An Interactive Robotic Cane

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ABSTRACT

A human-friendly interactive system that is based on the harmonious symbiotic coexistence of human and robots is explored. Based on this interactive technology paradigm, a robotic cane is proposed for blind or visually impaired travelers to navigate safely and quickly through obstacles and other hazards faced by blind pedestrians. The proposed robotic cane, "RoJi," consists of a long handle with a button-operated interface and a sensor head unit that is attached at the distal end of the handle. A series of sensors, mounted on the sensor head unit, detect obstacles and steer the device around them. The user feels the steering command as a very noticeable physical force through the handle and is able to follow the path of the robotic cane easily and without any conscious effort. The issues discussed include methodologies for human-robot interactions, design issues of an interactive robotic cane, and hardware requirements for efficient human-robot interactions.

Keywords : Interactive technology, Human-robot interaction, Robotic cane, Shared behavior control

1. Introduction

As robots increasingly become part of our everyday lives, they will serve as caretakers for the elderly and disabled, as assistants in surgery and rehabilitation, and as educational toys. Unlike industrial robots, these robots require cooperation between human and robots[1-3].

A human-friendly interactive system that is based on the harmonious symbiotic coexistence of human and robots is explored. Various methods for implementing the appropriate cooperative sensing, planning, and acting have been investigated[3-7].

Based on this interactive technology paradigm, a robotic cane is proposed for blind or visually impaired travelers to navigate safely and quickly through obstacles and other hazards faced by blind pedestrians[8-13].

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We outline a set of hardware solutions and working methodologies that can be used for successfully implementing and extending the interactive technology to coordinate human and robots in complicated and unstructured environments.

2. Robotic Canes

The successful and widely used travel aids for the blind are the white cane and the guide dog. Electronic travel aids are also used, but not so widely so[14-16]. These aids are used to detect uneven surfaces, holes, steps and other obstacles on the ground.

2.1 Robotic Travel Aids

The white cane is a successful and widely used travel aid for the blind. The white cane is inexpensive, lightweight and easy to carry. However, users must be trained in the use of the white cane for a period of over 100 hours[14].

The guide dog is a trained dog for the blind or visually impaired traveler to navigate safely. The guide dog is expensive, difficult to train, and sometimes unfriendly to other pedestrians[15].

In the past three decades, several electronic travel aids have been introduced that are aimed at improving the mobility of visually impaired people in terms of safety and speed. These robotic devices appear to lack utility and consequently, have not been widely used[16-23].

In 1973, the "C5 Laser Cane" was introduced by Benjamin, Ali and Schepis. It is based on optical triangulation with three laser diodes and three photo-diodes as receivers. It can detect obstacles at head-height, drop-offs in front of the user, and obstacles up to a range of 1.5 m or 3.5 m ahead of the user[17].

In 1994, the "NavBelt" was introduced by Shoval, Norenstein and Koren. It is based on obstacle avoidance technologies of mobile robots with a portable computer, ultrasonic sensors, and stereophonic headphones attached to the user[18, 19].

In 1997, the "GuidCane" was introduced by Borenstein and Ulrich. It is based on a user-steered cane with a long handle and a sensor head unit attached at the distal end of the handle[17, 19].

In 1998, the "Smart Long Cane" was introduced by Cai and Gao. It is based on data fusion of a cane with ultrasonic sensing[20].

In 1999, the "Robotic Cane" was introduced by Aigner and McCarragher. It is based on the shared control of a robot and its user, with powered wheels and ultrasonic sensors attached to the handle. Audio warning was utilized to alert the user[21].

In 1984, the "Guide Dog Robot" was introduced by Tachi and Komoriya. It is based on automated guided vehicle (AGV) technologies, with cameras and ultrasonic sensors attached to a mobile robot. A navigation map is stored in the robot's memory. A speech synthesizer generated by the robot's vision system guides the user. The robot's speed is adjusted by the user's walking speed[22]. The "MELDOG" was introduced by the engineers at Mechanical Engineering Laboratory of the Tsukuba Science Center in Japan. It is based on AGV technologies with induced wires installed on the floor. Unlike the robotic canes, it performs like a guide dog[23].

2.2 Interactive Robotic Cane

During the past decades, several researchers have conducted research in applying mobile robot obstacle avoidance technologies to assisting devices for the handicapped. Any mobile robot designed to avoid obstacles can be used as a guide for the blind. However, mobile robots are inherently unsuited for the task of guiding a pedestrian because they are large, heavy, and incapable of climbing up or down stairs or boardwalks[24].

