An Autonomous Wheelchair with a LonWorks Network based Distributed Control System.

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Abstract

Basic idea behind many distributed control architectures is that of decentralizing several tasks of a given system by increasing the intelligence of peripheral devices; in robotics that means sensors and actuators. This paper describes an application of a distributed solution (based on the LonWorks Technology) in the mobile robots field: the development of an Autonomous Wheelchair, designed to be easily upgraded with intelligent sensors and a high-level control system. A new I.C. called Neuron Chip have been tested and its capacity as a controller of dynamic systems has been assessed, exploiting both its capabilities in the transfer and exchange of messages, and its wide-ranging control possibilities using its input/output devices and programming objects.

1 Introduction

Works carried out by the Departamento de Electrónica (Electronics Department) of the Universidad de Alcalá for several years have been applied to a very important aim: helping people with severe mobility handicap with the construction of an autonoumous wheelchair.

Two previous versions were included in the UMIDAM project [Mazo, 1995a and 1995b]: the first one consisted of an electronic system for guiding the chair by means of a joystick and voice control, and in the second one a sensorial system, based on ultrasonic and infrared sensors, was also included.

An important requirement that a wheelchair has to fulfil is to respond quickly and efficiently to user commands. Basic idea behind the new work presented in this paper is to improve performance of the communication system; previous ones were based on a slower local serial bus configuration. Another purpose was to improve the multiprocessor architecture, with a better tasks distribution among processors.

LonWorks Technology (LON means Local Operating Network) developed by Echelon [http://www.echelon.com] is a very interesting option for this application: it allows to build powerful communication networks, specialy for distributed control systems, as shown in figure 1. Capacities of the system are thereby increased without increasing computing requirements of processors and, even more important, reducing the amount of information needed in system local buses.

Inside systems constructed with LonWorks technology, the Neuron Chip, a multi-processor chip which is the heart of every module in a LonWorks network, carries out both tasks of network management and control of the associated sensor or actuator system, furnishing each node with enough intelligence to control any device using the information received from the network. Furthermore, all this has a very short development time because of the very nature of the devices and tools available.

2 The LonWorks technology

LonWorks technology includes all of the elements required to design, deploy and support intelligent distributed control systems: hardware and software resources as well as development and maintenance tools are available.

Using its devices and tools, communication among nodes in any distributed control system is easier to implement. One of the advantages is that Neuron Chip

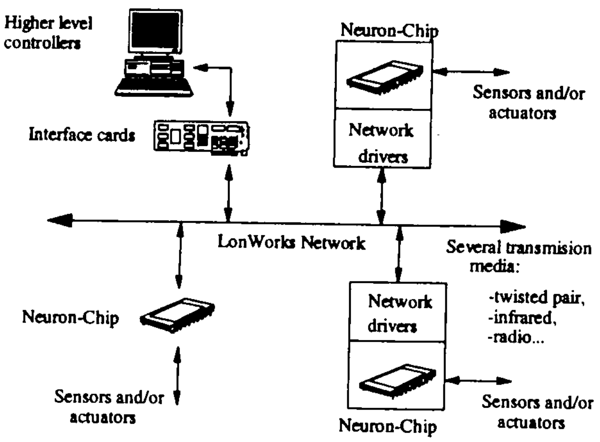

Figure 1.-Distributed Control Network based on LonWorks technology and Neuron Chip.

includes (in both: firmware and hardware) the seven communication layers specified by OSI protocol. Also Neuron Chip is able to perform control tasks itself: his I/O pins can implement functions such as PWM signal generation, serial and parallel interfaces, timer/counters functions, etc. Other features of interest are the following:

- Different communications media: the most common are twisted pair and power line networks; other media includes radio frequency, infrared, fiber optics, etc.
- Computing capacity: LonWorks devices can be programmed in a high level language (Neuron C).
- Application and I/O interfaces: many different I/O modes, with easy programming through high level functions in firmware. It needs a minimum of external components in most applications.

LonWorks networks and devices are optimized for control applications, where response time is more important than throughput. Therefore, messages in the network are short, usually less than 20 bytes per transfer. That feature allows minimal buffering requirements.

Message response time depends on several questions: size and type of data, bus speed, transferring mode and others. A lower bound is found in a 7ms application-to-application delay (that is through the whole 7 level OSI reference model in both senses) for 10MHz Neuron Chips at a network rate of 1.25Mbit/s.

