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AUTONOMOUS PLATFORM FOR DISTRIBUTED SENSING AND ACTUATION OVER BLUETOOTH

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Abstract: This paper presents a short range wireless network platform based on Bluetooth technology and on a Round Robin scheduling algorithm. The main goal is to provide an application independent platform in order to support a distributed data acquisition and control system used to control a model of a greenhouse. This platform enables the advantages of wireless communications while assuring low weight, small energy consumption and reliable communications.

Keywords: Bluetooth, Wireless communications, Control Architecture, Sensor Networks

1. INTRODUCTION

In this paper we describe the implementation of a short range wireless network, based on Bluetooth technology and on a Round Robin scheduling algorithm, designed to be used in a distributed data acquisition and control system. Such systems are composed of multiple sensors, actuators and processing entities geographically dispersed that interact in order to perform the functions required by the application. In its most basic form, the communication between these elements could be performed by direct point-to-point links, but this approach becomes less attractive as the number of required direct links increases. In this case, the use of a communication network becomes a better solution, as it allows the sharing of the same link by multiple entities.

Due to its strict requirements in terms of delay and loss, the traffic of distributed control systems is normally supported by specific cabled networks which are known generically by the term fieldbus (Decotignie, 1997), of which the CAN (Farsi, *et al.*, 1999) and Profibus are two of the most representative examples. These networks are used

instead of other general local area networks (LANs), like the Ethernet, mainly because the later doesn't provide adequate support to transport the traffic generated by these systems.

In this context, the replacement of conventional cabled networks by a wireless network can introduce several advantages. Cable elimination enables stations' mobility, opening a whole new range of potential applications. Another advantage is that the deployment of the network becomes much faster and easier. We have chosen commercial off-the-shelf Bluetooth (Bluetooth SIG, 2005) modules, which enable fast and easy integration of the whole system.

The application range of this type of systems is huge, with particular relevance on telemetry, monitoring and inspection (visual or other kind) of remote sites and installations.

The developed platform provides functionalities such that the overall control system works as a single entity despite its elements being spread all over. Therefore, the control algorithm may be distributed or centralized as required.

The proposed solution has various desirable properties. Firstly, the communication nodes provide a virtual machine that allows a total abstraction of Bluetooth protocol layer's complexity. We take advantage of this abstraction indirectly by using an application level balanced communications mode on a platform that is intrinsically unbalanced, such as Bluetooth. Secondly, the integrated development of the task scheduler and the application oriented software, characteristic of this solution, enable to optimize the system's overall performance, by avoiding the overhead of a generic operating system as those used by other solutions (Hill, *et al.*, 2004). Finally this Bluetooth based system enables a higher transfer rate relatively to the other sensor networks (Evans-Pughe, 2003).

Among major advantages of this platform when compared to cable-based solutions are: its distributed characteristic, the low cost, the low power consumption, small form factor and cabling elimination.

For demonstration purposes, a model of a greenhouse (see Fig. 1) was used, in which a light lamp was activated in order to raise the internal temperature of the greenhouse and a water valve was activated in order to regulate its interior humidity. Temperature and relative humidity were measured by appropriate sensors. The main idea was to show the flexibility of the wireless network, where acquisition, processing and actuation are made locally. This model allowed the demonstration of all the capabilities of this kind of system, in a very simple manner.

This application set-up was presented at the international fair ENDIEL'2005 (14th National Meeting for the Development of the Electric and Electronic Industries), and was awarded with the 3rd prize in a national competition promoted by the ANIMEE (Portuguese Association of Electrical and Electronics' Companies), regarding innovation and creativity (Santos, *et al.*, 2005).



Fig. 1. Greenhouse application set-up presented at the international fair ENDIEL'2005, which was held in Exponor, in Oporto, between 11 and 15 October 2005.

The platform presented in this paper is also being used to provide communications and control inside

an unmanned aerial vehicle (UAV) (Carvalho, 2005).

2. WHY BLUETOOTH?

Different types of wireless technologies could be used on the platform, each one of them having advantages as well as disadvantages. The ideal wireless technology would be the one having the best performance/power consumption ratio. One other issue would be the capability to handle interference problems.

The most widespread wireless local area network (WLAN) available today is based on the IEEE 802.11 standard. This network is available in multiple physical options, with modulation techniques that range from DSSS (Direct Sequence Spread Spectrum) to OFDM (Orthogonal Frequency Division Multiplexing) and with operating frequencies at the 2.4 GHz and 5 GHz bands.

However, due to characteristics like the design and complexity of the protocol stack of 802.11, it translates into relatively expensive, bulky and power hungry modules. Although these networks can be suitable to interconnect devices like computers, there is an enormous potential market to provide wireless communication capabilities to smaller and cheaper devices running on batteries without the need of frequently recharging. Such devices include computer peripherals, biomedical monitoring appliances, surveillance units and many other sensing and actuation devices, such as our platform.

