Communications system based on CAN and extended with optical fiber for the implementation of a mobile robot immune to the sabotage provoked by electromagnetic noise

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A new communications system based on CAN is presented in this work. This system has been implemented to interconnect the different devices that compose a mobile robot, able to operate in environments with elevated electromagnetic noise, being even tolerant to sabotages provoked by means of high electromagnetic fields.

The system is based on a shielded communications hub, that interconnects diverse nodes by means of CAN. On the other hand, the point to point communication between each node and the hub is carried out by means of economic optical fiber. With this approach all robot devices are connected by means of CAN, although a optical fiber arrives to each device. In this manner, the total immunity to the electromagnetic noise that the optical fiber transmission presents has been added to all the advantages of a system interconnected by means of CAN.

The communications system has been installed in the mobile robot obtaining highly satisfactory experimental results.

1 Introduction

The aim of this work is the development of a high dependability control architecture for a mobile robot. This system has been implemented as a distributed architecture with several fault tolerance capabilities. This will improve the reliability of the whole system.

Due to the application characteristics and requirements of the vigilance and tele-operation robots, it is necessary to provide some special characteristics that allow the robot to operate in adverse conditions. Indeed, on one hand, in most of industrial environments there are great amount of electromagnetic fields of high intensity and great variability that may cause malfunctioning to the computer systems. On the other hand, in certain applications of vigilance and security, possible "attacks" by means of electromagnetic noise with the objective of sabotaging these security systems must be prevented. For these reasons, it is necessary to provide the robot with different techniques that guarantee a correct operation under different "aggressive" environments.

In this paper, the communications system that has been implanted in the robot is studied in a detailed way, being proposed an architecture for this system that solves the described problems, without an excessive over-cost.

Due this requirements, it was considered interesting the use of optical fiber, because of its high immunity against the electromagnetic noise.

In addition, CAN network was selected to implement the robot because of its exceptional characteristics, deeply confirmed in industrial control applications. Furthermore, CAN network offers an easy and simple implementation of distributed control systems, due to the quantity of components available in the market and the great experience accumulated for the development of CAN based systems.

For this reason, in this paper an implementation of CAN over optical fiber is proposed.

There are few real implementations in which CAN nodes are interconnected by means of optical fiber. In many cases they are concrete solutions [1] or only one part of the system in which coexists twisted pair CAN with the optical fiber [2].

On the other hand, some manufacturers consider the implementation of optical fiber based physical medium, although these solutions are not very extended because of its cost [3]. Trying to achieve a high immunity to electromagnetic noise we can find designs like [4] that uses the transmission with optical fiber to avoid this problem. Anyway it is a very concrete system, designed for a complex application. In the mobile robots area there are few implementations based on CAN, and the communications network usually uses other standards [5]. This is due to these designs or prototypes are focused in solve complex control problems and not in the architecture an so on the communications network. For this reason, excellent designs from the control point of view fail when communicating the different modules. In this paper the CAN advantages in mobile robotics applications are shown, and stiller, the advantages of a low cost physical layer implementation with optical fiber.

The paper starts by describing the mobile robot architecture. After discussing the whole architecture, the different elements (central node, communication node and auxiliary node) are explained. In the following section the communications concentrator or CAN-fiber hub is presented, explaining the design and the enhancing dependability mechanisms. The paper closes with the conclusions and the future work lines in section four.

2 Robot description

The proposed robot architecture (see Figure 1) is based on a central node, a communication node and several auxiliary nodes. The central node is in charge of managing the basic tasks that will assure the correct operation of the mobile robot, such as the motion and positioning control. This node is integrated with the Motorola MPC555 microcontroller [6].

This main control node counts with the support of a secondary node that acts as a communication node. This second node can take the control of the basic tasks of the system in case of a failure of the central node.

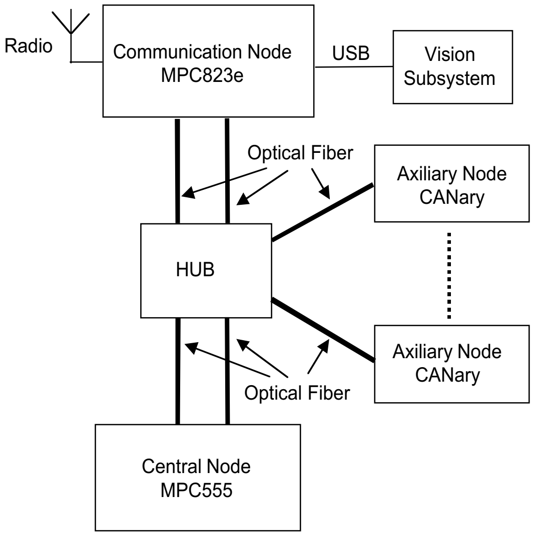

Figure 1. Distributed control architecture for a mobile robot

The main task of the communication node is to establish a communication channel between an external station and the mobile robot. In this way, the external station will be able to tele-operate and monitor the state of the robot. Besides, this node is in charge of receiving and processing the information the vision subsystem sends. A Motorola MPC823e microprocessor [7] manages of the tasks this node.

