

On the Implementation of a Robotic Assistant for the Elderly. A Novel Approach

IOAN SUSNEA*, GRIGORE. VASILIU*, ADRIAN FILIPESCU*,
GEORGE COMAN*

*Department of Automation and Industrial Informatics
University "Dunarea de Jos" of Galati
Str. Domneasca, 47, Galati, 800008,
ROMANIA

Ioan.Susnea@ugal.ro, Vasiliugrigore3@yahoo.com,
Adrian.Filipescu@ugal.ro, Georgecoman2002@yahoo.com

Abstract: - This paper describes an experiment aimed to demonstrate that a distributed system of embedded microcontrollers, wherein a number of control modules are located on the mobile robot, while others are deployed in an "intelligent environment" can significantly reduce the cost of developing a robotic assistant for the elderly and disabled. The structure of the experimental setup is described in detail, as well as the main algorithms used for each individual task: path following, obstacle avoidance, data acquisition. In the experiment described, didactic mobile robots (Pioneer3-DX and Peoplebot, from MobileRobots) were used, but the entire solution can be easily ported for the implementation of an intelligent wheelchair, capable either to carry an elderly or disabled person, or to move independently in a smart environment, as a sensorial extension of the assisted individual.

Key-Words: - robotic assistant, smart environment, embedded control, distributed structure, fuzzy path following, sonar based obstacle avoidance, intelligent wheelchair.

1 Introduction

Since 1985, when Borenstein, J. and Koren, Y [1] proposed the concept of "nursing robot", seen as a mobile platform, equipped with a robotic arm, a considerable number of researches have added new facets to the idea of creating a robotic aid for the elderly or disabled. Thrun et al. in [2], and [3] described the concept of "personal robotic assistant", while other researchers (see [4]) focused on the development of intelligent wheelchairs, provided with a certain level of autonomy in motion.

Advances in telecommunications and Internet technology allowed the introduction of the concepts of tele-embodiment, and virtual visit, in connection with the idea of a robotic assistant ([5], [6]).

This progress seems to justify the optimism of Bill Gates ([7]), who speaks about "a robot in every home", and estimates that the impact of the personal robots in everyday life will be comparable with that of the personal computers.

In spite of this optimism, and of the great number of individual solutions described in the scientific literature, the number of commercial applications of home robots is, so far, limited to the cleaning robots ([8]) and autonomous mowing machines ([9]). Significant results have been also

reported in the field of intelligent wheelchairs (see, for example [10]).

Meanwhile, the problem of aging of the population aggravates, and the number of people in need of a minimal permanent medical assistance is constantly increasing, thus bringing a considerable pressure on the social security budgets (see [11]).

Under these circumstances, it seems that there is an urgent social need for affordable robotic assistants for the elderly or disabled persons.

This paper describes a possible solution to this problem – the use of a distributed network of low cost, embedded microcontrollers to handle the tasks associated with the navigation of a mobile robot, as well as with the interaction between the robot and the environment.

The paper is structured as follows:

- The first section is a quick overview of the existing art in the field of robotic assistants.
- Section 2 contains the general assumptions and requirements deriving from the previous work, considered in the current experiment.
- Section 3 describes the proposed solution and the structure of the experimental setup.

- Section 4 presents details on the actual implementation of the navigation algorithms and the experimental results,
- Section 5 is reserved for conclusions.

2 Distinctive Features of a Low-cost Robotic Assistant

The complexity of the tasks associated with the control of autonomous mobile robots require high computational power for the control system, which results in high cost of the equipment, and even higher costs for developing the software for the control applications.

Besides that, most of the existing control solutions tend to achieve the maximum generality, by assuming that the robot is operating in a totally unknown/unstructured environment. In fact, the environment where a robotic assistant is destined to operate, such as a home, a nursing facility, or a community center for the elderly is fully known, and easy to structure in order to reduce the on-board equipment. For example, it is much more convenient to provide the robot with the capability to communicate with the alarm system of the building, rather than programming the robot to patrol, and try to use its on-board sensors to emulate the functions of the motion, or smoke detectors.

