquire information of sufficient accuracy to avoid dangers without problems.

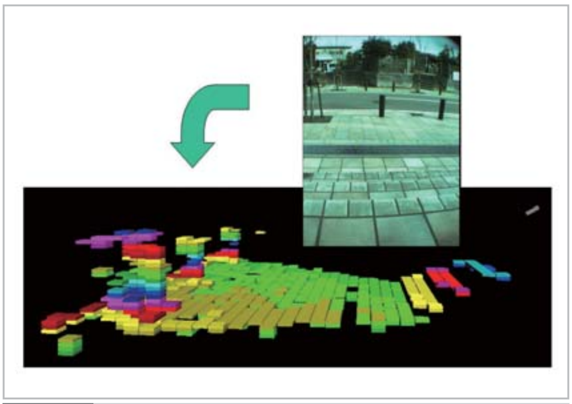

Fig.5 Three-dimensional grid

4.4 Determination of dangerous areas and avoidance of dangers

Based on the three-dimensional grid created in the manner described in the previous subsection, the system detects dangerous areas through the procedures indicated below.

(1) In each position, the system finds the highest grid cell for which the probability of an object's presence is above a set value and creates a two-dimensional step map.

(2) At each position on the two-dimensional step map, the system checks the height difference for four adjacent positions and regards this position as a dangerous area if the height difference is two units (8 cm in this case) or greater for any of the four adjacent positions.

Here, areas for which precise height is not obtained are excluded.

In this manner, the system can distinguish steps from areas where height changes continuously, allowing the vehicle to pass (such as ramps).

When the ICW recognizes a danger — from collision to possible toppling — based on this information and the sonar and infrared sensor data, the ICW takes over control from the user and automatically moves to avoid the danger. In the absence of sufficient space in the surrounding area to circumvent the danger safely, the vehicle stops on the spot.

Nevertheless, the ICW in principle runs according to user operation. This system is semi-autonomous and does not usually operate automatically, instead shifting to automatic mode only in danger. This design respects the user's enjoyment of his or her ability to drive the vehicle freely, and is also due to the extensive legal and technical barriers to completely automatic operation.

5 Outdoor experiments

5.1 Experiments combining mobile terminals and Environment-Embedded Terminals

To test the integration of the RCT terminals, we performed experiments combining mobile terminals and the Environment-Embedded Terminal, in which the mobile terminals were to direct an automobile to pass through a crossing with poor visibility (Fig. 6).

We used a commercially available wireless LAN in compliance with the IEEE802.11b standard for communications and constructed a private network between the terminals.

We performed the experiments at two locations: in Kamakura, in an experiment combined with a user-carrying mobile terminal (ICW); and in Koganei, in an experiment combining a user-carrying mobile terminal and a user-carried mobile terminal. Except for some degree of erroneous recognition caused by the swaying of the cameras due to strong winds, moving objects were detected and alarms were generated correctly. Here, it took two to three seconds from the moment an automobile was detected until the mobile terminals were notified of the automobile's presence.

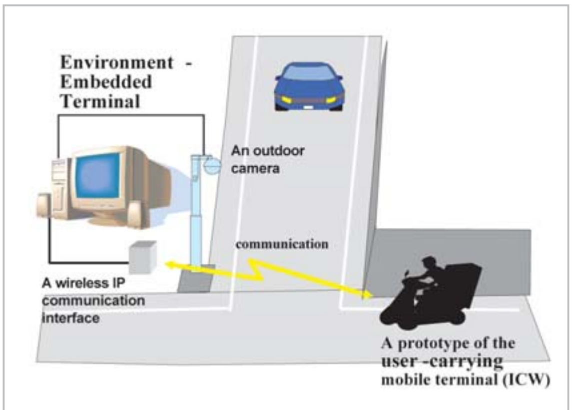

Fig.6 Experiment combining ICW and Environment-Embedded Terminal

In Kasugai, we also succeeded in an experiment to display the map of the surrounding area, including detected and recognized moving objects, on the monitor installed on the ICW.

5.2 Verification of ICW interfaces

As described earlier, the ICW can avoid dangers by itself based on information acquired by its sensors. To verify its capacity to avoid obstacles and to assess safety and comfort during the relevant operations, we performed demonstration field experiments with 11 volunteers over the age of 60.

Although slight differences were observed depending on the volunteer's knowledge of and attitude toward the ICW, the experiment confirmed that the ICW provides safe obstacle avoidance in terms of the timing of avoidance and the recovery trajectory after avoidance. As for the ideal timing for such avoidance, the results indicate that it is most comfortable to begin avoidance maneuvers 3 m short of the obstacle, regardless of speed.