One of these network types is the new ZigBee standard, whose standardization (for the physical and MAC layer) is under the scope of the IEEE 802.15.4 group (IEEE, 2003). This standard aims to provide an extreme low power and low bit rate PAN with the main purpose of enabling sensor networks. At the physical layer, the IEEE 802.15.4 relies on direct sequence spread spectrum (DSSS) to enhance the robustness against interference, and provides channels at either the 868/915 MHz band or the 2.4 GHz ISM band. As in the 802.11 networks, the ZigBee MAC protocol is a contention based CSMA/CA mechanism, but in this case the protocol is optimized for low power consumption.

Another low power and low cost wireless network technology is Bluetooth, which operates in the 2.4 GHz ISM band using frequency hopping spread spectrum (FHSS). At the MAC layer, the Bluetooth devices use a polling based protocol designed to transport both real-time and asynchronous traffic. The polling sequence is controlled by the master node, which can communicate with up to seven active slaves in the same network (piconet). Communication between nearby piconets is also possible. Due to its frequency agility techniques, Bluetooth presents mechanisms that deal smoothly with noise and narrow band interference.

3. PLATFORM OVERVIEW

We have chosen to interface with the Bluetooth stack at an application level, such that all Bluetooth implementation details are ignored. At this level of interface, all communication services are built on top of a Virtual Machine (VM), thus, Bluetooth stack details can be ignored and focus can be maintained on the application itself, despite having some loss of functionality due to the usage of the VM. The manufacturer's VM (ConnectBlue, 2003), implements a wireless multidrop access scheme where all slaves are able to listen to the frame sent by the master, in a point-to-multipoint strategy.

Fig. 2 presents the architecture of the network nodes of our platform. The architecture is microcontroller based, with local storage capacity, especially at the master station. Interfacing logic for local sensors and actuators is available on board. A serial connection is used for Bluetooth radio module local communication

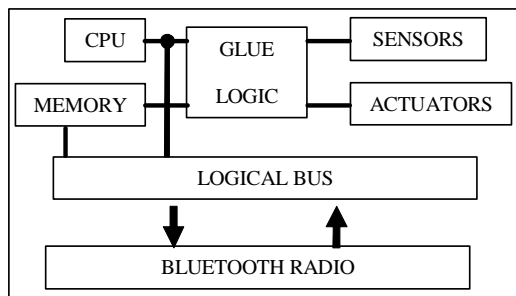


Fig. 2. Architecture of a node of the network.

3.1 Physical Details

The physical part of the platform is built around a low power Texas Instruments MSP430 microcontroller, a Von-Neumann 16 bit RISC architecture with mixed program, data and I/O in a 64Kbytes address space.

Besides its low power profile, which uses about 280 μ A when operating at 1MHz@2,2Vdc, MSP430 offers some interesting features, like single cycle register operations, direct memory-to-memory transfers and a CPU independent hardware multiplication unit. From the flexibility perspective, a flexible I/O structure capable of independently dealing with different I/O bits, in terms of data direction, interrupt programming, and edge triggering selection, two USART's supporting SPI or UART protocols, and onboard 12 bit SAR ADC with 200Ksps rate, beyond PWM capable timers, are all relevant features.

The Bluetooth modules we use are ConnectBlue OEM serial adapter devices, as shown in Fig. 3. The master unit is an OEMSPA33i module and the slave units are all OEMSPA13i modules, both including an integrated antenna.



Fig. 3. Bluetooth slave module from ConnectBlue.

Fig. 4 displays the physical layout of a slave node. The Bluetooth module is in the upper left corner and the microcontroller is in the center of the board. Since it's only an experimental design, the board layout is not optimized yet. In terms of physical construction, the master node resembles the slave nodes, with the size of the Bluetooth module (which is larger in the master node) being the only visible difference between them.

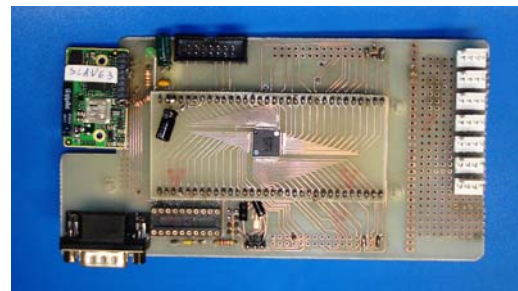


Fig. 4. Layout of a slave node of the network.

The master node is as light as the slaves in terms of computational power, mainly because it's only function was to receive messages from the slaves, process them (which could imply the comparison of the received values) and then send a command message, if necessary.