The rest of the tasks, such as the engine control, the sensors and actuators control, the battery charge level, etc, are managed from different auxiliary nodes. The central node will supervise the operation of these nodes. Each one of these auxiliary nodes is under the control of an ATMEL T89C51CC01 (CANary) microcontroller [8].

The central node, the communication node and the auxiliary nodes are interconnected by means of a plastic optical fibre net. The communication among the different nodes is performed under the Controller Area Network (CAN) communication protocol. This network will be duplicated between the central and communication nodes to tolerate transmission failures on one of the cables.

Each one of the nodes the distributed system consists of will be specified in detail in the following sections.

2.1 Central node

The central node of the control architecture has been implemented on a Printed Circuit Board (PCB) designed by our group. This PCB is based on a Motorola MPC555 microcontroller. His dual TouCAN allows the implementation of a dual internal communication network. In this way, it is possible to tolerate the failure of one of the two optical fiber cables. The internal communication among the nodes of the robot can continue using the other CAN network. The TPUs have been very useful to implement in an easy way the Pulse Width Modulation (PWM) control of the mobile robot engine.

The power stage of the mobile robot engine. The robot motion control will take place in this central node, taking into account the information that the vision subsystem and the different kind of sensors of the robot are sending.

The real-time operating system OSEK/VDX [9] "Open Systems and the Corresponding Interfaces for Automotive Electronics"), which is an standard in the automotive field, has been selected to manage the different tasks this microcontroller has to perform. This operating system has been selected taking into account the main features of the MPC555 the central node integrates.

It has been used an implementation of the OSEK specification 2.1: osCAN from Vector Informatik. This operating system can be profitably used in all areas in which resources such as memory and computing time are in short supply. The main characteristic that presents osCAN, apart from the numerous processors it supports, is the availability of different CAN communication protocols. This feature is very interesting in our case.

2.2 Communication node

The communication node has been implemented using a commercial board, STK823L from TQ-Group [10]. This board integrates the Motorola MPC823e microprocessor and all the necessary connectors to use the different peripherals this microprocessor can manage.

The MPC823e microprocessor is a versatile combination of microprocessor and peripherals, all integrated in a single chip. It is a low cost version of the MPC823 microprocessor that has been improved by means of additional communication and video capabilities. This microprocessor consists of a high-performance embedded MPC8xx core and a communication processor module that uses a RISC processor specialized in communication and image processing. This second module can perform embedded signal processing functions for image compression and decompression. It also has seven serial channels: two serial communication controllers, two serial management controllers, one I2C port, a USB channel and a serial peripheral interface.

This node must perform the following communication tasks:

- Communication with the central node. This communication will be performed using the two different CAN controllers the board has. This dual CAN network will support the failure of one of the optical fibre cables. In this way, the communication node can take the control of the basic tasks to manage the robot in a degraded mode in case the central node fails. In normal mode, it can act as a watchdog processor and supervise the correct execution of the tasks of the central node.
- Communication with the vision subsystem. This communication takes place via the available USB channel. The vision subsystem sends the captured images or the image processing results to this node to perform different tasks such as the 3D map generation, environment motion detection, among others.
- Communication with the external station. This communication is performed by means of a radio card using the available PCMCIA channel. In this way, the robot can send/receive data to/from an external station (usually a PC), and this station can received the sequence of images the robot is taking, can assumed the manual control of the robot, can monitor the state of the robot, etc.

The operating system RT-Linux has been chosen to manage the different tasks this node must perform. One of the reasons to choose this real-time operating system is that it implements a large number of the drivers necessary to manage the different controllers this node has (USB, PCMCIA, etc).

Due to the capabilities of the microprocessor and operating system used, it will be possible to connect a LCD display and a keyboard to the robot and reprogram its functionality when needed.

2.3 Auxiliary nodes

Each one of the auxiliary nodes has been implemented on a PCB designed by our group. This PCB integrates an ATMEL-CANary microcontroller, the T89C51CC01 is the first member of the CANary family, a family of 8-bit microcontrollers focused on can network applications. It offers a high-performance and flexibility in application domains such as industrial and automotive control. It maintains its compatibility with the 80C51 and offers a superset of this standard microcontroller. It is fully compatible with the standard CAN 2.0A and 2.0B.