We have implemented this finding in the functions of the ICW and have been performing demonstrations in numerous exhibitions and similar events on courses constructed with corrugated boxes and other materials.

In an exhibition held in July 2006, we distributed a questionnaire concerning the ICW interfaces after an approximately three-minute test drive per subject. The examinees consisted of 31 men and women in their pre-teens to their 60s, with most in their 30s and 40s. The questionnaire requested that the examinees assess the necessity for the monitor display in a five-grade evaluation and also asked about the timing of collision avoidance and the examinee's ideas on an appropriate future sales price.

The results show that map information (score: 4.53) is highly appreciated, that a rough indication of ambient conditions is sufficient (score of 4.17 for simplified display of obstacles and score of 3.93 for the detailed display), and that enthusiasm was low for button operation (score: 3.07).

The timing for collision avoidance was too early for 6 percent, just right for 74 percent, and too late for 19 percent of the examinees. The median of the appropriate sales price was 300,000 yen, which is approximately the same as the sales price for a commercially available electric scooter with no “intelligent” features.

5.3 Test-run experiments on public roads

In November 2005, we performed experiments open to the public in Seikacho, Kyoto. One of the experiments involved allowing the ICW to avoid a collision on its own. Another experiment was performed on a public road to allow the Environment-Embedded Terminal to recognize an automobile approaching in the blind spot of an ICW and to transmit information to the ICW through the network, allowing the ICW to autonomously avoid the automobile based on the provided information[18].

In these experiments, 10 general participants rode on the ICW and experienced the avoidance actions, and approximately 150 general participants watched the experiments.

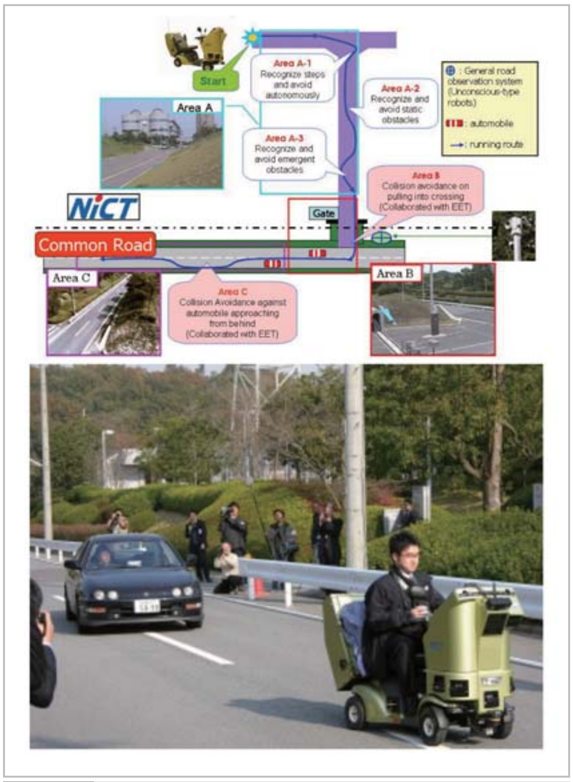

Fig.7 *Test-run experiments on public roads*

We submitted a questionnaire survey to these participants concerning the required aspects of future practical outdoor applications of the ICW, and 107 participants returned the questionnaire. The results revealed that the demand for safety is extremely high (72.0 percent), that the demand for operability is also high (48.6 percent), and that the demand for a low price is quite strict (47.7 percent)[11].

6 Conclusions

We are conducting research and development of Robotic Communication Terminals (RCT) to provide comprehensive support to pedestrians — particularly the elderly and the disabled — in outdoor mobility.

This paper specifically describes the details of the Environment-Embedded Terminal, which detects moving objects on general roads, and a user-carrying mobile terminal, the ICW. With the Environment-Embedded Terminal, we solved the problem of irregularly variable lighting by adopting the normalized distance method, which divides the images into small regions and evaluates similarities in texture, and have successfully arrived at a robust detection of moving objects. With the ICW, we developed an ambient environmental description using diverse types of sensors and have successfully developed a system that can avoid obstacles semi-autonomously as the user is driving. In addition, we performed demonstration field experiments on public roads and other locations incorporating a combination of these various components.

With respect to the future practical application of the entire RCT system, we need to solve a range of problems, including further safety improvements and legal concerns. In the meantime we believe that it is important that we further refine the elemental technologies and begin to promote partial commercialization of the constituent components.

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