By taking advantage of the white cane and the guide dog, we have been developing a robotic aid system that is capable of interacting with its environment and eventually with human. To achieve such overall interactions, various methods for implementing the appropriate cooperative sensing, planning, and acting have been investigated, as shown in Fig. 1[3, 8-13].

The proposed robotic cane consists of a long handle, two steerable wheels, a sensor unit that is attached at the distal end of the handle, and an user interface panel. Much like the widely used white cane, the user holds these robotic canes in front of him/herself while walking. The handle is painted in white to mimic the white cane. The sensor head, which is mounted on a steerable, powered, two-wheeled steering axle, includes three infrared sensors, two antenna-type contact sensors, and a sonic scanner.

The robotic cane makes independent decisions concerning the path it takes. However, the user and the cane may wish to go in different directions. The normal operating mode of the constructed robotic cane must include an override feature to allow the blind person to be in control when the need arises.

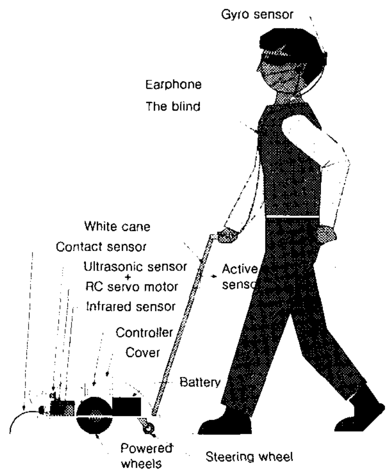
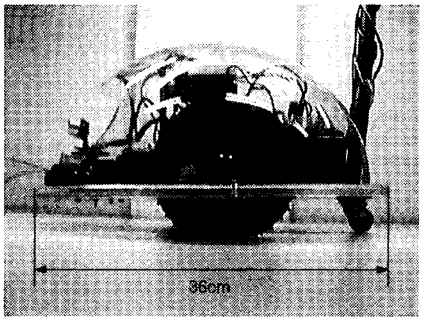
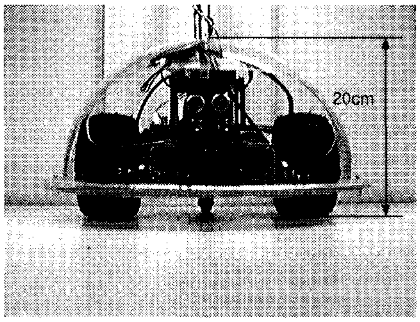


Fig. 1 Interactive robotic cane

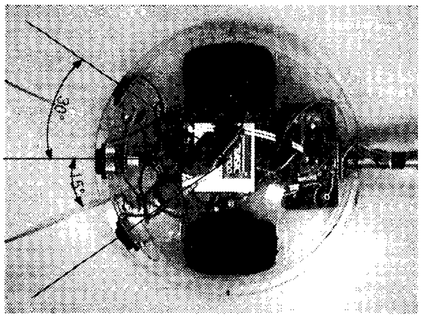
3. An Interactive Robotic Cane "RoJi"



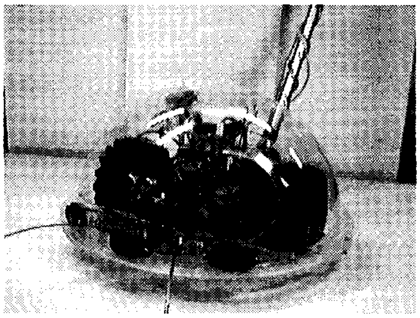
(a) Side view



(b) Front view



(c) Top view



(d) Perspective view

Fig. 2 An interactive robotic cane "RoJi"

The implemented robotic cane, named "RoJi," is shown in Fig. 2 and its specifications are summarized in Table 1.

Table 1 Specifications of "RoJi"

Gross mass	5.8 kg
Diameter of body	36 cm
Height	20 cm
Cane length	100 cm
Battery	12 Volt
Cover material	Transparent acryl
Degree of mobility	2
Radius of wheel	6 cm
Encoder resolution	3.78 cm/pulse
Maximum speed	37 cm/sec

3.1 Control and Action Module

"RoJi" utilizes an on-board PICBASIC 2000 microcontroller to process the sensor information and the timer counts, and also to generate control pulses for the DC servo motors. The PICBASIC 2000 can be easily programmed in Basic with the built-in analog and digital interface functions. The μ-controller is connected to thirty-two digital inputs/outputs, two PWM (pulse width modulation) outputs, one high-speed pulse counter, eight 10-bit A/D (analog-to-digital) inputs and a 64 Kbytes flash memory[25].

