A Human Robot Interactive System "RoJi"

Inbo Shim, Joongsun Yoon*, and Myeungsook Yoh

Abstract: A human-friendly interactive system that is based on the harmonious symbiotic coexistence of humans and robots is explored. Based on the interactive technology paradigm, a robotic cane is proposed for blind or visually impaired pedestrians to navigate safely and quickly through obstacles and other hazards. Robotic aids, such as robotic canes, require cooperation between humans and robots. Various methods for implementing the appropriate cooperative recognition, planning, and acting, have been investigated. The issues discussed include the interaction between humans and robots, design issues of an interactive robotic cane, and behavior arbitration methodologies for navigation planning.

Keywords: Human-robot interaction, interactive technology, robotic cane, shared behavior control.

1. INTRODUCTION

Robotic aids, used widely in areas such as health care and home assistance, require cooperation between humans and robots. The proper control commands for such systems would be a combination of autonomous commands from robots and commands from humans, rather than either autonomous commands or solely human commands [1-3].

This paper explores a human-friendly interactive system, based on the harmonious symbiotic coexistence of humans and robots. A robotic cane is an interesting and excellent media that can be used to explore various aspects of human-robot interactions. It opens up the possibilities for truly human-friendly machines. Firstly, the cane is an extension of the human body, allowing a point where the users' intentions and close interactions can be investigated. Secondly, if intelligence is fundamentally based on interaction and doing the right thing in the real world, then sensing is the most essential component because it is what allows robots to perform in an intelligent manner. Human sensing is dominated by sight. It is interesting to see what happens if sight is impaired and how robots can work things out together with human partners in this situation [1,4,5].

Our goal is to develop a robotic aid system capable of interacting with its environment and eventually with humans. Various methods for implementing appropriate cooperative recognition, planning, and course of action have been investigated [1,5,6].

We outline a set of hardware solutions and working methodologies that can be used for successfully implementing and extending the interactive technology to coordinate humans and robots in complicated and unstructured environments. The issues discussed include methodologies for human-robot interactions, design issues of an interactive robotic cane, hardware requirements for efficient human-robot interactions, and behavior arbitration methodologies for navigation planning.

2. ROBOTIC CANE "ROJI"

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 extensively. By taking advantage of the white cane and the guide dog, we have been involved in developing a robotic aid system named "RoJi" as shown in Figs. 1 and 2 [1,7,8].

The proposed robotic cane, "RoJi," consists of a long handle, two steerable wheels, a sensor unit that is attached at the distal end of the handle, and a user interface panel. Much like the widely used white cane, the user holds these robotic canes in front of him/her while walking. The handle is painted in white to mimic the conventional 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.

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Fig. 1. The interactive robotic cane "RoJi."

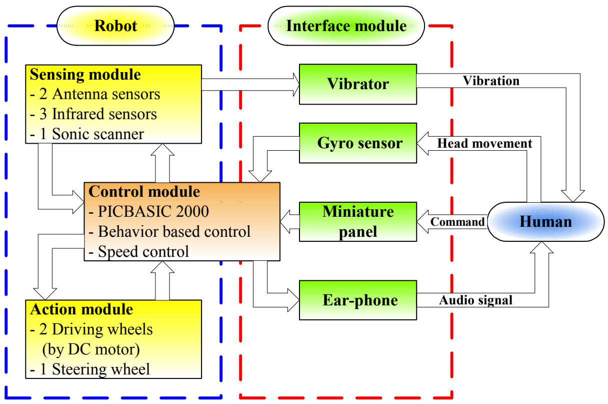


Fig. 2. Configuration of "RoJi."

The robotic cane named "RoJi," 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 visually impaired individual to be in control when the need arises. We have tried to build a system that is capable of interacting with its environment and eventually with humans.

The contents of the robotic cane system and how these components are used to provide desired functional capabilities are described.

2.1. 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 motor. 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 Kbyte flash memory [9].

"RoJi" is driven and steered by two powered motors. Therefore, it can guide the blind individual autonomously with sufficient power. The two front-steering wheels of the cane are controlled independently

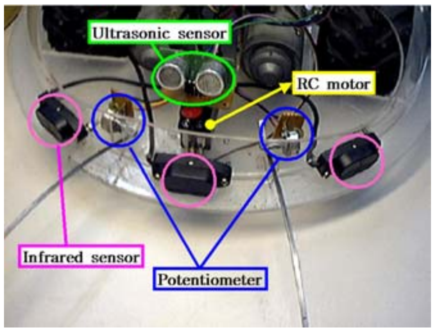


Fig. 3. Sensors for "RoJi."

by separate DC motors. One unpowered wheel in the back stabilizes the cane's stable structure, enabling sharper turns.

