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Semi-Autonomous Outdoor Mobility Support System for Elderly and Disabled People

Kentaro KAYAMA, Ikuko Eguchi YAIRI, and Seiji IGI
Communications Research Laboratory
Yokosuka, Kanagawa, 239-0847, JAPAN

***Abstract*— We have been developing the Robotic Communication Terminals (RCTs), which are integrated into a mobility support system to assist elderly or disabled people who suffer from impaired mobility. The RCT system consists of three types of terminals and one server: an *environment-embedded terminal*, a *user-carried mobile terminal*, a *user-carrying mobile terminal*, and a *barrier-free map server*. The RCT is an integrated system that can be used to cope with various problems of mobility, and provide suitable support to a wide variety of users.**

This paper provides an in-depth description of the *user-carrying mobile terminal* . The system itself is a kind of intelligent wheeled vehicle. It can recognize the surrounding 3D environment through infrared sensors, sonar sensors, and a stereo vision system with three cameras, and avoid hazards semi-autonomously. It also can provide adequate navigation by communicating with the geographic information system (GIS) server and detect vehicles appearing from the blind side by communicating with environment-embedded terminals in the real-world.

I. Introduction

Mobility is a basic and indispensable human activity that is essential for us to be able to lead independent lives on a daily basis. Elderly and disabled people with impaired vision, hearing, and mobility often find it difficult to get around because their physical impairments 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.

To comprehensively support these three elemental abilities for mobility outdoors, we have been developing *Robotic Communication Terminals (RCT)* [1], [2]. This can be regarded as a model system for pedestrian Intelligent Transportation Systems in the real-world.

As an element of the RCT project, we have been developing the *Intelligent City Walker (ICW)* as a user-carrying mobile terminal, which is an intelligent wheeled vehicle that directly supports user mobility.

It is an outdoor mobile support system especially for the elderly whose walking and recognition skills are impaired. As we are faced with an increasingly aging population, these systems are expected to become even more prevalent than they are today.

ICW is an intelligent mobile vehicle that is based on a commercial electric buggy and it is equipped with a monitor with a touch panel, various sensors, and processing computers. It is also equipped with a wireless LAN device. Because of these features, various types of extraneous information can be obtained from the local physical environment and the Internet.

This paper is organized as follows. The concept behind the RCT project is explained in Section II and its elements are datailed in Section III. Section IV has descriptions of the hardware and software systems for the ICW.

We also did experiments with the ICW on avoiding hazards in an actual outdoor environment and Section V discusses these.

II. Comprehensive Mobility Support System: Robotic Communication Terminals (RCTs)

A. RCT Concept

The RCT project we engage in needs to satisfy the following criteria. It needs to:

- Assist a wide variety of elderly and disabled people.
- Provide a comprehensive method that allowed them to cope with the various problems of mobility, and
- Actively adopt the current technology to produce a practical system for the near future

Our aim is to comprehensively support recognition, locomotion and information acquisition following these criteria.

First, we need to think about recognition support. It is necessary for a pedestrian, who is outdoors, to be able to recognize various obstacles and navigate his/her way around them. Moreover, to assist in human recognition of the environment, the support system needs to provide not only static information, such as that on obstacles and landmarks, but also dynamic information, such as that on approaching vehicles. There have been many studies in this area on avoiding collisions, particularly those using local sensors mounted on wheelchairs. However, local sensors have numerous blind spots and cannot detect fast moving vehicles.

It is essential to be able to acquire treatable information easily and this should contain data on the best route or obstacles in the near area. Moreover, information should be customized to the each user, especially if he/she is elder or disabled.

There have been a number of studies on mobility support systems for the elderly and infirm, e.g., a system that uses speech beacons and hand-held receivers to guide blind people, and an intelligent interface for a wheelchair [3], [4], [5]. Almost all of these systems, however, have been for indoor use.