"RoJi" is driven and steered by two powered motors. By this way, it can guide the blind person autonomously with sufficient power. The two front-steering wheels of the cane are controlled independently by separate DC motors. One unpowered wheel in the back stabilizes the cane's stable structure and produces sharper turns.

3.2 Sensing Module

"RoJi" has a sensor head unit that is attached at the distal end of the handle to detect obstacles. This sensor head unit consists of an active ultrasonic sensor unit, three infrared sensors, and two antennas for contact sensing. A sensor unit, as shown in Fig. 3, is mounted above the guide wheels of "RoJi."

The sonic scanner, mounted above the guide wheels, has an ultrasonic sensor driven by a RC motor, as shown in Fig. 4(a). The unit scans the area ahead of it to efficiently detect obstacles or safe paths. It can reduce the missing areas caused by the narrow coverage due to the fixed sensor arrangement. Its scanning angle is ±90° wide. The ultrasonic sensor detects any obstacle up to the distance of 250 cm and within the range of ±30°. The ultrasonic sensor for "RoJi" shows an effective detection range, as shown in Fig. 4(b). This unit can operate by itself and/or by the user.

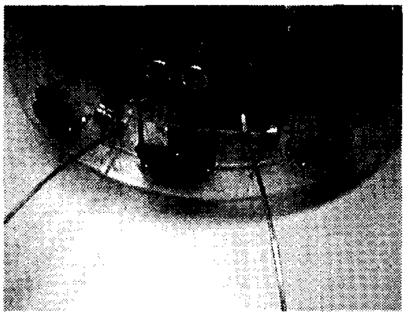
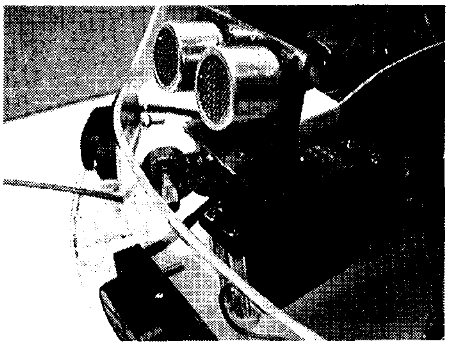
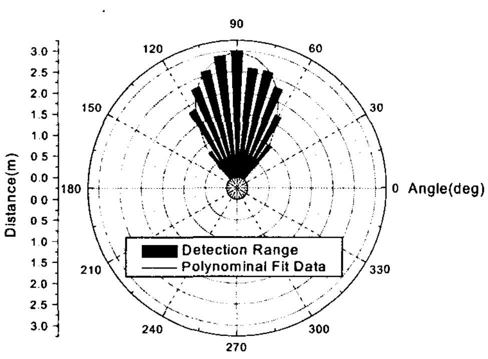


Fig. 3 Sensors for "RoJi"



(a) Sonic scanner



(b) Detection range of the ultrasonic sensor

Fig. 4 Active sensor for "RoJi"

An array of three infrared sensors is utilized to detect the convex obstacles blocking the cane's pathway. These three sensors are arranged in a semi-circular fashion, 30° apart from each other, and can detect any obstacle within a distance of 60 cm. This arrangement is based on the user's shoulder width. Including the size of the robot platform with the radius of 18 cm, we can assure a safe pathway up to approximately 80 cm wide.

For short-range coverage, additional antennas for contact sensing could effectively complement these infrared sensors and the active sensing unit. Limit switches, angle detectors, or torque sensors attached to these antennas quickly and easily detect dynamic changes in the environment when the potentiometers contact a surface or a bend[24, 26]. Limit switches were utilized for the earlier prototypes of the robotic canes[8]. Instead, potentiometers are utilized for "RoJi," as shown in Fig. 5[9-13]. Each antenna is arranged between the infrared sensors. It must be made of flexible materials so as not to interfere with navigation when it touches the surface to detect obstacles. Steel was selected for "RoJi," and the length of each antenna is 22 cm. These antennas are connected to the potentiometer to detect sudden irregularities of the surface and to react properly to them. Antennas are especially suitable to take advantage of the most visually impaired people's superb tactile information processing capabilities.