2.2. 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 active sensing unit mounted above the guide wheels has an ultrasonic sensor driven by a RC motor, as shown in Fig. 3. The unit scans the area ahead of it to efficiently detect obstacles or safe paths and can reduce the missing areas caused by narrow coverage due to the fixed sensor arrangement. Its scanning angle is ±90° wide. The ultrasonic sensor detects any obstacle up to a distance of 250 cm and within a range of ±30°.

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.

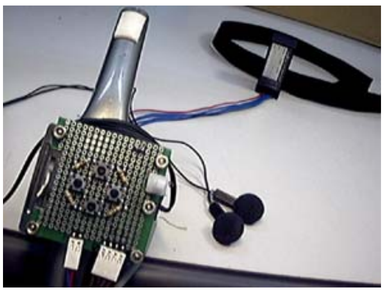
For short-range coverage, additional antennas for contact sensing could effectively complement these infrared sensors and the active sensing unit. Limit switches, angle detectors, or torque sensors attached to these antennas quickly and easily detect dynamic changes in the environment when the potentiometers contact a surface or a bend [10]. Limit switches were utilized in the earlier prototype of robotic canes [11]. In place of these, potentiometers are utilized for "RoJi" [1]. 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 appropriately to them. Antennas are especially suitable to take advantage of the visually impaired individual's superb tactile information processing capabilities.

2.3. 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. 4(a). This operator interface module also allows the user and the cane to 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. It then triggers the proper navigational command buttons.

The user can point the active sensing unit in his or her viewing direction. The active sensing unit of "RoJi," as shown in Fig. 4(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 [12].

Users can recognize the distance and the direction of the obstacles based on audio and gyroscope information. Once the navigational 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



(a) A miniature user-interface panel.

(b) Gyroscope sensor for head tracking.

Fig. 4. User interface for "RoJi."

and his/her tactile and auditory information processing capabilities.

3. NAVIGATIONAL PLANNING

3.1 . Shared navigational planning

Pedestrians usually detect obstacles and navigate properly according to 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 relating to the obstacles and goals. A blind or visually impaired traveler assisted by a white cane and/or a guide dog only require approximate geometric information concerning the obstacles and goals.

Robotic aids, such as robotic canes, need cooperation between humans and robots. The constructed robotic cane is self-steering, based upon the interpretation of its input. The steering command of the robotic cane is based on the absence or presence of obstacles sensed by photo sensors. Without a shared control framework in place, the cane would want to avoid objects such as stairs, doors, or chairs that the user might wish to use. The operator's decision making must be included. Clearly the normal operating mode of the robotic cane must be overridden to allow the person to be in control when the need arises.

The proper control commands for such a system would be a combination of autonomous commands and commands from humans, rather than either autonomous commands or solely human commands. Our robotic cane has two control modes, the robot control mode (RCM) and the user control mode (UCM). This shared control framework is as shown in Figs. 5 and 6 [1,7].

The cane's navigational control allows the robot to detect the obstacles and navigate safely and quickly based on the robot's autonomous commands and the

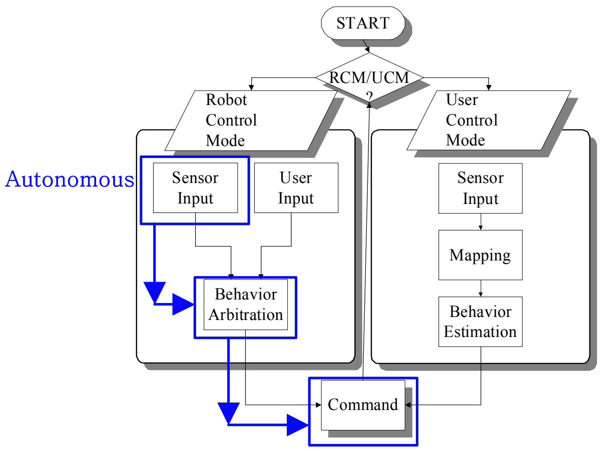


Fig. 5. Control flow of "RoJi."