Kotani, Kiyohiro and Mori proposed a Robotic Travel Aid that assisted visually handicapped people to walk

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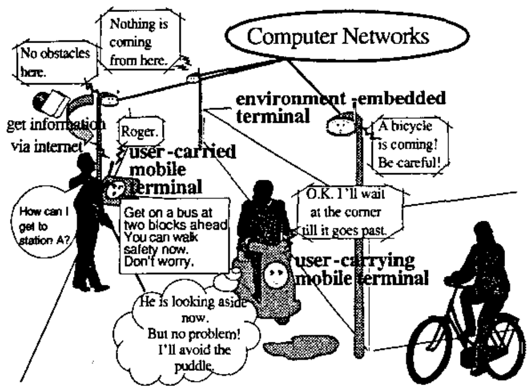

Fig. 1. Outline of Robotic Communication Terminals

through city areas [6]. The system can recognize obstacles along the way and traffic signals and inform the visually impaired so that they could stop or avoid danger. The system, however, like seeing-eye dogs does not support locomotion and it do not permit dynamic changes in route.

These studies only addressed small components of the mobility problem and were thus only suitable for a small fraction of the population needing assistance with mobility. These systems were not sufficiently comprehensive to support the three elemental abilities of actions: recognition, locomotion, and information acquisition.

B. RCT Outline

As discussed in the introduction, we have been developing Robotic Communication Terminals (RCTs) in the real world [1], [2] and Fig. 1 has an outline of these. An RCT system consists of three types of terminals and one server. These are:

- An environment-embedded terminal (EET) located at the sides of roads and at railway stations,
- A user-carried mobile terminal,
- A user-carrying mobile terminal, and
- A server that provides geographic information.

These elements communicate and collaborate with one another, and assist users in reaching their destinations more easily, while permitting movement with a higher degree of safety and freedom.

Moreover, as these terminals and servers are connected to the Internet, users can access a variety of information that is on outside of the RCT system.

The *environment-embedded terminal (EET)* is a kind of antenna that is fixed in sidewalks and at railway stations and it provides an access point to the Internet for the other two types of mobile terminals enabling interactive communication among them. It monitors roadways and detects emerging obstacles and events, such as motor vehicles, bicycles, and on-going construction hazards. Detected impediments or moving objects are broadcasted to mobile terminals in the surrounding area, and are stored so that they can also be accessed by other users in remote areas.

The *user-carried mobile terminal* is an intelligent navigation system for elderly and disabled people that comes in the form of either a wearable or hand-held computer. This terminal communicates with the EET and geographic information system (GIS) server and obtains various information on the surrounding environment and optimal routes, which are then presented to the user.

The *user-carrying mobile terminal* is an intelligent wheeled vehicle for the elderly and disabled that resembles an electric wheelchair equipped with joysticks, or an electric buggy with handlebars. In addition to the functions of the user-carried mobile terminal, it offers driving support, i.e., it automatically avoid detected obstacles through sensors mounted on the body. It also provides the users with suitable driving interfaces that complement his/her physical impairment.

The *geographic information system server* is designed for pedestrians. The system itself has information on not only roads but also sidewalks and this is linked to barrier information and barrier-free information. The server is connected to the three types of terminals via the Internet and information is updated as often as needed.

C. RCT Characteristics

The RCTs provide tailored hardware and software interfaces to complement each user's physical impairment, such as its type, level, combination, and history. As the users' personal data that automatically adapts the software interface users will be able to flexibly buy or rent various kinds of hardware that are easy for them to use. The real-world information that is detected and accumulated by the environment-embedded terminal and the information from the Internet (e.g., maps, guides, and emergency information) is put into a format that is accessible to users, and transmitted to them by mobile terminals.

Characteristics of RCTs can be summarized as follows. They

- Provide suitable support to a wide variety of users that is based on their physical status, such as the types, levels, combinations and histories of impairment to their eyes, ears, and legs,
- Assist users in coping with their problems of recognition, actuation, and information access through interaction and task-sharing between the environment-embedded system, the mobile system, and users, and
- Make real-world information and information from the Internet accessible to each user in his/her required format at any time or place by connecting the real-world, the Internet, and users.

