



Intelligent Robotic Walker Design

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Abstract

This paper aims to present the current development of an intelligent robotic walker. This machine is designed as a walking aid for the visually impaired. The machine is equipped with different sensors to navigate its motion in the indoor environment such as hospitals, hotels, airports, and museums. The user drives the walker while the two front wheels have the ability to steer in order to avoid obstacles and to seek the target. The control system interacts continuously with the user via voice commands. A self-autonomy goal seeker is developed using fuzzy logic. A discrete logic navigator is used to avoid obstacles in the work space. The indoor environment is described using a 2D road map. The hardware architecture is designed using a hierarchical approach. It is currently under development using microcontrollers. In the paper, the system design and preliminary simulation results are presented¹.

Keywords: *Autonomous robot, Embedded systems, Fuzzy logic, Navigation, Assistive technology.*

1. Introduction

The visually impaired people are increased to 230 millions in the world according to the last report of the international health society. The annual rate of increasing is expected to be 7 millions per year. How to help this population sector to make their daily life more ease is an important question. The use of assistive technology could be one of possible solutions. The most successful and widely used walking aid for visually impaired people is the *white cane*. It is used to detect obstacles on the ground, uneven surfaces, holes, steps, and puddles. The white cane is inexpensive, and is so lightweight and small that can be folded and tucked away in a pocket. However, users must train to use it over than 100 hours and it is not intelligent to guide the use to his target in autonomous manner. Conventional electronic walking aids are basically three categories:

electronic travel aids ETAs (equipments to improve the user mobility in terms of safety and speed) [1-2], *guidance cane* (small mobile base to navigate obstacles) [3-6], and *navigation belt* (portable device equipped with ultrasonic sensors to navigate obstacles) [6]. Currently, *robotic aids* are widely used in the area of health care and home assistance [7-12]. A more reliable device is a robotic walker especially inside buildings (indoor navigation). This device would function as a normal walker most of time, but it has the ability to steer and to avoid obstacles. Robot assistant navigation can help the visually impaired to walk at ease and more safe for several reasons [7]:

- Users can interact easily with the robot in different ways using voice commands, audio alarms, and speech synthesizer feedback messages. The user will feel more at ease and can enjoyable more than using guide dogs or white canes.
- Available sensors and actuators in the market are optimized significantly in sizes, prices, and amount of required hardware interfaces. Therefore, they can be mounted on the mobile robot and powered from on-board batteries. Consequently, the navigation related physical load is significantly reduced.
- Robotic guides can carry useful payloads, e.g. suitcases and grocery bags.

The remainder of the paper is organized as follows: Section (2) presents the system design and specifications for the robotic walker. Section (3) involves the functional description for the different hardware control modules. Section (4) demonstrates the developed simulation environment using SIMULINK toolbox of MATLAB 7. Section (5) presents preliminary results obtained via simulation. Finally, Section (6) concludes the main concepts and contributions.

2. System Design

The sequential system development approach is adopted as shown in figure (1). This model consists of a sequence of processes from user requirements (quality, performance), through system requirements (technical specifications), architectural design, and component development to the testing cycle of integration,

¹This research work has been implemented at the University of King Saud and has been funded by the Faculty of Engineering Research Center; Project#426/8.

installation and operations. At each process boundary, a review or a test allows progress to be monitored and a commitment made to the next stage [13]. These boundaries act as quality milestones, controlling the gradual transformation from a high risk idea into a complete product.

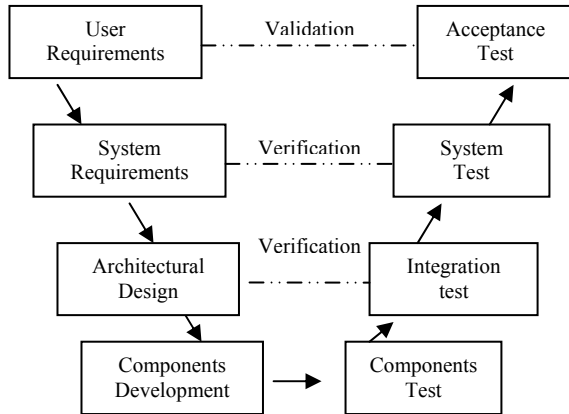


Figure 1: System development life cycle (V-diagram)

User Requirements: A set of performance goals are selected to help the visually impaired (see Table 1).