2.1 The Neuron Chip.

The Neuron Chip is a CMOS VLSI circuit designed to implement low cost LonWorks networks, its main sources are Motorola and Toshiba. Included in Neuron Chip are all of the functions required to acquire and process information, make decisions, generate outputs and propagate information, via standard LON protocol. Figure 2 shows a block diagram of it.

This circuit can send and receive information on either the 5 pin communications port or the 11 pin I/O port. Neuron Chip is available in four different versions. Their main features are:

- Three 8 bit pipelined CPUs, with input clock rates from 625KHz to 10MHz (a 20MHz version has been recently announced).
- On-chip memory:
  - SRAM: 1Kb (Neuron Chips 3120 & 3120E1)
    2Kb (Neuron Chips 3150 & 3120E2)
  - EEPROM:512 bytes (N. Chips 3120 & 3150)
    1Kb (Neuron Chip 3120E1)
    2Kb (Neuron Chip 3150E2)

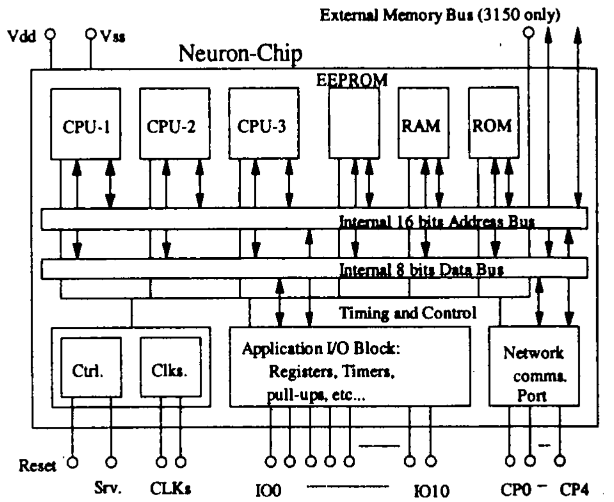

Figure 2.- Neuron Chip block diagram.

  - ROM: 10Kb (Neuron Chip 3120xx)
  - Neuron Chip 3150 has not on-chip ROM, but it has an external memory bus to support more complex applications.
- Eleven programmable I/O pins with as many as 34 selectable modes of operation; some of them have got programmable pull-ups and 20mA current sink capabilities.
- Two 16 bit timer/counters for frequency and timer I/O.
- Sleep mode for reduced current consumption while retaining operating state.
- A Network Communication Port with different modes avalaible: single-ended, diferential or special purpose. Transmission rates can be selectable from 610bits/s to 1.25Mbits/s. Output current reaches 40mA for direct driving differential twisted pair networks.
- Firmware: LonTalk protocol conforming to seven layer OSI reference model. I/O drivers and event-driven task scheduler also incorporated.
- Unique 48 bit internal identifier.
- Built-in low voltage detection for added EEPROM protection.

Figure 3 shows processor organization inside Neuron Chip and its associated memory buffers. First processor, CPU-1 in the figure, is the Media Access Control layer processor (MAC) that handles layers one and two of the seven-layer network protocol stack. This includes driving

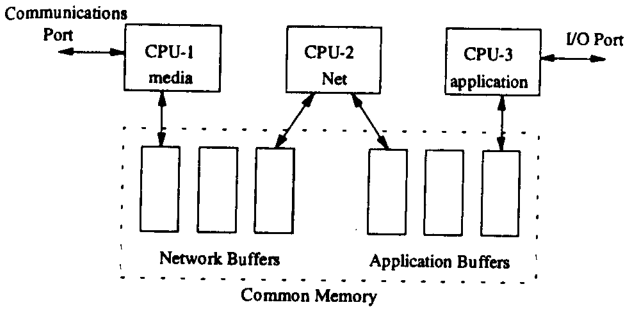

Figure 3.-Processors distribution inside Neuron Chip

the communications subsystem hardware as well as executing the collision avoidance algorithm.

Second processor, CPU-2, is the Network Processor that implements layers three to six of the ISO model. It handles network variable processing, addressing and other routing functions.

CPU-3 is the Application Processor. It executes the code written by the user, together with the operating system services called by user code.

Each of the three CPUs has its own register set, but all three share data and address ALUs and memory access circuitry. Communications among processors are made through specific buffers allocated in shared memory. The three processors are pipelined allowing the execution of three processes in parallel without time-consuming interrupts and context-switching.

2.2 Neuron C.

The primary programming language used by most applications is Neuron C, a derivative of the ANSI C language optimized and enhanced for LON distributed control oriented applications. Some of the characteristics of Neuron C language are:

- Input/Output subsystem is accesed through high-level functions.
- A built-in multitasking scheduler allows the programmer to express logically parallel event-driven tasks, and to control priority execution as well.
- A new sentence, the **'when'** clause, defines events and their flow sequence.