The auxiliary nodes are in charge of performing a specific task in the global architecture of the robot, such as the engine control, the battery control, etc. Each one of these tasks is implemented by means of a control loop directly programmed on the board microcontroller. Since these are very simple tasks, it has no sense to overload the processing in this node with an operating system or a microkernel.

3 Description of the communications hub

As can be observed in the figure 1, the whole interconnection of the different nodes previously described is carried out by means of point to point optical fiber links among each device (node) and the HUB, being carried out inside the hub the interconnection with CAN. In this manner, under the denomination of HUB it is considered the developed circuitry in charge of implementing a CAN network that interconnects all the system nodes, being the connection with this nodes by means of optical fiber links.

As figure 2 shows, in any system the connection of a node to the CAN network is carried out by means of the corresponding transceiver that connect the UART to the network, both components can be integrated in the microcontroller that implements the node.

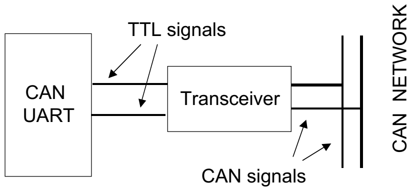

Figure 2. Connection to the CAN network

In our case, in order to use optical fiber as connection element, the interconnection is intercepted between the UART and the corresponding transceiver (implemented by means of a TTL signal) and, how can be observed in figure 3, by means of the opportune optoadapter, the TTL signal is converted in an optical signal that is transmitted through the optical fiber connection, being reconstructed the original signal in the other side of the link.

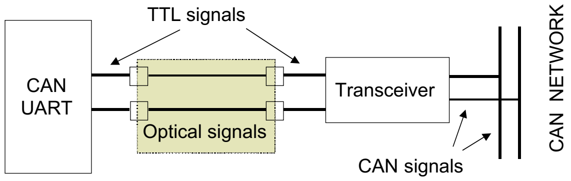

Figure 3. TTL – Optical signal conversion

On the other hand, it is also possible to use this methodology in systems with the output to the CAN network already mounted. In this case the figure 4 indicate how should be proceeded.

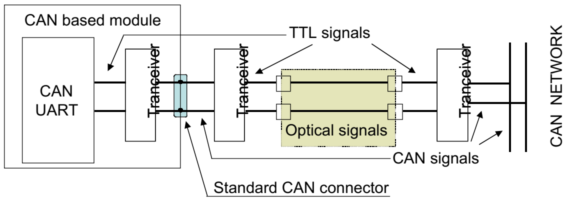

Figure 4. Connection scheme for already mounted systems

Lastly, by means of this method it is possible to interconnect several nodes by means of optical fiber connections in a simple way, establishing a module (denominated HUB), which contains all the transceivers of the system nodes and the corresponding CAN network. An scheme of the hub is shown in the figure 5.

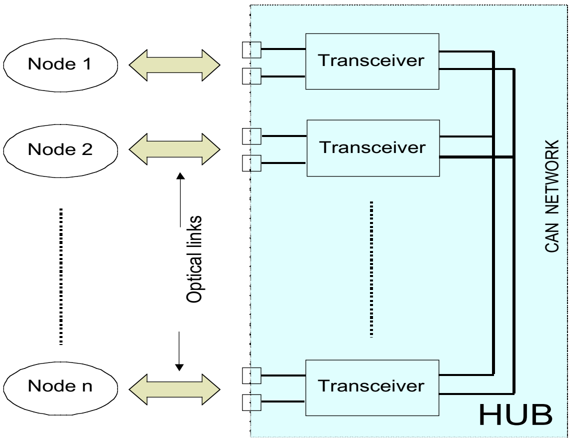

Figure 5. CAN-fiber hub scheme

To carry out the implementation of the proposed system it has been used the optical fiber components corresponding to the "Versatile Link" family of the Agilent manufacturer [11] [12]. The main characteristic of this range of components of plastic optical fiber is its low cost. Concretely the model HFBR-0501 have been used. The HFBR-0501 series includes transmitters, receivers, connectors and cable specified for easy design.

This series of components is ideal for solving problems with voltage isolation/insulation, EMI/RFI immunity or data security. The optical link design is simplified by the logic compatible receivers and complete specifications for each component. The key optical and electrical parameters of links configured with the HFBR-0501 family are fully guaranteed from 0º to 70º C [11].