III. Implementation of RCT

A. RCT Components

The current RCT system consists of:

- *General Road Observation Systems* that act as environment embedded terminals,
- Various types of user-carried mobile terminals,
- *ICWs (Intelligent City Walkers)* as user-carrying mobile terminals,

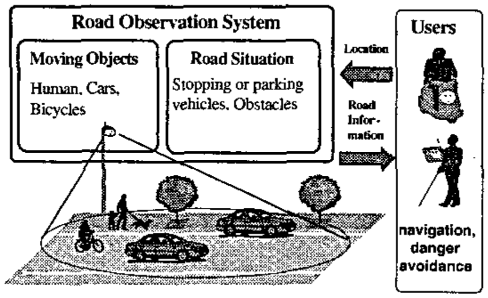

Fig. 2. Outline of General Road Observation Systems

- A *BFM (Barrier-Free Map)* that acts as a GIS server, and
- A system server that supports communication between each terminal

The ICW, which is a user-carrying mobile terminal, will be described in more detail in the next section and this section explains the other four elements.

B. General Road Observation Systems

A *General Road Observation Systems* consists of a camera mounted about 5 meters above the ground alongside roads or stations. It is a recognition system that can calculate road conditions and trajectory of moving objects from images captured by the camera, and communicate with other terminals [7], [8].

The system is outlined in Fig. 2 and one of its most important function is to determine the position of users via network communications, to estimate whether they and moving objects will collide, and if so, to send alerts to users so that they can take the necessary action to avoid these collisions. User and moving object trajectories are estimated as sectors and if they are overridden the system concludes that they are in danger of colliding.

C. Geographic Information System Server: Barrier-Free Map

We have been developing a prototype of a barrier-free route information database (BFM: Barrier-Free MAP).

The prototype has information on barrier-free routes in Koganei City, which covers an area of approximately $11 km^2$ and has a population of over 110,000. The prototype uses a high-resolution map with a scale of 1:500 [9](Fig. 3).

We developed a novel route network for pedestrian that includes sidewalks and paths described on the map. It is linked to barrier information and barrier-free information deemed useful for the physically challenged and visually and hearing impaired. Registered barrier and barrier-free information includes the width and incline that would be experienced on each route. The BFM suggests the best route for that user's particular impairment. The BFM is also connected to the Internet and can be accessed not only from an ICW but also a web browser.

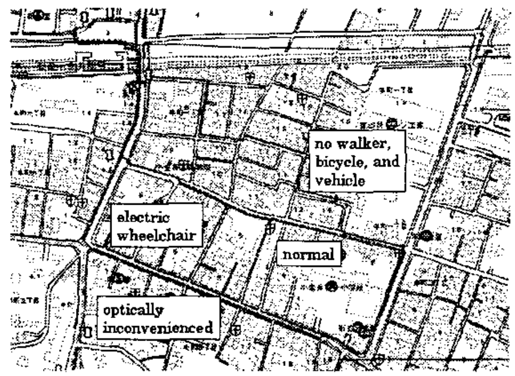

Fig. 3. Barrier-Free Map

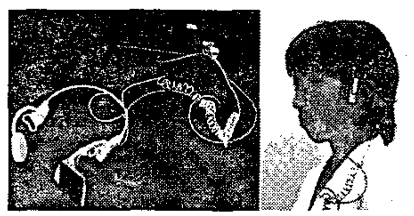

Fig. 4. User-carried Mobile Terminal (Bone-conduction Headphone-Type)

D. User-carried Mobile Terminals

We have been developing compact earphone-type, vibration-type, and bone-conduction headphone-type receptors that can be utilized as user-carried mobile terminals. A communicator on the roadside emits infrared signals by laser or directive LED and the receptor converts these to voice or vibration [10].