This leads to the idea of a robotic agent that operates in a “smart environment”. This idea is not entirely new. Park et al. describe in [12] a “smart house” for people with physical disabilities, wherein an intelligent wheelchair, and a smart bed are capable to support the disabled for movement.

Moreover, Gharpure and Kulyukin propose in [13] a robotic system aimed to support blind people for shopping.

Based on the above mentioned literature, and on the analysis of many other projects not listed here for lack of space, we have extracted a list of distinctive features required for a low cost robotic assistant.

A simple and robust navigation system is an absolute requirement for such a robot. Although LASER and LIDAR sensors have better performances, sonar based navigation should be also considered, for economic reasons. A self calibration system to compensate odometric cumulative errors is recommended, to improve the overall robustness.

It is highly desirable that the robotic assistant can perform the function of walking aid for persons with limited locomotion impairment. An intelligent wheelchair, or even a walker could be the ideal solution.

A robotic arm may seem desirable, but it is likely to dramatically increase the cost of the whole project. Therefore we did not consider this option.

It is desirable that the robot have the capability to recognize a limited number of vocal commands. The attempts to design robots able to sustain a conversation in natural language with human operators have produced questionable results at much higher costs.

It is desirable that the robot can monitor some signals from the environment (e.g. the alarm system of the building, or some medical equipment) and control various appliances, lights, heating, air conditioner, etc. With this approach, the robot is seen as part of a “smart environment”

It is desirable that the robot can interact with the communication system of the environment and select between various levels of emergency calls.

The function of cognitive prosthesis (e.g. reminding the assisted person to eat, take medication etc. at certain moments of time) is optional, since it can be easily implemented on a stationary computer.

And, last but not least, it is highly desirable that the robot can be easily programmed by a user with little or no knowledge of robotics.

3 Proposed Solution

Considering the above stated requirements, we propose a minimal structure for the robotic assistant as shown in figures 1 and 2. Figure 1 depicts the equipment located on the robot, and figure 2 shows the equipment deployed in the environment.

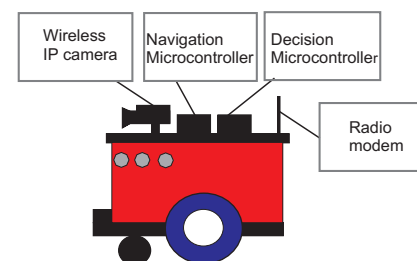


Fig. 1 The on-board equipment

Besides the equipment presented in figures 1 and 2, the robot have additional built-in electronics including power drivers for the wheels, sonar sensors, odometric system, and communication interfaces (see figure 3).

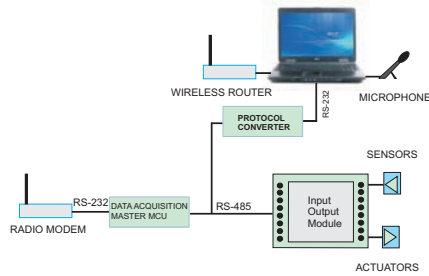


Fig. 2 The equipment located on the ground

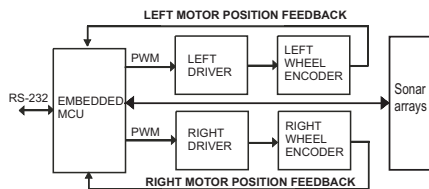


Fig. 3 The built-in electronics of the robot

Note the presence of four embedded microcontroller units, having the following functions:

- The *navigation module* receives as input the odometric information and sonar data reported by the built-in electronics of the robot, and the coordinates of the current goal point transmitted by the decision module. Generates as output elementary motion commands, by transmitting reference values for the speed v_R , v_L of each drive wheel. This module is also responsible with the obstacle avoidance.
- The *decision module* receives as input general robot status information (such as: battery status, bumper status, stall, etc.), as well as the state of the sensors connected to the inputs of the data acquisitions modules and the codes associated with a set of voice commands. It generates motion commands for the robot, and activation commands for the actuators connected to the I/O modules (e.g. to control the appliances, lights etc., or to transmit emergency calls).
- The *data acquisition master* module is responsible with the time consuming task of scanning the data acquisition modules. It generates synthetic reports for the decision module.
- The *protocol converter* module was introduced to convert the output of the speech recognition software to a format compatible with the protocol required by the data acquisition modules, so that all the information from the environment can be handled by the same data acquisition master module.