Table 1: Performance goals

Performance Criterion	Function
Usability	Interactive user interface using multimedia without need for training hours.
Environment	Known structure with random obstacles. Indoor navigation and can be used for different floor types.
Capabilities	Provide guidance to destinations via pre-programmed maps. Obstacle avoidance during navigation.
Physical stability	Stable navigation without turn over at different walking speed
Communication	Provide care-monitoring and recording

System Requirements: the walker has to be simple enough to be designed easily and to obtain practical results. Table (2) involves the system design goals to be achieved.

Mechanical Model Design: System goals in table (2) are considered in the implementation as follows:

- The frame is made of a light weight metallic material (aluminum alloy) to compromise between high yield strength and a low density selection criterion. A light weight side sheets are fitted to install different sensors. Two wooden plates are used for the mobile base and the top surface. The weight is approximately 30 kg.
- Stable mobile base with four wheels to permit a high degree of stability and maneuverability. Large swivel

castors are used to facilitate the motion on different types of floor surfaces. Front wheels can steer using 12 V DC geared motors (the walker is derived by the user pushing force). Optical encoders are mounted on the rear casters wheels to detect the current position.

- Comfort handgrips, these are fitted over the top surface to make it more comfortable to hold.
- The height is suitable for many users with the dimension of 70cm X 66cm X 100 cm.
- A front rubber bumper is added to protect the walker from collision with other objects and to increase the safety for other people.



Figure 2: Robotic walker prototype

Table 2: System design goals

Specification	Description
Dimensions	Compact for indoor environments
Weight	30 kg Maximum
Material	High yield strength and low density
Linear walking speed	Up to 0.5 m/sec maximum (stable navigation)
Power supply	Rechargeable DC batteries with long duty cycle
On-board hardware	Hierarchical embedded microcontrollers
Self autonomy	Equipped by different sensors for obstacle navigation and guidance
Maneuverability	On spot rotation to navigate in a small moving zone
Integration	Control and diagnosis functions
Inputs	Voice commands, user driving force
Outputs	Audio feedback messages, auto-steering, video monitoring and recording
Cost	Low cost using the available components in the market
Alarming	Sound alarm for critical situations
Communication	Standard wireless video transmission 2.4 GHZ
Testing and commissioning	Telemetry module with 400MHZ and LCD display for commissioning

3. Hardware Control Modules

A hierarchical approach is used to develop the hardware design and to facilitate the debugging of any troubleshooting problem. The block diagram of the complete control system is given in figure (3).