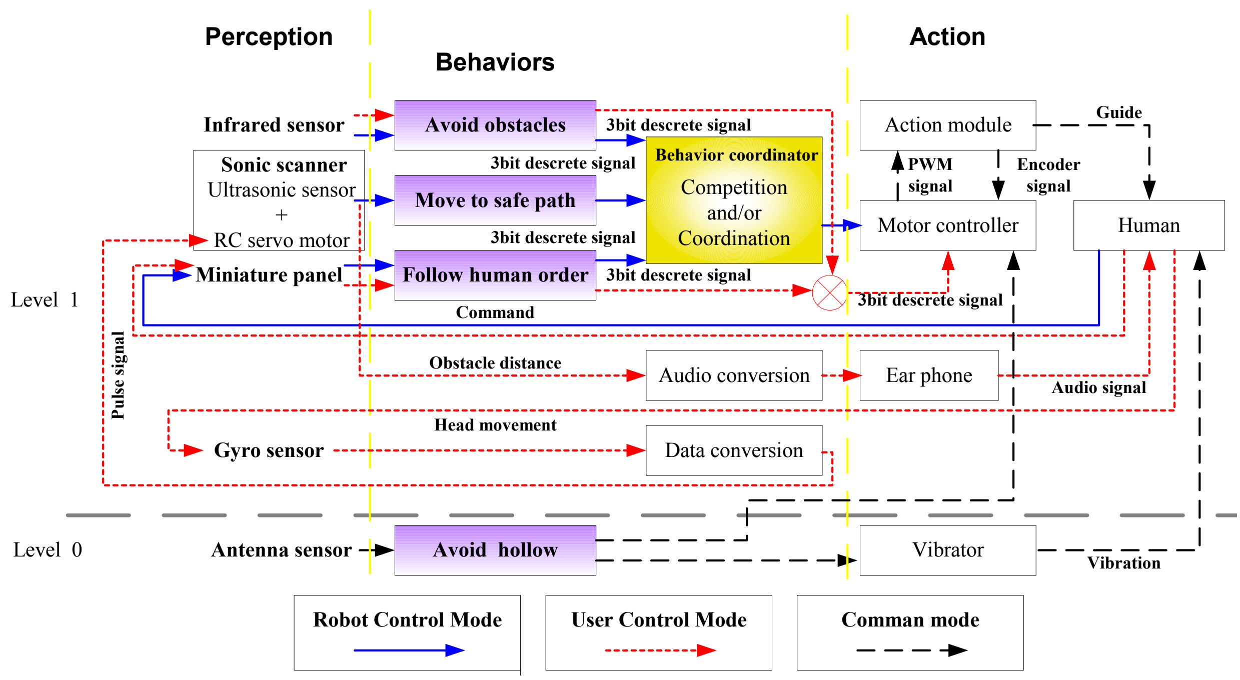


Fig. 6. Control architecture of “RoJi.”

user’s input commands. User’s can initiate the RCM or the UCM by switching the navigational mode button.

The cane’s RCM is an extended autonomous navigational mode, which includes the user’s intention. The traditional autonomous navigational mode can be described as a flow with bold outline as shown in Fig. 5. The cane’s UCM allows the user to navigate safely when the cane and the user make conflicting and/or difficult decisions to follow.

3.2. Robot control mode

The robot control mode (RCM) contains three different behavior modes: “Follow Human Order,” “Avoid the Obstacles,” and “Move to Safe Path.”

The first behavior mode, “Follow Human Order,” determines the navigation direction based on the user’s intention. The cane performs the same actions as the user’s commands: “Go Straight,” “Turn Left,” and “Turn Right.”

The second behavior mode, “Move to Safe Path,” determines the navigational direction for a safe path. The active sonar scans the area ahead of it from left to right to decide the path direction that is furthest from the obstacles. The cane navigates following such directions. Considering the detection range of the ultrasonic sensor, the area is divided into three zones. The scanning period is 1 sec. The safe path is set to be the latest zone detected when the distance from the obstacle for each scanning direction is the same or further than the maximum detection range of 250 cm. When the active sensing unit scans the area ahead of it and the left zone has the maximum possibility avoidance, the cane turns left and follows the corresponding path.

