Modular Architecture for Wheelchairs with Environment Integration capabilities

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Abstract. *This paper presents the results of research work carried out in the field of electronic systems for the automation of powered wheelchairs for the disabled and/or the elderly. These electronic systems have been designed to meet a wide range of needs experienced by the users of this type of wheelchairs. Several interesting features are: modularity, making them adaptable to the particular needs of each user according to the type and degree of handicap involved; interoperatibility, by using a standard Serial Bus equipments coming from different builders can be easily incorporated on-board; and environment integration, because that Serial Bus is one of the broadest in use for Building Automation.*

1.- Introduction

The need for artificial means to assist the mobility of people with some type of disability is a question of great interest to many national and international organisations and institutions. The reasons for this interest are varied (to live an independent life, access to the media, etc) but without any doubt the most important are those to do with the quality of life, the need for integration into the working world. In terms of mobile robotics applications, assisted mobility is considered one of the most interesting research areas.

Most solutions therefore aim at incorporating advanced control equipment on standard mobile platforms, i.e., on conventional powered wheelchairs [1][2]. Several electronic configurations have been tried for the automation in that kind of wheelchairs, but the more flexible systems are those with a distributed architecture [1][3][4][5]. One of the most important aims in the distributed electronic systems implementation is the choice of the right communication media among different modules. In this way there have been some works aimed to design a robust and flexible modular architecture based on a powerful but at the same time easy to use communication network.

Other European working groups (the CALL Centre in Edinburgh [1], the OMNI Team [5] or the TetraNauta project [6]) have also designed wheelchair systems based on Serial Buses. The most appropriate systems to this application are those using industrial Fieldbuses, but many choices can be found in this area: ProfiBus, CAN (Controller Area Network), FutureBus, and some others, each of them supported by powerful industrial groups or companies.

A very interesting effort in order to get a suitable standar to equipments on-board a wheelchair is the M3S (Multiple Master Multiple Slave) specification [7]. This bus has taken some characteristics from the CAN system physical layer, with a data rate of 250kbit/s and has got a six wire interface: 2 for communication, 2 for power distribution and 2 other for safety proposes.

The working group of the University of Alcala [3][8][9], in order to give a solution to this architectural problem, decided to use the LonWorks Network system. This technology developed by Echelon (http://www.echelon.com), has been specially designed for distributed systems as the one needed for this application. A full 7 layers OSI protocol has been integrated in the Echelon microController itself (the NeuronChip, built by Motorola and Toshiba) and so direct communication among application codes within different processors is done. Also, the NeuronChip is able to execute control code of the module involved, so the result is a very flexible and complete architecture. Recently, lower levels of LonWorks system have been adopted by the specification EIA 709.1.

2.- System Architecture.

The SIAMO prototype (that means 'Integral System for Assisted Mobility' in Spanish) has been thought of as versatile. Therefore it allows the incorporation or removal of varied services by simply adding or removing the modules involved in each task. The functional blocks making up the whole system, as shown in figure 1, are the following:

a) Low Level Control,
b) Human-Machine Interface,
c) High Level Control, and
d) Environment Detection and Integration.