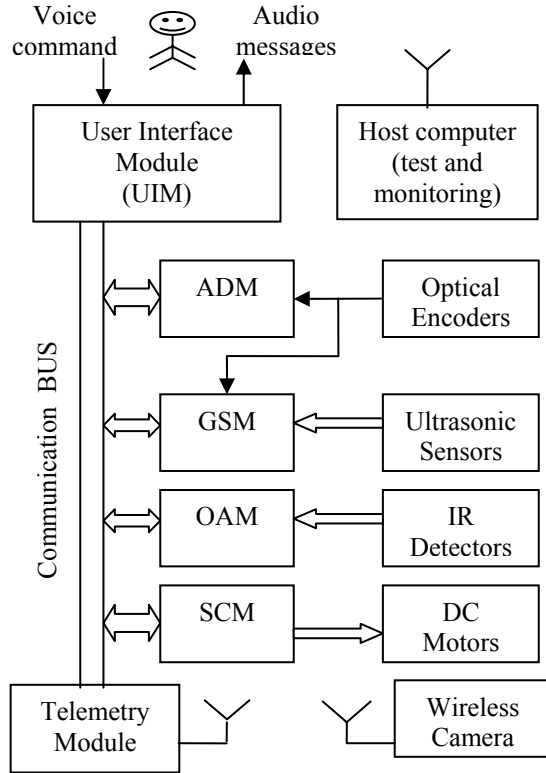


Figure 3: Hierarchical embedded control system

Different modules are designed and linked via a common bus to complete the system design. A telemetry module is used to transmit different data to a host computer for further testing and commissioning. While, a wireless CMOS hole in camera is fitted in the front of the robot model to transmit video signals for monitoring and recording. The control modules are:

User interface module (UIM); is the main module to receive the voice command and determines the required tasks. This module is the master one while others are slaves. It distributes different tasks for other modules.

Audio alarm & Display Module (ADM); this module computes the linear walking speed using measured data from the wheels encoders. If the speed exceeds the maximum limit value, an audio alarm will be activated. It displays the current speed and testing parameters values on the LCD.

Goal Seeking Module (GSM); this module searches the target position in a 2D map (lookup table) using the starting position and the measured heading angle. A fuzzy logic controller is designed to steer the front wheels in order to seek the target position. The steering control is equivalent to a nonlinear PD controller using fuzzy logic [14-16]. The use of fuzzy logic is justified where the accurate mathematical model is difficult to be obtained (especially under varying load) and there is a

parametric uncertainty in the model. The use of other techniques such as nonlinear control or adaptive control requires a good estimation of the model parameters which is not an easy task. The heading error and its rate of change angle are the two inputs to the fuzzy controller. The following membership functions are used to fuzzify the heading error as shown in figure (4).

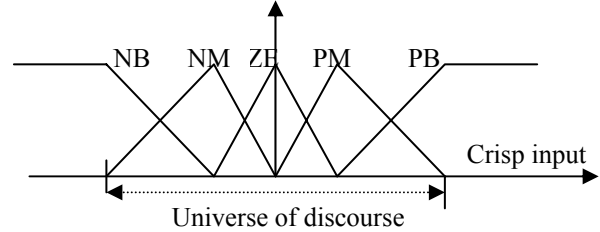


Figure 4: Fuzzy membership functions

Triangular membership functions are used to give a smooth action around zero error with a less odd number of functions (five for error and three for error variation). The universe of discourse is $(-180^\circ \rightarrow 180^\circ)$ for the crisp input in heading error. Similar membership functions are used for the change of heading angle $(-7^\circ \rightarrow 7^\circ)$ and the controller output with the universe of discourse $(-45^\circ \rightarrow 45^\circ)$. The developed rules are given in table (3).

Table 3: Fuzzy rules

Heading error	Change of heading angle		
	NEG	ZE	POS
PB	PM	PM	PB
PM	ZE	PM	PM
ZE	ZE	ZE	ZE
NM	NM	NM	ZE
NB	NB	NM	NM

These rules construct a smooth control surface evaluated by the use of fuzzy toolbox in MATLAB as shown in figure (5).

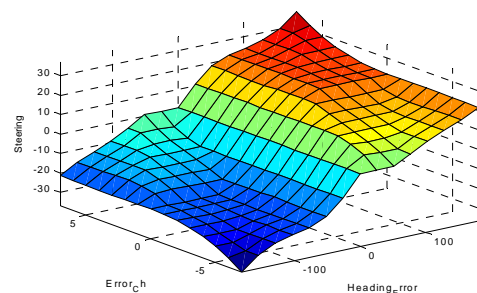


Figure 5: Fuzzy control surface

Obstacle Avoidance Module (OAM); this module applies a discrete control to avoid obstacles. IR detectors are used to measure the presence of obstacles at a pre-setting distance equal to 80cm.

Servo Control Module (SCM); this module acts directly on the front wheels motors. It receives the commands and guides the user to his/her target.

Discrete Control Module (OAM): Six IR detectors (s1→s6) are installed around the walker body with a pre-setting value of 80 cm as shown in figure (6).