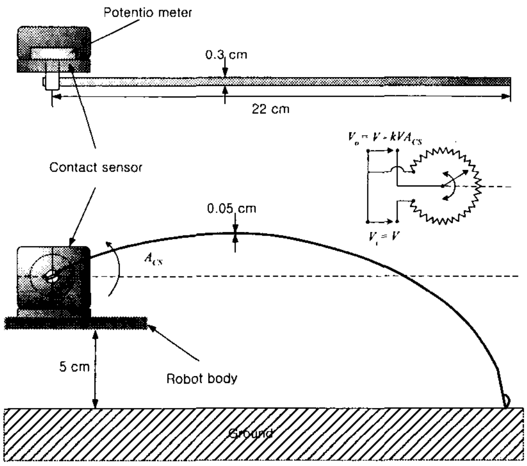


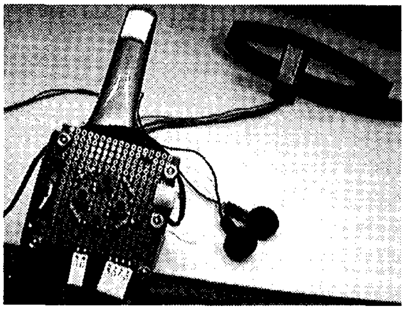
Fig. 5 Antenna-type contact sensor for "RoJi"

3.3 Operator Interface Module

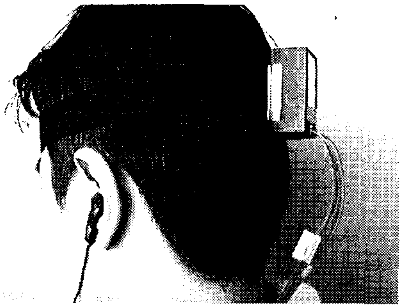
A miniature panel that can be operated with the thumb allows a user to specify a desired direction of motion, as shown in Fig. 6(a). This operator interface module also lets the user and the cane share information to cooperate with and compensate for each other. The user receives the cane's obstacle information as different tones of audio signals proportional to the distance and triggers the proper navigation command buttons.

The user can point the active sensing unit to his or her viewing direction. The active sensing unit of "RoJi", as shown in Fig. 6(b), can track the user's head movements by utilizing a gyroscope sensor attached to his/her head. A semiconductor-type gyroscope, muRata's ENV-05S, is utilized[27]. The mapping between the head movement and the gyroscope sensor is described by Eq. (1), where P_{RC} is the control pulse for the RC motor and V_{gyro} is the rotating velocity of the head. The value of K is estimated to be 1.4.

$$P^{t}_{RC} = P^{t-1}_{RC} + K(V^{t}_{gyro} - V^{t-1}_{gyro}) \quad (1)$$



(a) A miniature user-interface panel



(b) Gyroscope sensor for head tracking

Fig. 6 User interface for "RoJi"

Users can recognize the distance and the direction of the obstacles based on audio and gyroscope information. Once the navigation path is determined, the user can control the robotic cane by pressing the buttons on the interface panel. The operator interface module contains four command buttons: "Go Straight," "Turn Left," "Turn Right," and "Stop." A small motor attached to the panel vibrates back to the user, depending on the ground information. Also, speakers carry alarm sounds to alert the user. The cane benefits from the user's flexible decision capabilities and his/her tactile and auditory information processing capabilities.

4. Navigation

For proper navigation, the direction of navigation and the radius of rotation must be determined. The proposed behavior coordinator provides three navigation directions: "Turn Left," "Go Straight," and "Turn Right," considering the locations of obstacles and the user commands. Experiments were performed to investigate the proper radius or rotation.

4.1 Estimation of Driving Velocity

The two steering front wheels of the cane are controlled independently by separate DC motors. When the maximum velocity of one of the wheels is 1.4 km/h, the radius of rotation as the wheel velocity of the other side varies is shown in Fig. 7. The allowable radius of rotation to avoid the obstacle detected on the rightside is shown in Fig. 8. The maximum velocity of the right wheel is set to 1.4 km/h. Considering safety, we operate the cane at the velocity of 0.37 m/sec. This relationship can be generalized to Eq. (2) with the estimated parameters given in Table 2.

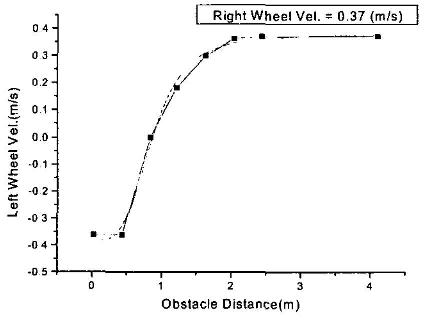


Fig. 7 Radius of rotation versus wheel velocity of the other side when the maximum velocity of one wheel is 1.4 km/h

$$y = \frac{A_1 - A_2}{1 + (x/x_0)^p} + A_2 \quad (2)$$

In Eq. (2), y is the wheel velocity of the other side to avoid the obstacles when the wheel velocity is maximum,

A_1 is the maximum velocity in reverse direction, A_2 is the maximum velocity in forward direction, x is the distance to the obstacle, and x_0 is the distance to the obstacle when the direction of rotation changes from the reverse direction to forward direction. Parameters in Table 2 are estimated utilizing curve-fitting utilities from a scientific program Origin [3].