Fig. 4 is a photograph of a bone-conduction headphone-type receptor.

E. System Server

A system server manages IP addresses and the physical location of all terminals. It also controls the communication between these terminals. Fig. 5 has a flow diagram for the system server and RCTs.

A General Road Observation System (EET) is connected to the system server as soon as it is booted, and it sends its IP address and GPS latitude and longitude. A mobile terminal (ICW or user-carried mobile terminal) periodically sends its IP address and latitude and longitude to the system server. Then, the system server calculates whether there is an EET near the mobile terminal. If the mobile terminal is in the "observation area" of the EET, the system server send the IP address of the EET. Through this procedure, the mobile terminal can be sent alerts and other messages by the EET.

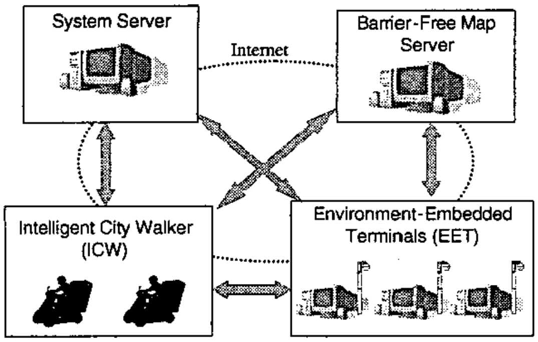

Fig. 5. System Server on Robotic Communication Terminals

IV. User-Carrying Mobile Terminal: Intelligent City Walker (ICW)

A. ICW Outline

We have been developing Intelligent City Walker (ICW), which is an improved commercial electric buggy, as a prototype of the user-carrying mobile terminal for elderly people (Fig. 6).

The ICW has the following functions. It:

- Searches for routes by communicating with the Barrier-Free Map,
- Receives collision alerts by communicating with the EET (General Road Observation System),
- Detects obstacles in surrounding areas through various sensors mounted on it, and
- Semi-autonomously avoids obstacles by using the above data.

ICWs are usually controlled by users and do not move automatically in the normal mode. However, an ICW does always monitor surrounding obstacles through sonar sensors, infrared sensors and a stereo vision system with three cameras, and if there is danger of collision it assumes control to prevent this or stops itself automatically.

The ICW send its position and speed to the EET via a network. When an ICW is within the observation area of an EET, the EET estimates whether the ICW is in danger and sends an alert if there is the possibility of colliding with moving objects.

ICW users can also access Barrier-Free Map (GIS server) via LCD monitor equipped with touch panel and they can search for the best route or resister new obstacle information.

Subsection IV-B explains the hardware system for ICWs and IV-C explains the software system. We will then describe each function.

B. ICW Hardware System

ICW is an intelligent wheeled vehicle, which is based on a commercial electric buggy for those who find difficulty with walking. It is equipped with various sensors, an LCD monitor with a touch panel and PCs as its information processing unit. Various interfaces enable interaction between the ICW, other terminals, users and the real world.

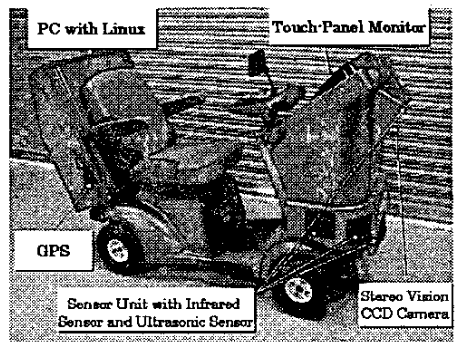

Fig. 6. Intelligent City Walker

TABLE I
Intelligent City Walker Specifications

external sensor	7 sensor units with sonar and infrared sensor, stereo vision camera system with three cameras
position sensor	GPS
internal sensor	gyroscope, manipulation degree sensor
interface	LCD monitor with touch panel, microphone, wireless LAN device (802.11b)
max speed	6km/h
power supply	transport for 2 1/2 hours with charge of 30 min.
processing unit	PC (Linux OS) $\times 2$

Fig. 6 has a photograph of the latest version of the ICW and Table I lists its specifications.