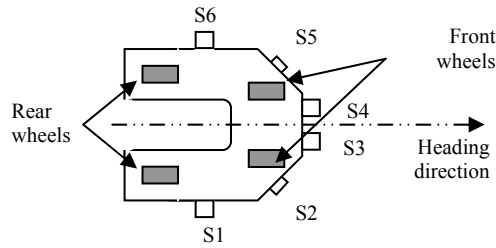


Figure 6: Mounting of IR detectors

As the measuring signals from the IR detectors are digital 0 or 1; a set of rules of thumb are developed for obstacle avoidance. These rules activate one of the possible outputs:

- Steer right with -20°
- Steer right hard with -40°
- Steer left with $+20^\circ$
- Steer left hard with $+40^\circ$
- No obstacle detection and activate goal seeking

A shared control strategy will be applied to select among: goal seeking, obstacle avoidance, and user intervention.

4. Simulation work

The robotic walker prototype is implemented and currently developed in the electrical engineering department. A selected area (30mX40m) is used to test the simulation results and thereafter the real time experiments. This area is mapped as shown in figure (7).

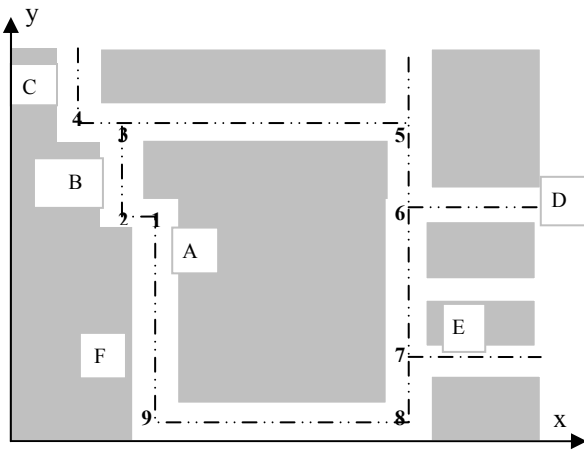


Figure 7: Robot work environment (2D Map)

The shaded area in the above map represents staff offices and labs, while the dashed paths are the possible and restricted paths to move the robot without collisions. Table (4) represents the coordinates x-y values for the initial and destination points on the map points (A→F) and via points (1→9).

Path Planning: The path planner uses table (5) to select the shortest path between initial point and target point using linked list via points. The criterion is the shortest distance for any alternative solution. Points (1→9) are via points that the feasible solution has to path with in avoiding collision with static obstacles (walls).

Table 4: X-Y Coordinates values

Target Location	Office	X-axis (m)	Y-axis (m)
A	2C108/1	6	20
B	2C116	3	31
C	2C115	1	37
D	2C91/1	25	27
E	2C98	22	7.5
F	2C127	4	6.5
Via points for path planning		X-axis (m)	Y-axis (m)
1		5	22.5
2		3.5	22.5
3		3.5	34.5
4		1	34.5
5		18	34.5
6		18	26.5
7		18	7.2
8		18	1.5
9		5	1.5

Table 5: Linked list via points

* direct link - No link		Target points					
		A	B	C	D	E	F
Start points	A	-	1-2	1-2-3-4	1-2-3-5-6	9-8-7	*
	B	2-1	-	3-4	3-5-6	3-5-7	2-1
	C	4-3-2-1	4-3	-	4-5-6	4-5-7	4-3-2-1
	D	6-5-3-2-1	6-5-3	6-5-4	-	6-7	6-8-9
	E	7-8-9	7-5-3	7-5-4	7-6	-	7-8-9
	F	*	1-2	1-2-3-4	9-8-6	9-8-7	-