In addition to the four microcontrollers described above, a regular personal computer and a wireless

router connected to the Internet were included in the system. The tasks associated with this equipment are:

- Run a dedicated software for speech recognition. When a predefined voice command is recognized, the computer sends a identification string through a serial port to the protocol converter module.
- Provide the physical interfaces for transmitting the images and sound collected by the wireless IP camera carried by the robot through the internet.

Besides the hardware modules described above, the experimental setup includes the following software applications:

- A robot simulator (MobileSim) offered by MobileRobots ([14]). This is a modified version of the Player/Stage Simulator ([15]). A very useful resource to speed up control software development.
- Since the robot simulator communicates via TCP, and the actual robot is controlled through a RS232 communication line, a special software application, called “Serial to Ethernet Connector” (Eltima Software. [16]) is required to assure direct communication compatibility between the microcontroller navigation module and the simulator software.

With this structure of the control system, each of the four embedded microcontroller module can be reduced to a minimal configuration, as shown in figure 4A. Figure 4B shows the actual size of the embedded module.

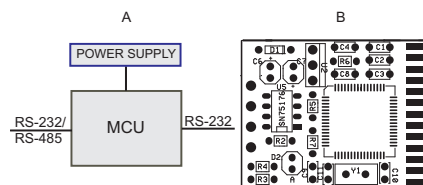


Fig. 4 Structure and layout of the MCU modules

4 Experimental Results

Two navigation problems have been addressed in this study: the path following problem, and the obstacle avoidance.

4.1 The Path Following Problem

Since the environment is fully known, the user can define a number of routes (a route is an oriented path) as a succession of line segments. Each segment is described by the equation (1).

$$Ax + By + C = 0 \tag{1}$$

where:

$$A = y_{i+1} - y_i$$

$$B = -x_{i+1} - x_i \quad (2)$$

$C = x_{i+1}y_i - x_iy_{i+1}$
 (x_i, y_i), (x_{i+1}, y_{i+1}) are the coordinates of the points that determine the segment.

With these notations, the distance from the point (x_0, y_0) to the current segment of the segment, defined by two successive points (x_i, y_i), (x_{i+1}, y_{i+1}) is determined by (3).

$$d = \frac{|Ax_0 + By_0 + C|}{\sqrt{A^2 + B^2}} \quad (3)$$

The position error for a vehicle attempting to follow the curve (1) is the signed distance between the current point (x_0, y_0) and the line (1):

$$e = \frac{Ax_0 + By_0 + C}{\sqrt{A^2 + B^2}} \quad (4)$$

and the derivative of the position error is:

$$e' = \frac{\Delta e}{\Delta t} \quad (5)$$

By defining three fuzzy domains N(Negative), Z(Zero) and P(Positive) for each of the variables e and e' , with membership functions as shown in figure 5, it is easy to define a set of linguistic rules to describe the desired behavior of the fuzzy controller.

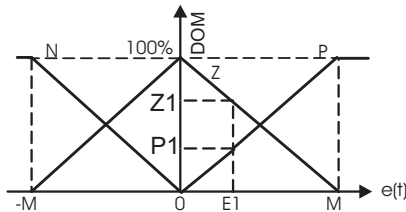


Fig. 5 Shape of the membership functions for $e(t)$, $e'(t)$

The general structure of the logic sentences for the fuzzy controller is:

“If the error is positive and the error dot is positive, then v_R must be HIGH and v_L must be LOW.” The entire “rule base” describing the fuzzy controller is presented in Table 1.