Unlike ANSI C, Neuron C does not include a standard run-time library supporting file I/O and other features common to other processors, such floating point arithmetic. Also, as a result of its event-driven scheduler, function **'main()'** does not exist. Other major differences are data types: *int* type is 8 bit wide and *long* type is only 16 bit wide.

But the most interesting features of Neuron C and LonWorks technology are related with a special class of static objects called *network variables*. This new data type may be of class *input* or *output*. Assignment of a value to an output network variable causes propagation of that value to all nodes declaring an input variable that is connected to the output network variable. The network variable concept greatly simplifies the programming of complex distributed applications [De Lucia, 1997]; programmers need not to deal with message buffers, node addressing, retry processing and other low-level details.

A network variable may be a Neuron C variable or structure up to 31 bytes in length. If more than 31 bytes must be sent in one transaction, a special protocol called 'explicit messaging' can be used, but throughput is then reduced.

2.3 LonWorks in Mobile Robots.

Different systems have been implemented over mobile robots based on LonWorks technology; main idea behind all of them was to build and test, using LonWorks tools and devices, distributed systems capable of controlling different motors and sensors.

For instance, the swedish company Volvo Automation (a division of Volvo Car Components Corporation, in Skövde, Sweden) has been recently involved in the design and manufacture of an Autonomous Guided Vehicle (AGV) with a LonWorks network distributed architecture [Moore et al., 1997], with a modular design integrating over a mobile robot a full set of sensors and actuators, a safety subsystem and a PC-based supervision system.

Electronics Department of Alcala University also worked on a mobile robot [Rodríguez, 1997] using the Neuron Chip as a communication node in the guidance by artificial vision of an industrial lift truck. High level application software, running on a PC, communicates with traction and steering motors of the truck through a LonWorks adapter board.

Experiences from this first design were then applied to the construction of an autonomous wheelchair with a full distributed architecture. The new system tested also the Neuron Chip in a new application: a DC motor digital controller.

3 The Autonomous Wheelchair

System constructed on board of the wheelchair has the distribution shown in figure 4. It has been designed as an open system, so that new sensor modules or controllers can be simply fitted to and removed from the assembly. Furthermore, each node is capable of acting on its own initiative in response to events occurring in the module, so tasks of the robot are thereby decentralised.

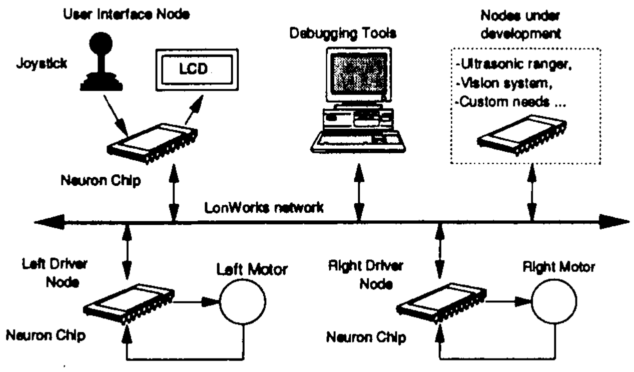

Figure 4.- Block diagram of the basic Wheelchair.

3.1 System Architecture

Wheelchair is moved by a pair of DC-motors controlled by two H-bridges [Mazo et al., 1993]. The H-bridge transistors are driven by specific drivers that receive a PWM signal, the working cycle of which indicates motor speed. A closed loop system was constructed to control speed of the robot's wheels. This loop is closed through a system of encoders that determine the position of the motor at all times.

Experiments have shown that Neuron Chip has all the necessary support to carry out all the control tasks developed in the node described.

- It can generate a PWM signal by simply indicating to one of the I/O objects the desired working cycle. This signal goes directly to the driver of the transistor bridge.
- It can gauge the encoder signals to obtain the real speed of the motor, a task carried out through the specific I/O object built into the Neuron Chip firmware.
- It executes a control algorithm, written in Neuron C and loaded in the same chip. Modifying part/all of this software is very simple, especially bearing in mind the multiple firmware functions included in the Neuron Chip. The great time constant (over 100ms) of the typical traction motors means that the algorithm can be executed without problems.

No additional circuit is necessary to carry out all the low level control of the robot's wheels, since each node acts as an intelligent component of the system, eliminating the need of a specific motor controller I.C. It should also be noted that each node includes all communications support. Also, upgrading of software can be done at any time in any node, with a simple downloading process through the network into on-chip EEPROM.