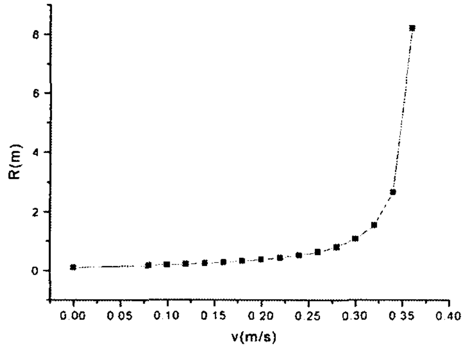


Fig. 8 Allowable wheel velocity (Radius of rotation) versus obstacle distance

Table 2 Estimated parameters for driving velocities

Parameters	Values	Errors
A_1	-0.38428	0.02686
A_2	0.37732	0.02255
x_0	0.86557	0.0403
P	3.67888	0.60823

4.2 Navigation Planning

Pedestrians usually detect obstacles and navigate properly based on visual information. The user's decisions for proper navigation are based on the user's a-priori, intuitive, and heuristic mental processing, instead of precise computations. In contrast, mobile robots' lack of intuitive nature requires precise geometric information about the obstacles and goals. A blind or visually impaired traveler with a white cane and/or a guide dog only require approximate geometric information about the obstacles and goals.

Robotic aids such as robotic canes require cooperation between human and robots. Our robotic cane has two control modes, the robot control mode (RCM) and the user control mode (UCM). User can initiate the RCM or the UCM by switching a navigation mode button. The cane's RCM is an extended autonomous navigation mode, which includes the user's intention. The traditional autonomous navigation mode can be described as a flow with bold outline as shown in Fig. 9. The cane's UCM lets the user navigate safely when the cane and the user make conflicting and/or difficult decisions to follow.

This shared control framework is shown in Fig. 9[28-33]. The cane navigates successfully avoiding complex obstacles, as shown in Fig. 10.

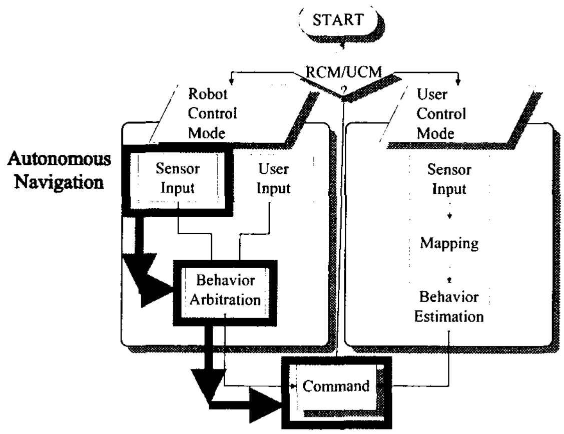


Fig. 9 Control flow of "RoJi"

Fig. 10 Navigation of "RoJi"

5. Summary

A human-friendly interactive system is explored. Various methods for implementing the appropriate cooperative sensing, planning, and acting have been investigated. Unique features of our robotic cane include an active sensing unit, antennas for contact sensing, powered wheels, and a customized-off-the-self (COTS) design.

The ultrasonic sensor in the sonic scanner can detect obstacles or safe paths efficiently by scanning the area ahead by a RC motor. It can reduce the missed areas caused by the narrow coverage due to fixed sensor arrangement.

Additional antennas for contact sensing effectively cover mid-range and/or long-distance sensing. Insects have successfully survived for a long time in hostile environments only equipped with seemingly limited sensing organs such as antennas. We attempted to use the fractal nature of antennas of insects, which assess their environment by few strokes of touching. Antennas are especially suitable for blind user's superb tactile information-processing capabilities.

Our robotic cane is driven and steered by two powered motors. Thus, it can guide the user autonomously with sufficient power. The cane needs to sustain enough power to be utilized for a full working day. This could be achieved by implementing autonomous recharging methods, such as recharging batteries with solar energy.

A human-friendly interactive system requires cooperation between human and robots. To explore the potential for rich and varied interactions with the surroundings, we programmed our robot to explore its environment with simple sensing mechanisms. The robotic cane's autonomous behaviors share human's flexible and reactive decision-making capabilities and visually impaired people's superb tactile and auditory information processing capabilities.

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