Each cell of table 1 contains a logic sentence and should be read as: “If $e(t)$ is Negative AND $e'(t)$ is negative, THEN v_L must be HIGH and v_R must be LOW”

Table 1. Rule base for the Fuzzy controller

error dot $e'(t)$	error $e(t)$		
	N	Z	P
N	HL	LH	LM
Z	HL	MM	MH
P	ML	MH	LH

where H,M,L designate the singleton values for HIGH, MEDIUM and LOW fuzzy domains of the outputs v_L , v_R respectively.

The truth value of the antecedent of the above sentence is $\min(N(e), N(e'))$, where $N(e)$, $N(e')$ are the degrees of membership of $e(t)$ and $e'(t)$ to the domain N.

The crisp output of the fuzzy controller is a combination of all the rules in the rule base as follows:

$$v_{OUT} = \frac{\sum_{i=1}^K z_i S_i}{\sum_{i=1}^K z_i} \quad (6)$$

where:

$$z_i = \min(E_i, E'_i) \quad (7)$$

S_i is the corresponding singleton value of the fuzzy output, and K is the total number of rules in the rule base. E_i , E'_i are the degrees of membership of $e(t)$ and $e'(t)$ to the domain corresponding to the cell i.

The actual output variables of the fuzzy controller are the reference values for the speed v_R , v_L of each drive wheel. Thus, both translation speed (8) and steering (9) are controlled by the same fuzzy controller.

$$v = \frac{v_R + v_L}{2} \quad (8)$$

$$\omega = \frac{v_R - v_L}{b} \quad (9)$$

where b is the kinematic “bias” of the robot (distance between the planes of the drive wheels).

See (17) for more details on the implementation of the fuzzy controller.

Figure 6 shows a plot of the successive positions reported by the real robot, following a path in the absence of obstacles, and figure 7 is a snapshot of the trail of the simulated robot moving from a start point S to a goal point G, on two different routes, as recorded by MobileSim.

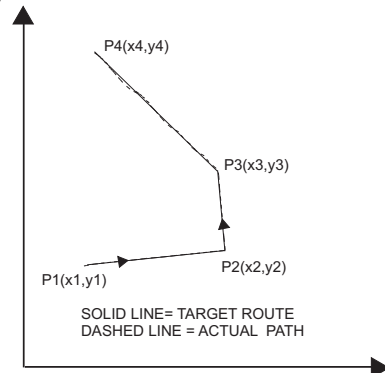


Fig. 6 Results recorded with the fuzzy controller

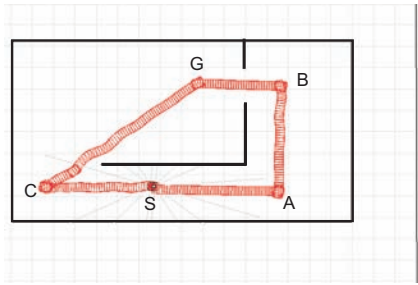


Fig. 7 Trajectory of the simulated robot

4.2 The Obstacle Avoidance Problem

The robot used in this experiment have an array of 8 sonar cells located on a semi-circular band on the front panel of the robot, as shown in figure 8.

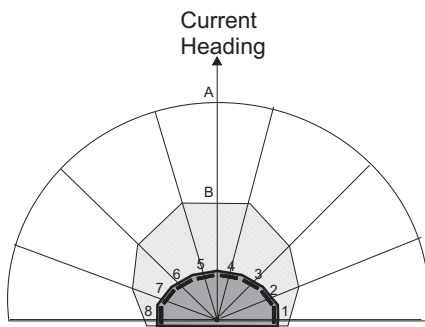


Fig. 8 Angular disposition of the sonar cells

The readings of the sonars are unsigned integers in the range [100mm, 5000mm]. Therefore, the “visible” universe for the robot is a semi-circular area, delimited approximately by the curve A in figure 8. Under these conditions, it would be difficult, if not impossible to attempt a rigorous path precomputation based on environment mapping.