Other prominent characteristics of this component are: Easy Connectoring Simplex, Duplex, and Latching Connectors; Flame Retardant; Transmitters Incorporate a 660 nm Red LED for Easy Visibility; and compatibility with Standard TTL Circuitry [11].

In [11] can be observed the scheme to use the module HFBR-0501. The configuration to connect the TTL signals that provide the CAN controllers to the transmitter module is shown in the figure 6.

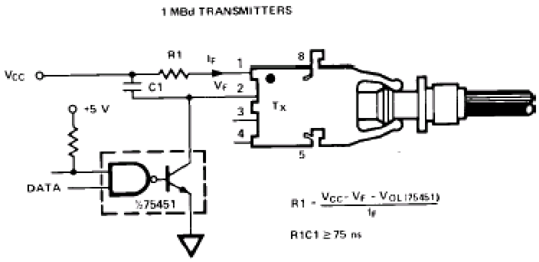

Figure 6. Transmitter module connection

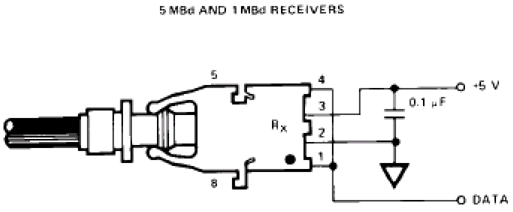

Figure 7. Receiving module connection

Also, the connection of the receiving module follows the connection scheme shown in the figure 7.

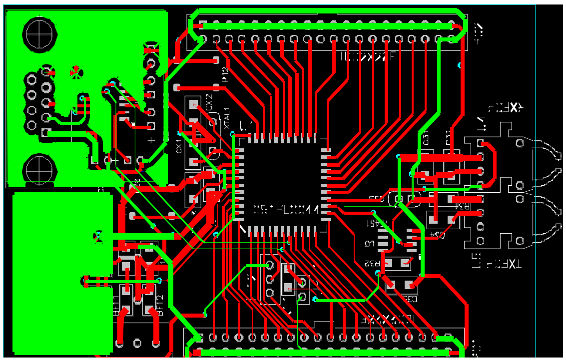

Figure 8. Developed PCB for the Canary microcontroller

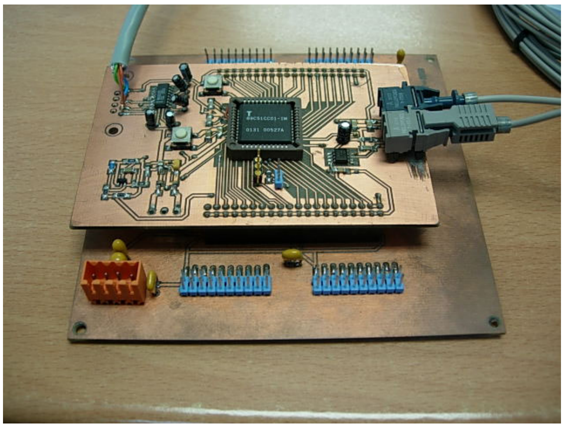

Figure 9. Photography of an implemented node

lines are routed to the receiver and transmitter modules of optical fiber.