In the current architecture the user guides the robot (wheelchair) by means of a joystick that, when operated, controls in turn another node managed by a Neuron Chip. This node is higher in the control hierarchy, so the suitable speed and direction commands are sent through the network to each motor controller node. The tasks thereby carried out are the following:

1. Obtaining movement commands thorough the joystick. The signals of the joystick have therefore to be digitalized and converted to speed commands for each of the wheels.
2. Comparing the intended speeds with the actual speed of the wheels, received through the network, executing a second feedback loop additional to the one of the lower level, incorporated in the motor nodes themselves.
3. Lastly, this controller node also controls a display LCD and a series of buttons that complete the system communication with the user.

Furthermore this superior node carries out with a blow based steering system. This is very useful for people with heavy mobility disfunctions. With different blow sequence the user can drive the wheelchair easily. The superior node have to decide which commands the mobile have to follow: those from the joystick or from the blow system.

There are two speed control loops to establish the trayectory selected by the user (figure 5):

1. First level operates directly over the angular speed, ωr and ωl, of the right and left wheels from the information obtained from the optical encoders placed in the axes of the motors. This distributed first loop is executed by the lower nodes.
2. Second level operates over linear and angular speeds (V and Ω) of the chair itself. This allows to establish simple trajectories (lines and curves), where the curve radius comes from the ratio between the two angular speeds, ωr and ωl, of the driving wheels.

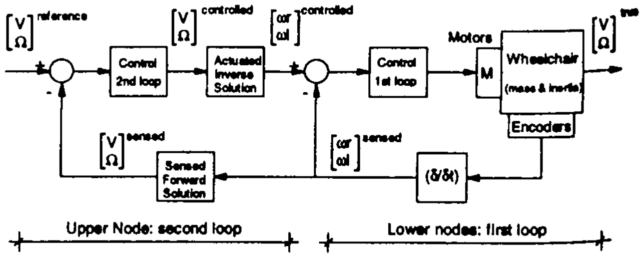

Figure 5.- Distributed Double Control Loop on board of the Wheelchair.

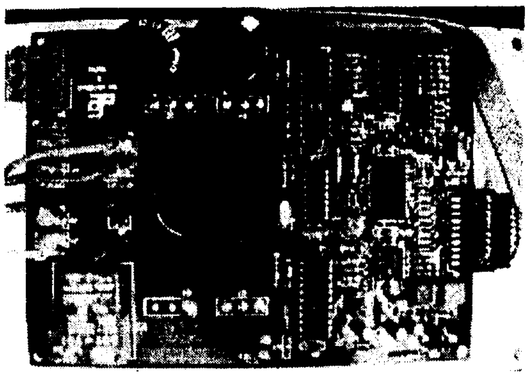

Figure 6.- DC-motor board, with the controller, drivers and H-bridge.

Lower nodes, directly connected to DC motors, execute the first loop while upper node in the hierarchy computes transformations among the different kinds of speeds and executes the second loop. Therefore, network variables among nodes are only angular speeds, both sensed and controlled. Sampling rates are 10ms in the first loop and 50ms in the second one; these rates are enough for this application.

In the wheelchair developed there is no other controller than the Neuron Chip, distributed in three independent modules connected by a twisted pair network. One of this modules, the DC-motor controller, is shown in figure 6.

Sensor modules and processors of a higher level (planners, etc) will be phased into the development to give the system the desired autonomy. Some of these, such as voice guidance and ultrasonic rangers were previously tried out in the previous versions and need only to be switched over to the new system.

3.2 System dynamics

Results obtained with different step set points are shown in figure 7. Linear speed set point is applied in t=1s, and angular speed step is applied in t=2s. Units in the graphic are all relatively referenced to the maximum wheelchair speeds.

Measurements where done under loadless conditions. So, variable load effects do not appear as it will happen when the wheelchair is on the floor. In this last case castors can perform strong resistance in the system depending on their position referred to the global wheelchair movement. These speed transients can not be avoided in a real situation, but they are of no interest for studying network capacities in controlling dynamic systems.

System response shown in figure 7 is satisfactory, although two remarks can be pointed out:

1. It is more difficult to reach angular set point speed than linear speed set point. Reason is that in the second loop angular speed transformations are very sensible to control processor arithmetic resolution. So this angular speed response is the best that can be obtained with actual Neuron Chip processors, as there must be a balance between its processing speed (related with sample time) and available numerical resolution.
2. There is a clear transient in sensed angular speed evolution, related with the moment when linear speed steps on. This effect depends on the time delay between the arrival of network variables coming from the two DC-motor nodes.