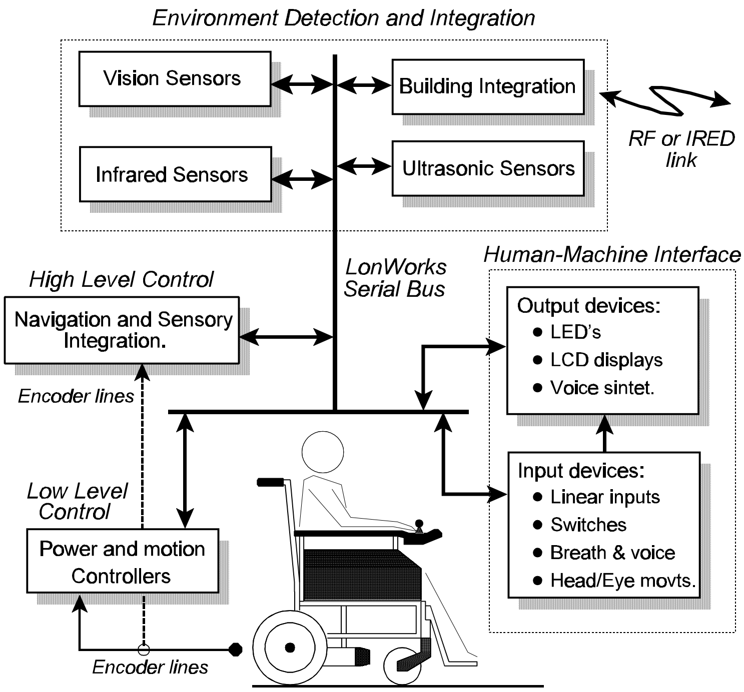

Figure 1.-SIAMO system, functional diagram.

Each functional block of the SIAMO wheelchair is made up by several subsystems, some of them in order to implement basic functions and some optional ones to extend, adapt or change them. Thus, the Human-Machine Interface function, for example, can be equiped or not with a display, depending on user demands, in order to show useful information of the global state of the system and, optionally, the state of any other subsystem, such as the manual control (i.e. joystick or switches) or the word-recognition guidance unit.

The type and number of modules fitted suitably reprogrammed define the facilities of the system, the latter being adaptable to the particular needs of each user. In its basic configuration, the SIAMO system needs only the low-level control modules and the simplest user-machine interface, a linear joystick, to work as a conventional powered wheelchair.

LonWorks Serial Bus, in its simplest version, needs only three hardware lines, two for signals and one for ground; but in order to standardise modules accessing to the Bus with different functionalities and requirements, such as power, control or commanding, several lines have been added to the SIAMO Serial Bus, so it has got six lines (as M3S):

- 2 data lines, as the serial bus link;
- Power and Ground, to close data path and to distribute energy;
- Security and Synchronization as additional functions.

On board the SIAMO wheelchair, communications are carried out by a simple twisted pair cable (three pairs, six wires) at a rate of 1'25Mbit/s. This allows a transaction time (between applications, so up to the highest level directly) as low as 7ms, beeing around 10-20ms in worst cases such as high traffic or high volume of data. Also the synchronization line allows an appropriate timing to modules that need such performance, as the ones on charge of navigation an sensory integration.

The SIAMO architecture matches a distributed control system. So, in meeting the aforementioned versatility requirements, the nodes making up the modules have been designed as independent entities, endowed with enough intelligence to take decisions and give information on their state, exchanging a limited amount of information through short messages.

And finally, a noteworthy feature of the LonWorks networks is the possibility of their application to building automation (at present time, more than 5 million nodes have been installed in the USA), thereby making easier the interaction between the wheelchair and its immediate environment. Communication with off-board modules or devices (as lifts or automatic door controllers, appliances, etc.) can be done by several transmission media, including Infrared and Radio links, but with the same protocol so that no other interface is needed but the hardware driver itself.

SIAMO system uses this feature in its navigation subsystem, as it will be described in next paragraphs. Another interesting solution integrating the environment (a building) with a wheelchair and also using the LonWorks system is being under development in the ARIADNE project of the University of Reading (UK) (http://cyber.rdg.ac.uk/DSRG/ariadne/ariadne.htm).

3. SIAMO Architecture highlights: modular upgrading and environment integration.

Two features of the SIAMO Architecture can be highlighted here: its modular upgrading capabilities, so it gives a solution from the very simplest system to the most complex one; and its environment integration capacities. According to the number and quality of the modules on-board, the SIAMO system incorporates different operational modes. In general these modes can be divided into three major categories:

1) Direct drive,
2) Semi-autonomous and
3) Fully autonomous system.

In the *Direct drive* mode the wheelchair is under the absolute control of the user, who takes all high-level tracking decisions. Inputting of orders can be made effective through varied means, depending on the user’s degree of disability. Linear inputs can be made via the joystick and discrete inputs by switches of different types. Where fitted, several safety and obstacledetection options can be activated in this mode.