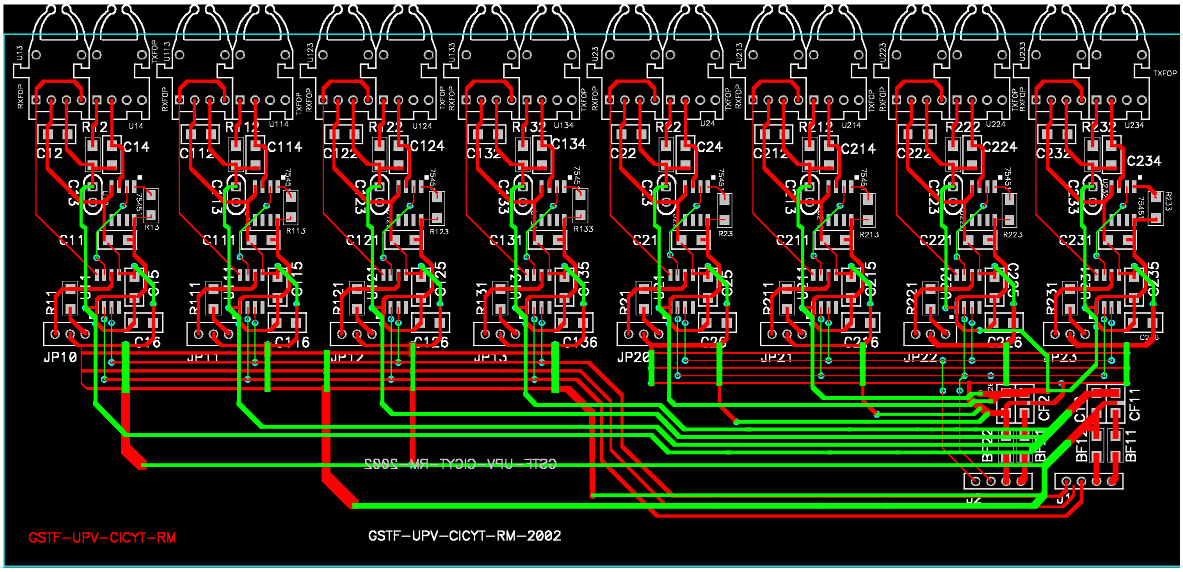

Figure 12. PCB of the developed CAN-fiber hub

In order to build the system of the figure 1 it has been developed different systems based basically on micro controllers of Atmel (CANary 89C51CC01) and the Motorola MPC555, in which the modules of Agilent have been incorporated for the CAN outputs. For example, in the figure 8 can be observed the developed PCB for the Canary microcontroller of Atmel, with the optical fiber outputs, and in figure 9 a photography of an implemented node is shown.

On the other hand, in order to connect the modules corresponding to the MPC555 (main node) and the MPC320 (communications node) to the HUB by means of optical fiber links, and due to the used boards was commercial evaluation boards with the standard CAN output, it has been necessary to develop an adapter. The adapter converts the CAN signal in TTL by means of a transceiver, and finally converts the TTL signal in an optical signal, that will be used to connect with the hub. The PCB corresponding to this adapter is shown in the figure 10, and a photography of his implementation can be seen in figure 11.

In the figures 10 and 11 can be observed the DB9 connector (that fulfils the CiA connections standard) that receives the CAN levels. The CANH and CANL lines are routed to the transceiver (82C250) obtaining the TTL signal again. Finally, this

Lastly, in the figure 12 the developed PCB of the HUB (for 8 connections) is shown.

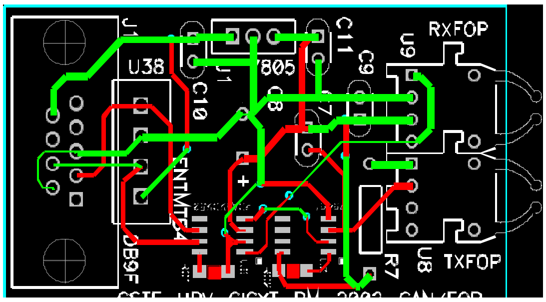

Figure 10. PCB of the TTL-optic adapter

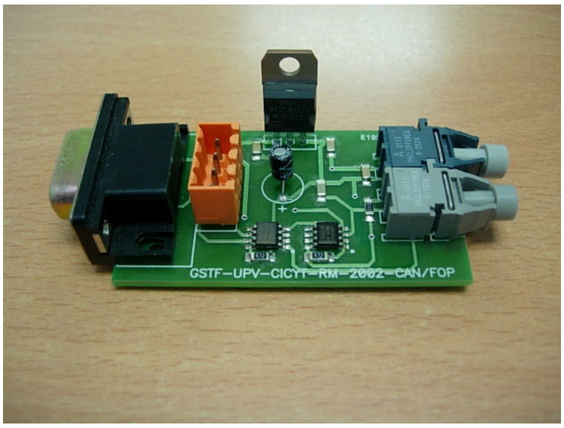

Figure 11. Photography of the implemented TTL-optic adapter

As can be observed in the figure 12, the different nodes (eight in this example) are connected point to point with the HUB. The hub implements the CAN network, in this manner can communicate all the nodes, redistributing the information among all the nodes that compose the system.

4 Conclusions and future work

A new communications system based on CAN and immune to EMC has been presented. This innovative system is fruit of the experience of the Fault Tolerant Systems Group (GSTF) in applications of CAN to critical and fault tolerant systems.

The developed system is based on a shielded communications hub, that interconnects diverse ports by means of CAN. On the other hand, the point to point communication between each port and the corresponding robot device is carried out by means of economic optical fiber, providing to the whole system, in our case the mobile robot, a high robustness to EMC, and therefore provides protection against errors and sabotages provoked by electromagnetic noise.

In this manner the implemented system results in a low-cost, high-performance and robust option for the communications in noisy environments, that incorporates some interesting features and provide all the advantages of a CAN based system, everything with a competitive price.

The communications system has been installed in a mobile robot obtaining highly satisfactory experimental results.

Finally, this technology can be applied to other control systems that should work in industrial environments with high electromagnetic noise.

Acknowledgments

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