C. ICW Software System

The ICW software consists of five parts (Fig. 7). These are the:

- Personal Customized Brain that is engaged in general control, such as communication management between each software parts, log data maintenance, and user customization,
- User Communication that captures the user's attention via a monitor with touch panel and sends them alerts and some information,
- Network Communication that communicates with other terminals such as EET and BFM,
- Image Recognition that connects with the stereo vision system, and
- Real World Communication that communicates with the Sensor Actuator Unit and Image Recognition recognizing the surrounding environment, plan a route for avoiding danger, and issue orders to Sensor Actuator Unit.

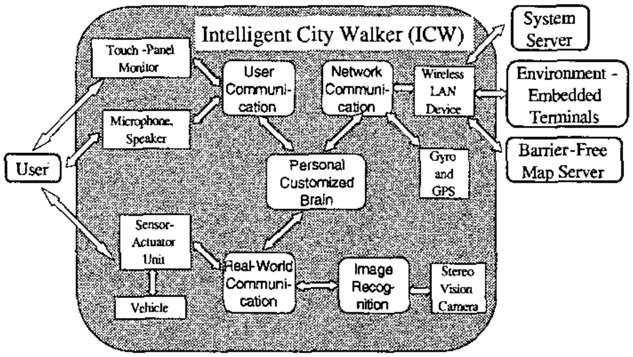

Fig. 7. ICW Software System

D. Route Search through BFM

The ICW has three display modes via the monitor with the touch panel. These are the:

- Normal mode (control panel, speed, simple map and alert are displayed),
- Sensor information mode (speed, values of all sonar and infrared sensors and processing results for image recognition are displayed), and
- Map mode (specific map is displayed and users can search for best route)

The map mode allows the user to send information on position acquired by the GPS sensor to the BFM server via a wireless LAN device and obtain map information near this location. Route searches which are based on the perticular user's impairment or favorite are also provided by the Barrier-Free Map.

E. Receiving Collision Alerts from EET

The ICW can receive the IP address of the EET (General Road Observation System) near it by sending positional information acquired by the GPS sensor to the system server.

The ICW sends its position to the EET periodically. The EET calculates the trajectory of the ICW and estimates whether it and moving objects which can be recognized from images provided by the camera mounted on the EET are in danger of colliding. When the EET determines there is a possibility of collision it sends an alert to the ICW.

F. Obstacle Recognition

The ICW has a total of seven sonar-sensor and infrared-sensor units, which are mounted on the front, the lower front, the front right, the front left, the back, and the right and left sides. A stereo vision system with three cameras is also mounted at the front of the ICW.

The sonar sensors are used to detect obstacles at relatively long distances (farther than 3 meters) and the infrared sensors are used to determine whether there are obstacles near the ICW (nearer than 3 meters). They return a binary value whether there is a obstacle or not.

The 3D camera detects depressed areas which are difficult to detect with sonar and infrared sensors. The system's main objective is to distinguish passable slopes from impassable steps. The current system prepares an elevation map by using three-dimensional evidence grids [11] and it calculates dangerous areas from this where the likelihood of steps is high.

G. Semi-Autonomous Avoidance of Obstacle

A human operator normally drives the ICW. This is because the RCT system respects the user's right to drive. However, this is automatically circumvented when there is imminent danger of collision and the user does not take the appropriate steps to avoid this.

Data used to estimate the danger and avoid collision is obtained from the:

- Values of the sonar and infrared sensors,
- Results of image recognition obtained by the stereo vision system, and
- Real-time direction and speed.

The ICW determines whether it will detour the danger area or stop. This processing is done like an expert system. For example, if there is an obstacle in front of the ICW and there is not on the left, the ICW will turn left. If all sensor units on the front, the front right, and the front left detect obstacles, the ICW will stop.