In the *Semi-autonomous* mode the on-board sensory structure of the system provide additional facilities to help the user in low-level tracking tasks, the high-level decisions still being taken by the user. The most important semi-autonomous facilities are the following: passing through doors, entering lifts or docking under tables, tracking corridors and an accompanying function whereby another mobile object (person or thing) in the immediate vicinity of the wheelchair may be followed.

For *Fully autonomous* mode the wheelchair has to be fitted with a High Level Control unit (figure 1) and some sensors can execute complex navigation tasks, based on a description of the environment and the final objectives marked out by the user.

3.1. Minimum system: first step to upgrading

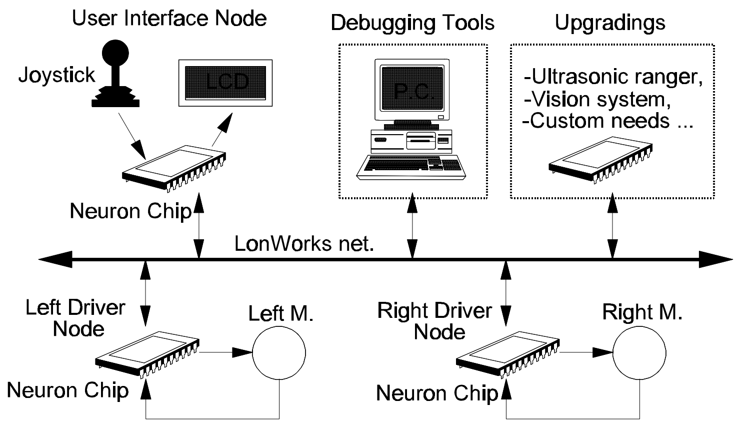

Figure 2.-Block diagram of the distributed system.

The wheelchair's two drive wheels are led by two individual power modules (figure 2), each of them equiped with its own controller being an independent node in the network.

Control of the motors may be in closed or open loop. In Closed Loop mode, NeuronChip executes a PID speed control; nevertheless, several Digital algortihms can be tried because the programable feature of the Driver node. Open Loop mode allows the wheelchair to be used on standard platforms without needing to add encoders to motors, although the rest of the system's facilities (tracking and dynamic behaviour) would be diminished.

As the rest of the modules of the SIAMO system power drivers have enough intelligence and autonomy to be controlled by messages; these are of two types: orders (input messages) and state feedback (both input and output messages)

3.2. Navigation in structured environments

Navigation is done using 'dead-reckoning' based on encoders information. Sensory system data is used both to avoid obstacles and to recover information from the environment. A locally stored map of that environment is needed to identify initial and final positions and to build some kind of path planning, although most of the navigation task are simple reactive behaviours.

Dead-reckoning navigation alone is not a good option without systematic errors correction and an appropriate self-localization subsystem; solutions to this problem have got two main choices: to increase computing capabilities, looking for higher inteligence 'in the machine'; and to increase sensory system precision and performance, looking for better information recovery from the environment.

Nevertheless, one of the design criteria in the SIAMO project has always been to keep an appropriate cost/performance ratio in the whole system. So, no high cost investments have to be done in both the wheelchair or the environment.

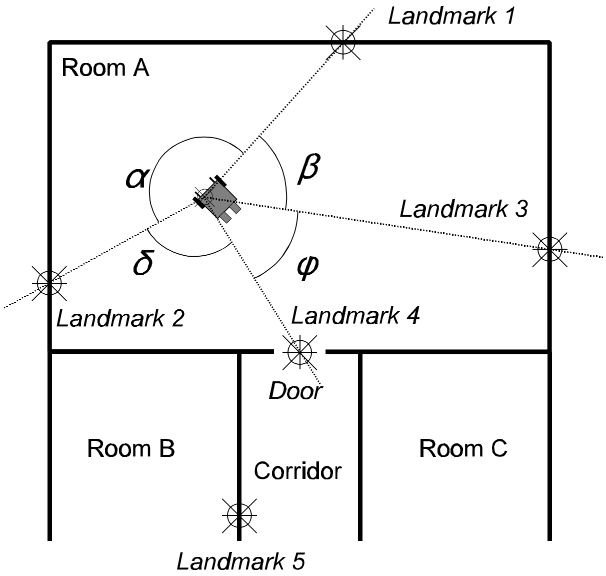

Figure 3.- Landmark absolute positioning

To keep computing needs inside the limits of low-power and low-cost processors, an absolute positioning system based on artificial landmarks has been developed. The landmarks are simple A4 paper sheets (about 21x30cm.) with a black and white pattern printed on them. Positioning is performed by triangulation after the identification of three or more landmarks, as shown in figure 3.