The simulation is achieved using SIMULINK toolbox of MATLAB 7 on a PC using a non-linear kinematics model as given in the following equations:

$$\dot{x}_m = v \cos(h) \quad ; \quad \dot{y}_m = v \sin(h) \quad (1)$$

$$\tau_1 \frac{dh}{dt} = \theta \quad ; \quad \theta + \tau_2 \frac{d\theta}{dt} = \theta_r \quad (2)$$

$$d = \sqrt{(x_g - x_m)^2 + (y_g - y_m)^2} \quad (3)$$

Where

- x_m, y_m x-y coordinates to the current position
- x_g, y_g x-y coordinates to the target position
- v Linear walking speed m/sec
- h Heading angle (integration of steering)
- θ, θ_r Steering angle and its recommended value
- τ_1, τ_2 Dynamics time constants
- d Distance to the target point

The simulation environment is built as similar as to the real environment. Simulation parameters are chosen as:

- Time constants in equation (2) are 0.2 and 0.5 seconds respectively.

- Walking speed is $[0.3 + 0.1 \sin(\pi t/10)]$ m/sec
- Initial heading angle is 180°
- Simulation time 200 sec
- Stopping criterion (either distance error is less than 0.3 m or simulation time is elapsed)

5. Simulation results

Figures (8-A, 8-B, 8-C, and 8-D) represent the obtained results using goal seeking from the initial position (point A) to the target position (point D) on the map.

Figure (8-A) shows that the robot has an autonomous capability to select his path according to the linked list via points as given in table (5).

Figure (8-B) gives the output from the fuzzy controller to change the heading direction. The output is zero when the robot moves in a straight line as between via points (2, 3) - (3, 5) - (5, 6) and (6, D). While, the steering is positive to rotate left (via points 1, 6) and negative to rotate right (via points 3, 5).

Figure (8-C) presents the current direction of the robot. It is clear that the walker moves from via point 2 to via point 3 in parallel to y-axis (positive direction $+90^\circ$). This value is equal to -90° from point 5 to point 6 because the motion is in the negative direction of y-axis. When the walker moves horizontally in the positive direction of x-axis; the angle is 0° (from point 3 to 5).

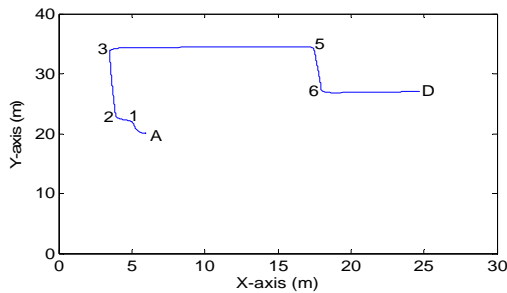


Figure 8-A: Optimal path trajectory

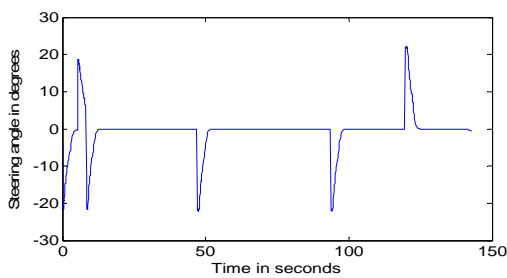


Figure 8-B: Fuzzy controller output

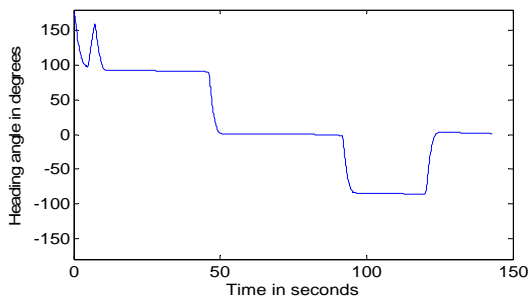


Figure 8-C: Heading angle

The switching in figure (8-D) is due to the change of the local target point (via points) in order to track the optimal path on the map. At the starting point A, the target is point 1. When the robot reaches to point 1, switching occurs to the target point 2 and so on. The error distance is nonlinear with respect to the time between any two successive via points because the walking speed is affected by a low frequency sinusoidal signal at low amplitude. If the walking speed is constant, the error distance will be a linear function in time.