The third behavior, “Avoid the Obstacles,” establishes the navigational direction by moving around obstacles. The RCM models the possible infrared sensor states, S1 or S0. S1 and S0 represent the presence and the absence of a detected obstacle, respectively. With an array of three sensors, the RCM of the robotic cane represents eight possible states. Additional sensors could be utilized to plan diverse obstacle-avoidance strategies. State changes in the RCM are triggered by sensor events at each discrete time interval. To avoid colliding with obstacles, the RCM generates controller events in the form of a discrete representation of the desired turning angle.

The output of each behavior is channeled into a coordination mechanism that consists of logic operators. The coordinator produces an appropriate overall motor response for the robotic cane at any point in time, given current existing environmental stimuli including human orders. Through coordination and competition of behaviors, the coordination module arbitrates proper behaviors to produce an appropriate overall motor response. The RCM, described as a stimulus-response diagram, is as shown in Fig. 7 [1,7,13].

The earlier version of navigational planning was based on a table lookup method in which the navigational rules are tabulated and the cane performs

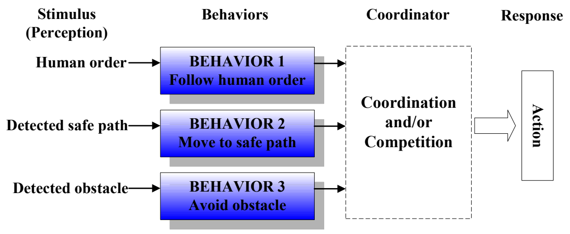


Fig. 7. Stimulus-response diagram for "RoJi."

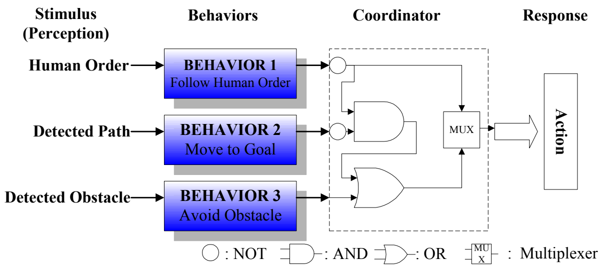


Fig. 8. A heuristic navigational strategy coordinator.

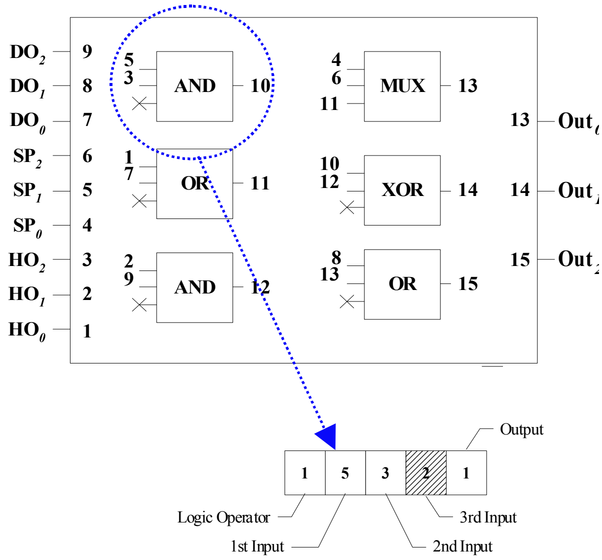


Fig. 9. Phenotype and genotype of behavior coordinator with logic operator.

navigation following these rules. Each behavior is represented by a 3-bit discrete signal. The first behavior includes three user's commands. The second behavior includes three directions of safe path. The third behavior includes seven states of sensors. The possible number of navigational rules is 36. This rule-based method suffers from programming inefficiencies when the behaviors are increased due to the nature of constructing the corresponding rules [1,11].

As an alternative method, a heuristic behavior arbitration method based on logic operator has been proposed as shown in Fig. 8. The behavior arbitration procedure is as follows. A "NOT" operation flips the digital signals of the first behavior and the second behavior. This confirms the stimulus condition for the third behavior. An "AND" operation finds a common stimulus for the first behavior and the second behavior. This common stimulus can be a virtual obstacle. An "OR" operation applies the presence of both real obstacles and a virtual obstacle. When the output status of the coordinator is [0 1 0], the user input overrides the autonomous command. Otherwise, the autonomous commands are performed [7].

The construction of a behavior coordinator, based on this trial and error method, becomes extremely difficult when robot systems and behaviors are more complicated. We can overcome this problem by applying an evolutionary approach to construct the behavior coordinator in automatic and efficient ways.