The timing to avoid collisions is very user-dependant and there is a brief report in Section V-B.

This avoidance function also works when the ICW is not connected to the network.

V. Hazard-Avoidance Experiments

A. Concept behind Experiments

We have developed the following RCT prototypes. They are:

- Six Environment-Embedded Terminals (three in Koganei City, one in Kamakura City and two in Kasugai City),
- Three Intelligent City Walkers, and
- A Barrier-Free Map for Koganei City

These elements are connected to the same network and can communicate with each other.

This section describes two experiments:

- The ICW performance test and
- the auto-avoidance of unseen dangers achieved by communication between the ICW and EET

B. ICW System Experiments

We tested the performance of the ICW with the help of eleven subjects who were over sixty years old. The objective was to check whether obstacles could be avoided, safely and comfortably.

This test was done on a configured model course and ICW performance was genellay as expected.

When auto avoidance engaged, many subjects felt that the "stopping" to avoid collisions was too drastic. Many liked the fact that the system returned control to the user as soon as the obstacle no longer presented a threat. Most subjects felt that the timing for avoidance to commence was adequate when the distance between the user and obstacle was $3m \pm 20cm$.

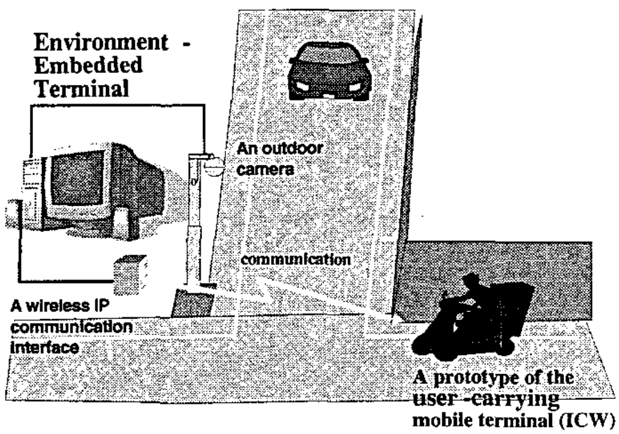

Fig. 8. Experiment to prevent collision at intersection

We exhibited and demonstrated the ICW at various exhibitions around Japan. Many guests took it for a test drive around the model course and it was highly evaluated.

C. *Experiments using Environment Embedded Terminals*

The experiment where hazards were avoided automatically was done with an environment-embedded terminal prototypes (in Koganei and Kamakura City). The experimental layout is in Fig. 8.

The location of the ICW was detected by an on-board GPS, and the data was sent to the EET through a wireless IP device. When a near miss was determined based on the detection of a speeding car and the location of the ICW, the EET informed the ICW of the danger. The mobile terminal then stopped automatically and avoided colliding with the speeding car.

The experiment was done during the day, and the detection of moving objects and transmission of alerts were successful except for one case of miss recognition that occurred because the camera was vibrated by strong wind. It took about two to three seconds to display the alert and stop the ICW after a speeding car was detected by the EET.

VI. Conclusion

In this paper we described the concept of Robotic Communication Terminals (RCTs), which was integrated into a mobility support system for the elderly and disabled. We also described the *user-carrying mobile terminal* Intelligent City Walker (ICW) in detail, which is an element of the RCT.

As our purpose is to construct a system that would work in the real world we conducted experiments on its performance, which we described in this paper.

Future work is to improve recognition level each mobile and environment-embedded terminal presently has. These terminals must be able to work robustly in more complex environments.

The current system only uses local information in predicting hazards, not global. However, global information is necessary to provide increasing levels of safety.

It is also necessary to provide individualized hazard-avoidance information or interfaces that users feel comfortable with. To achieve this, we conducted an extensive questionnaire and are now analyzing the responses so that we could incorporate this data into future work.

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