This lack of synchronization will always exist, as network variables are sent according to the local processor clocks in each node. Also network delay depends on several conditions that cannot be avoided: traffic, media access, possible collisions, etc. If both nodes were synchronized, transient will decrease strongly. In measures shown in figure 7, a 15ms delay has been forced, being the maximum expected in the system.

However these problems are not very important in a system like this one, although a deeper study would be necessary if a more precise movement is required.

As a final comment the actual system properties can be exposed:

- Integral speed control algorithm in both control loops. This way the encoder low resolution is compensated.
- Position is registered in a 32 bits format, both for wheels angular speeds and for mobile global speeds.

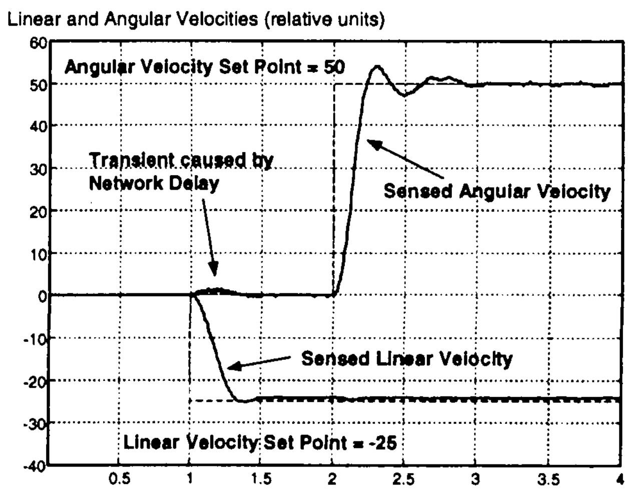

Figure 7.- Sensed Speeds versus Set Points. A Network delay transient is also shown.

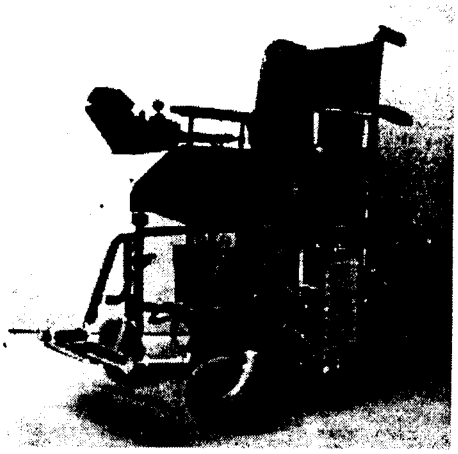

Figure 8.- Wheelchair with Lonworks architecture.

- Linear speed range: from 0.52 cm/s to 2.35 m/s.
- Angular speed range: from 0.01 to 9.43 rad/s.

An overview of the constructed wheelchair prototype can be seen in figure 8.

4 Results and Conclusions

The communication channel between motor controller boards and user board consists of a simple twisted pair cable and a pair of termination resistors. No specific transceiver is necessary since Neuron Chip itself includes it for this type of channel. Moreover, with an external transceiver other communication channels are possible if necessary (infrared, radio, power transmission,etc.).

Extensive firmware included in the Neuron Chip, combined with the fact that it is programmed in a high level language called Neuron C (derived from standard C), means that control system can be quickly adapted to any configuration change (number and type of modules incorporated).

Different modules are under development at the present time, some of them are: an ultrasonic ranger, an artificial vision subsystem, a voice recognition system, etc. These modules aim to complement the original design by adapting it to the physical peculiarities of users, even to severely handicapped persons. The intrinsic flexibility of LonWorks technology provides a fast modification and adaptation of the whole system to each particular case, simply by using the appropriate module.

One of the most interesting features of LonWorks technology is the possibility of interacting with buildings. LonWorks Network is a standard 'de facto' in home and building automation in U.S.A. Now, system compatibility between the wheelchair, as a mobile robot, and the environment close to it can be assumed, where only is needed an apropriate building interface to open door, switch lights on , etc.

Intelligent features included in the system permits the chair to cover certain distances in autonomous driving mode, without needing any intervention from the user. This performance could be of interest in hospitals, recreation centers, etc, because it allows the following of prefixed routes.

The work carried out has managed to apply LonWorks technology to a field with as much scope as that of mobile robots, obtaining a reliable, low cost system easy to install, upgrade and re-program, flexible, and user friendly.

Acknowledgments

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