Each behavior is represented by a 3-bit discrete signal. The behavior coordinator can be constructed as a combination of logic operators. A gene representing each logic operator consists of two or three inputs to a logic operator, a type of logic operator, and one output from a logic operator, as shown in Fig. 9. The multiplex has three input connections and all the other logic operators have two input connections. Allowed logic operators: AND, OR, MUX, NAND, NOR, XOR are numbered as 1 to 6, respectively [7].

The evolution algorithm used to evolve the behavior coordinator is a simple form of $(1+\lambda)$ evolutionary strategy, where λ is 5. The maximum number of logic operators has been set to 15 for computational efficiency. The maximum number of generations is set to 10,000. The mutation rate is 20%, i.e. 3 out of 15 logic operators. The lookup table presents a guideline for the proper actions a robotic cane can take. Fitness can be evaluated counting matching rules from this table [1,14].

3.3. User control mode

In the UCM, the user operates the robot directly based on the information that can be recognized by a blind individual, such as auditory information. The robot provides the user with auditory information as converting visual information that is obtained by sensors into sound. The visually impaired user receives the cane's obstacle information and the cane benefits from the user's flexible decision-making capabilities and his/her tactile and auditory information processing competence.

The user can point the active sensing unit of the robotic cane in user's viewing direction. The active sensing unit of "RoJi" can track the user's head movements by utilizing a gyroscopic sensor attached to the user's head. The robotic cane provides the user with auditory information as converting visual information, which is obtained by sensors, into sound. Also, speakers carry alarm sounds to alert the user.

Users can recognize the distance and the direction of the obstacles combining the gyroscope/audio information from the cane and the auditory/tactile information from the user. Once the navigational path is determined, the user can control the robotic cane by pressing the buttons on the interface panel.

4. NAVIGATION

Fig. 10 presents two autonomous operations of the robotic cane for avoiding two obstacles and guiding the user to a safe path when the user command is "Go Straight" and "Turn Left." The two cubic objects are 21 cm (L) × 30 cm (W) × 25 cm (H) and 60 cm (L) × 20 cm (W) × 60 cm (H). In both cases, the robotic cane avoided these obstacles and returned to the original course of the user.

Fig. 11 shows two operations of the robotic cane for avoiding both complicated and unexpected dynamic obstacles, and guiding the user to a safe path. In the first navigational experiment, the cane navigates around the chair in shallow and complicated shapes. In the second navigational experiment, the robotic cane avoided the sudden approaches of human pedestrians and returned to the original course of the user.

Four shared navigational experiments, as shown in Figs. 10 and 11, demonstrate efficiencies of the "RoJi." These tests demonstrate the cane's good performance on flat surfaces. The weight of the constructed cane is 5.9 kg. If we make the cane small enough to lift, it can be useful in more diverse user environments, such as uneven surfaces like stairs.

Fig. 10. Navigation of "RoJi" under static obstacles.

5. SUMMARY

A human robot interactive system was explored. Based on interactive technology, a robotic cane, "RoJi," is proposed for blind or visually impaired travelers to navigate safely and quickly among obstacles and other hazards faced by visually impaired pedestrians. Unique features of our robotic cane include an active sensing unit, antennas for contact sensing, powered wheels, and a customized-off-the-shelf (COTS) design.

Four shared navigational experiments demonstrate the efficiency of the "RoJi" on flat surfaces. To evaluate performance of the interactive cane, we need a more realistic working model for the handicapped. If we make the cane small enough to lift, it can be effective in more diverse user environments, such as uneven surfaces like stairs. To obtain substantial physical results, we are currently working on theoretical backgrounds regarding emotions and human-robot interaction issues [15-17].

Our robotic cane is operated based on a shared control approach, which contains the robot control mode (RCM) and the user control mode (UCM). The RCM is implemented by a lookup table and a heuristic logic operator. As the number of behaviors

(a) Complicated obstacles.

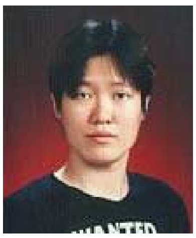
(b) Dynamic obstacles.

Fig. 11. Navigation of "RoJi" under unusual obstacles.

increase and the system becomes more complicated, it will become more difficult to find an appropriate coordinator for behavior arbitration. We are currently investigating an easy way to evolve the coordinator elements based on an evolutionary engineering approach [18-23]. The UCM is implemented by the user's heuristic decision-making capabilities. The UCM allows the cane and the user to share geometric information about their environment and navigate following the user's operation.