Instead of an active vision system, landmark seeking and tracking is performed using a pasive omni-vision system based on the image taken by a set of four low-cost digital cameras. Landmarks can be fully recognized at distances under 5 meters, but can be detected in distances up to15 meters, that is long enough for environments as homes, hospitals or public buildings.

3.3. Building integration: maps 'stored' in the building

Navigation task needs a full mapping of the environment; so, processors on-board need to store those maps in a full and extensive data-base with all the problems related with wide information processing. In the SIAMO system part of the inteligence has been translated to the environment itself: it is the building the one which loads or removes its own map to the wheelchair when needed.

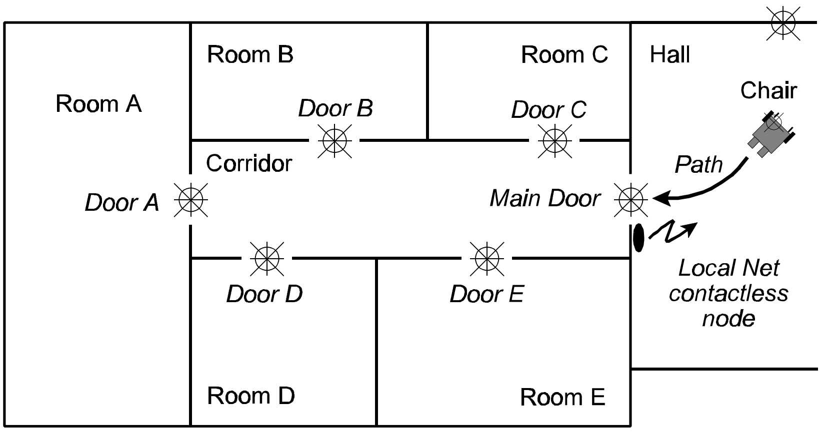

Figure 4.- Local mapping based navigation: self-identifying environment

This system is shown in figure 4. As formerly mentioned, the Serial Bus used (a LonWorks network) has a deep application in Building Automation; among the communication media available there are wireless drivers, as infrared or radio frequency links. One contactless node, equiped with a wireless driver can be placed on main-doors and loaded with a full description of rooms identification, landmarks location and routing inside the section of building accesible through it. So, the only detailed mapping needed can be stored “on-the-fly”, just entering to a new building section.

That integration between wheelchair and environment has got many advantages: computing power needs decreases strongly and navigation capabilities can grow and cover even places never visited before, as public buildings (hospitals, business or government offices). Some other advantages of the building integration nodes are the access from wheelchair electronics to any electronic device conected to a compatible building local network; this is not a navigation task itself but it is really useful, because it opens a full range of actions to be made on-board the wheelchair as to give (or even receive) commands to lifts, lights or other home devices.

4. Conclusions

As a result of the research work carried out by the SIAMO group in the field of assisted mobility, diverse electronic systems have been developed to facilitate movement and provide for a configuration tailor-made to suit users’ needs.

The SIAMO Architecture has got two highly interesting features: it is a *modular upgrading system*, that allows easy upgrading and reconfiguration using a fully compatible structure from the very simplest modules set; it has the ability to communicate with the environment (buildings) opening an interesting field in assisted autonomous navigation, and even in the related field of mobile robotics.

Further research will be directed in improving the assisted navigation feature with a layered mapping structure and a definition of the hierarchy of nodes in buildings, in order to minimize cost in building automation investments.

5. Acknowledgements

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