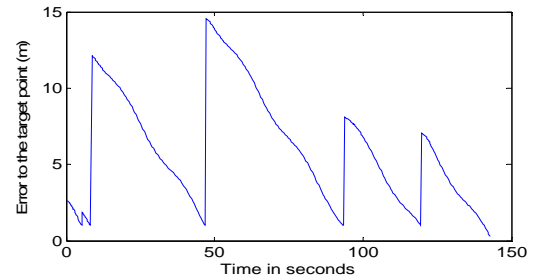


Figure 8-D: Error criterion

Figure (9) represents similar results to reach point E from A. The robot moves in the shortest path via points 9, 8, and 7 to reach the point E.

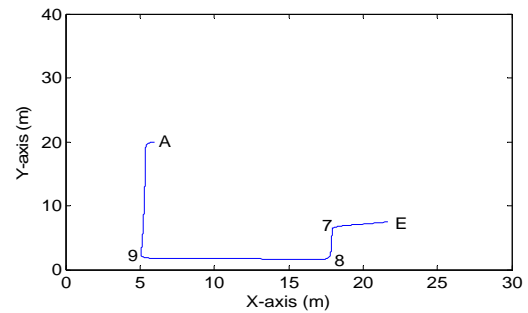


Figure 9-A: Optimal path trajectory

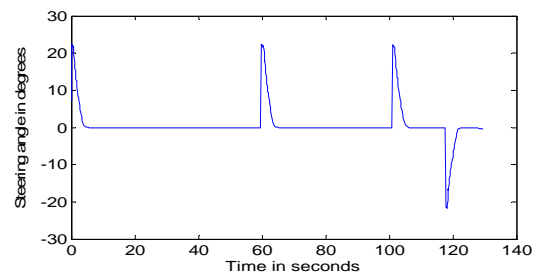


Figure 9-B: Fuzzy controller output

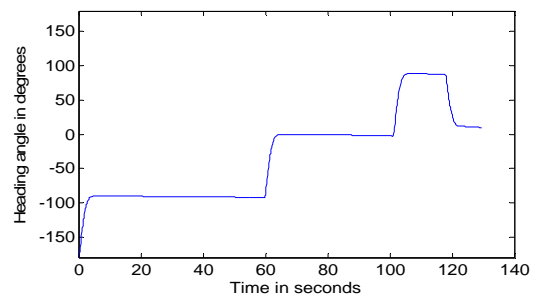


Figure 9-C: Heading angle

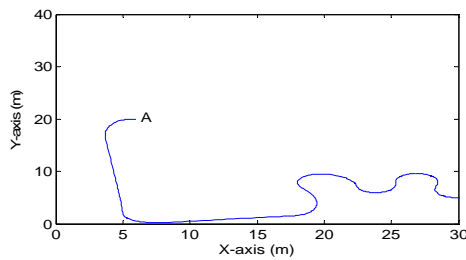


Figure 10: Unstable maneuverability

Figure (10) represents the obtained results when the walking speed exceeds the maximum limit. It is clear that the robot has been lost his way to reach the target point E and moved outside the map. The instability is due to the high speed of robot motion. Moreover, a high risk for collision with walls has been increased and the maneuverability is very difficult. The maximum walking speed has an inversely relationship with kinematics model parameters τ_1 and τ_2 . As these parameters decrease (fast steering action); a higher maximum speed can be allowed and vice versa. This relation is investigated with several iterations via the simulation work. In real time application, the linear speed of the robot will be measured and a sound alarm will be activated when it exceeds its maximum limit (0.5 m/sec). Moreover, an audio message will be applied to alert the user that he has to reduce the walking speed.