REFERENCES

[1] I. Shim, *Interactive Robotic Cane*, Master Thesis, Pusan National University, Pusan, Korea, 2003.
[2] P. Aigner and B. McCarragher, "Shared control framework applied to a robotic aid for the blind," *IEEE Control Systems Magazine*, vol. 19, no. 2, pp. 40-46, April 1999.
[3] G. Lacey and K. Dawson-Howe, "The application of robotics to a mobility aid for the elderly blind," *Robotics and Autonomous Systems*, vol. 23, pp. 245-252, 1999.
[4] R. Aylett, *Robots: Bringing Intelligent Machines To Life?*, Baron's, Hauppauge, 2002.
[5] J. Yoon, "Interactive technology: soft engineering," *Proc. of the 2003 International Conference on Control, Automation and Systems*, CD-Rom, Gyeongju, 2003.
[6] J. Yoon, I. Hwang, and S. Chang, "Metatechnology: Correspondence of the arts, sciences, technology and humans," *International Journal of the Korean Society Precision Engineering*, vol. 1, no. 1, pp. 71-78, June 2000.
[7] I. Shim and J. Yoon, "A human robot interactive system "RoJi"," *Proc. of the 2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, vol. 2, Kobe, Japan, pp. 723-728, 2003.
[8] S. Shoval, I. Ulrich, and J. Borenstein, "NavBelt and the GuideCane," *IEEE Robotics and Automation Magazine*, vol. 10, no. 1, pp. 9-20, March 2003.
[9] COMFILE Technology, *PICBASIC2000 DATA BOOK*, COMFILE Technology, Seoul, 2000.
[10] U. Nehmzow, *Mobile Robotics: A Practical Introduction*, Springer-Verlag, Berlin, 2000.
[11] I. Shim, H. Park, and J. Yoon, "Robotic cane for blind travelers," *Proc. of the 2nd Workshop on Human-friendly Welfare Robotic Systems*, KAIST, Taejon, Korea, pp. 154-161, January 15-16, 2001.
[12] muRata, "Piezoelectric Vibrating Gyroscopes: Gyrostar® ENV," Available http://www.avnet.se/avnet_times /september96/murata.html, 1996.
[13] R. Arkin, *Behavior-Based Robotics*, The MIT Press, Cambridge, 1998.
[14] M. Negnevitsky, *Artificial Intelligence: A Guide to Intelligent Systems*, Addison-Wesley, San Francisco, 2002.
[15] D. A. Norman, *Emotional Design: Why We Love (or Hate) Everyday Things*, Basic Books, New York, 2004.
[16] J. Yoon, M. Yoh, and H. Lee, "Tangible media based on interactive technology: iT_Media," *Proc. of the 2004 International Conference on Control, Automation and Systems*, Bangkok, 2004.
[17] J. Yoon, M. Yoh, and B. Cho, "Emotional robotics based on iT_Media," *Proc. of the 2004 International Conference on Control, Automation and Systems*, Bangkok, 2004.
[18] J. Yoon, "Evolutionary robotics based on interactive technology," *Proc. of the 15th Korea Automatic Control Conference*, Yongin, Korea, October 17-18, 2000.
[19] J. Lee, I. Shim, and J. Yoon, "Realtime evolutionary learning of mobile robot behaviors," *Proc. of the 2003 Spring Annual Meeting of Korean Society of Mechanical Engineering*, Korea Maritime University, Pusan, Korea, May 24-25, 2003.
[20] I. Shim and J. Yoon, "Evolutionary learning of mobile robot behaviors," *Proc. of KFIS Fall Conference 2002*, vol. 12, no. 2, pp. 207-210, December 7, 2002.
[21] H. Son and J. Yoon, "Evolving neural network for realtime learning control," *Proc. of the 15th Korea Automatic Control Conference*, Yongin, Korea, October 19-20, 2000.
[22] S. Han and J. Yoon, "Action selections for an autonomous mobile robot by artificial immune network," *Proc. of the 15th Korea Automatic Control Conference*, Yongin, October 19-20, 2000.
[23] S. Nolfi and D. Floreano, *Evolutionary Robotics*, The MIT Press, Cambridge, 2000.



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