We have defined an obstacle detection area as a petal-shaped region, more elongated along the motion direction (the gray area delimited by the curve B in figure 8), which is permanently scanned by the navigation unit. If any of the sonar reports an obstacle within this area, the control unit computes the least resistance angle:

$$\alpha_0 = \frac{\sum_{i=1}^8 \alpha_i D_i}{\sum_{i=1}^8 D_i} \quad (10)$$

where α_i is the position angle of the sonar cell i , relative to the current heading, and D_i is the reading of the sonar cell i . Note that the entire sonar visibility range is considered in (10).

The rotation angle computed with (10) is also relative to the current heading.

See figure 9 for an example of a possible distribution of obstacles.

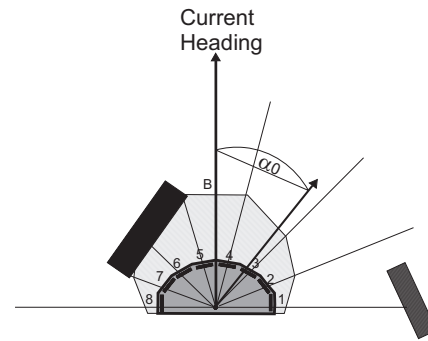


Fig. 9 Illustration of the concept of least resistance angle

Having the least resistance angle computed, the robot abandons its current path, and adjusts its heading to the new path, then moves forward a distance $d = \min(D_i)$, or until it detects a new obstacle. After this detour, it checks whether the original goal point became visible, and if so, it defines a new path to the goal point, as a line defined by the current point and the goal point.

A schematic of the process of moving between a start point S and a Goal point G, in the presence of an obstacle is presented in figure 10.

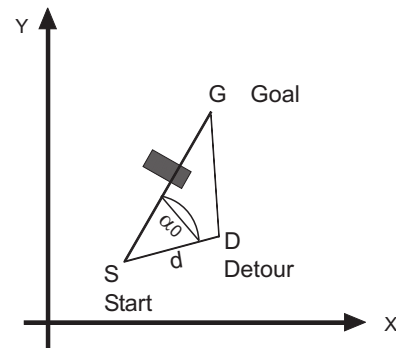


Fig. 10 Modified path upon detection of an obstacle

The actual recording of the motion of the robot while detecting and avoiding obstacles is presented in figure 11.

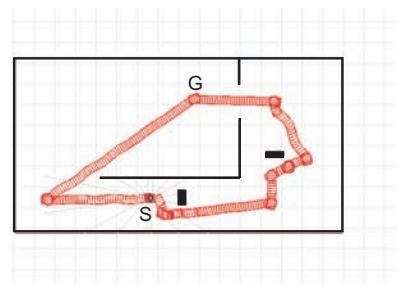


Fig. 11 Trajectory of the simulated robot with obstacles

The obstacle avoidance algorithm described above produces reasonably good results with static obstacles. It can even handle dynamic obstacles, provided that the moving objects have speeds comparable to the speed of the robot.

4.3 The Decision Problem

The selection of the solution for the robot decision problem, was mainly determined by the requirement that the robot must be easily programmable by means of translating simple linguistic sentences like: "If the input I_j is activated, AND there is no voice command, then move on route R_n ."

This leads to a PLC-like programming language, with the difference that, voice commands are treated like any other inputs, and predefined routes are treated as regular digital outputs.

Another difference is that the actual inputs and outputs of the system are integrated in the environment.

5 Conclusions

This experiment demonstrates that the idea of controlling a robotic assistant with a distributed structure of embedded microcontrollers is entirely feasible and can lead to significant cost reduction.

Besides the low cost, there are many other advantages in the proposed solution: low power consumption, less effort to develop the software, use of regular, low cost data acquisition modules, etc.

Obviously, any of the sub-systems described here is almost endlessly perfectible, and further research for improving the navigation algorithms, and the user programming techniques are definitely worth the effort.

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