6. Conclusion

The system design for an intelligent walker machine to assist the visually impaired is presented. Different requirements are discussed and integrated with the performance goals. The architectural design for hardware modules is emphasized. The goal seeking module is tested via simulation using a 2D map. A simple path planning is developed using a linked list via points table. A PD fuzzy logic controller is developed to achieve the goal seeking objective. The preliminary simulation results for goal seeking module are encouraged us to continue our development. A virtual reality module will be added to the simulation in order to demonstrate the maneuverability of the walker machine in a real time environment. Moreover, hardware integration and installation will be achieved tacking into account the obtained limits from simulation results.

7. Acknowledgements

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8. References

[1] R. Velazquez, E. E. Pissaloux, J. C. Guinot and F. Maignreaud. Walking Using Touch: Design and Preliminary Prototype of a Non-Invasive ETA for the Visually Impaired. Proc. Of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, Sept. 1-4, 2005.

[2] J. Borenstein and I. Ulrich. The GuideCane – A Computerized Travel Aid for the Active Guidance of Blind Pedestrian. *Proc. IEEE Int. Conf. on Robotics and Automation, NM*, pp.1283-1288, April 1997.

[3] W. Gharieb and G. Nagib. Smart Cane for Blinds. *Proc. 9th Int. Conf. on AI Applications*, pp.253-262, Cairo EGYPT, Feb. 7-10, 2001.

[4] P. H. Aigner and B. J. McCarragher. Shared Control Framework: Applied to a Robotic Aid for Blind. *IEEE J. Control Systems, Vol.19, no 2*, pp.40-46, April 1999

[5] S. Dubowsky, F. Genot, S. Godding, H. Kozono, A. Skwersky, H. Yu, and L. Shen Yu. PAWM – A Robotic Aid to the Elderly for Mobility Assistance and Monitoring: A “helping-Hand” for the Elderly. *Proc. Of Int. IEEE Conf. on Robotics& Automation, Vol. 1/4*, pp.570-576, 2000.

[6] S. Shoval, I. Ulrich, and J. Borenstein. NavBelt and the GuideCane. *IEEE Robotics & Automation Magazine*, pp.9-20, March 2003.

[7] V. Kulyukin, C. Gharpure, P. Sute, N. De Graw, and J. Nicholson. A Robotic Wayfinding System for the Visually Impaired. Research Report in American Association for Artificial Intelligence, 2004.

[8] Andrew J. Rentschler, Rory A. Cooper, Bruce Blasch, and Michael L. Boninger. Intelligent Walkers for elderly: Performance and Safety Testing of VA-PAMAID Robotic Walker. *J. of Rehabilitation Research and Development Vol.40. No.5*, pp.423-432, Sept./Oct. 2003.

[9] B. Graf, M. Hans, and R. Dieter Scharft. Mobile Robot Assistants. *IEEE Robotics & Automation Magazine*, pp.67-77, June 2004.

[10] B. Graf. Reactive Navigation of an Intelligent Robotic Walking aid. *Proc. Of IEEE Int. Conf. on Robotics and Human Intelligence*, pp.353-358, Paris FRANCE, 2001

[11] G. Wasson, J. Gunderson, S. Graves, and R. Felder. An Assistive Robotic for Pedestrian Mobility. *AGENTS'01*, pp.169-173, Montreal CANADA, May 2001.

[12] M. J. Matarie. The Role of Embodiment in Assistive Interactive Robotics for the Elderly. AAAI Fall Symposium on “Caring Machines: AI for the Elderly”, Arlington, VA, Nov 4-6, 2005.

[13] R. Stevens, p. Brook, K. Jackson, and S. Arlund. *Systems Engineering: Coping with Complexity*. Prentice Hall Europe, 1998.

[14] L. A. Zadeh. *Fuzzy Sets Inform. Contr*, Vol.8, pp. 338-353, 1965.

[15] E. H. Mamdani and S. Assilian, An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller, *Int. J. Man-Machine Studies*, Vol. 7, pp.1-13, 1975.

[16] C. C. Lee, *Fuzzy Logic in Control Systems: Fuzzy Logic Controller – Part I & II*, IEEE Trans., Syst. Man, Cybern., vol. SMC-20, n° 2, pp. 404-435, 1990.