The module used on the slave nodes (OEMSPA13i), has a limitation, compared to the module used in the master node (OEMSPA33i), which is the fact that it allows only three simultaneous connections, while the OEMSPA33i allows up to seven simultaneous connections are possible. But since the slaves only need to establish one connection (to the master), this limitation doesn't represent a constraint to the system. The modules have the possibility to automatically connect themselves to a determined master node at startup. This functionality, among others implemented in the module's Virtual Machine, allows the system to provide a serial interface to the

microcontroller, hiding the complexity of the Bluetooth stack, so it has only to care about character transmission, reception and processing.

3.2 Logical Details

The logical architecture developed is a two layer state machine implementation. The first layer provides a packet delivery service, under control of master unit, capable of transparently deliver data packets across the network. The first level of this two layer hierarchy is implemented by two state machines: one for the master node and another for the slave node. The basic structure of the master state machine is shown in Fig. 5.

The master state machine has an added flexibility of triangulation, which allows for peering between slave stations. This functionality is implemented in the Forwarder state. From time to time, in RUN state, when Round Robin algorithm needs to send a message to network, condition “message to send” (Msg2Snd) becomes valid and a wireless multidrop message is sent.

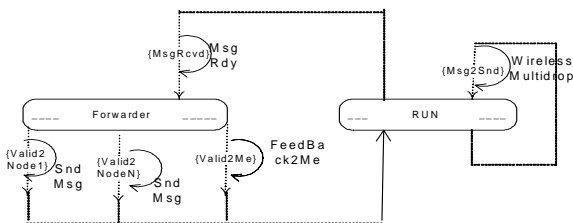


Fig. 5. Basic structure of the master’s state machine.

Fig.6 shows the slave state machine (first level). When a master message is received (MsgRcvd signal), the frame is parsed and a message valid condition (MsgValid signal) is triggered in order to signal application level state machine that a message is waiting to be processed.

It is at this first layer that a Round Robin scheduling algorithm is implemented, in a way that every slave is granted an opportunity to dispatch its packets. This layer is application independent, and interfaces with the top level application layer, using data space for buffering, and a set of signalling control bits, that allow total synchronization between the two layers.

The second layer, the application layer (not represented), is application dependent. In the greenhouse application, the main goal is to compare the temperature and humidity data received from the data grabber node and respond accordingly, sending an appropriate message to the actuator slave device.

This layer is responsible for cyclic refreshing the temperature and humidity values inside the greenhouse, maintaining their values inside parameters specified by a phantom node, which is a PC with some simple software indicating the desired humidity

and temperature. This phantom node is connected to the network through a Bluetooth USB dongle device.

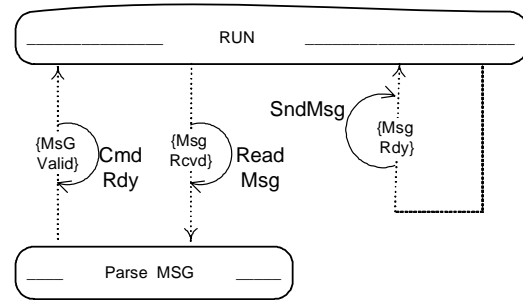


Fig. 6. Basic structure of the slave’s state machine.

In experimental results with this platform and a network topology composed by a master and six slaves, we achieved an average sampling rate of 20 samples/sec, which is more than sufficient for the envisioned application.

4. THE GREENHOUSE APPLICATION

In this specific application a greenhouse controller was designed, using a distributed approach. Master node was used as a communications controller, handling received data frames from the several slaves, and deciding which actions to trigger and where (i.e. in which nodes). Sensor reading and conversion is made locally at each slave, as well as actuation. Master node only function is to receive messages from the slaves, parse them and then send a command message if necessary, to the relevant slave station. These messages, once received by the slaves, are parsed and a local action is taken when needed.

Three slave nodes were used on the greenhouse: one node responsible for grabbing data from a Sensirion’s temperature and relative humidity (RH) sensor, one node to act on a water valve for local humidity control and another one used to control a fan and a heating element to control room temperature. With the exception of the later node, all nodes are free from cables, thus they can be located where is more appropriate.

The first slave grabs data from the sensor through a SPI interface. This sensor, shown in Fig. 7, generates a very specific type of frame for the node to read. The node formats this information and sends it to the master node for processing.

The second slave node has the responsibility of acting on a water valve, and thus regulating the humidity on the interior off the greenhouse. The water valve and respective node, as well as the RH sensor mounting, can be seen on Fig. 8. With a proper message received from the master node, the

water valve opens, increasing the humidity on the greenhouse's interior. The reverse effect is provided by the third slave node, which can raise the temperature by turning on a lamp, thus reducing the interior humidity.



Fig. 7. Sensirion RH and temperature sensor.



Fig. 8. The water valve and RH sensor mounting.

The third slave node actuates in a heater and a fan in order to control the temperature inside the greenhouse. This node switches on the heater (in this case, a 12 Volt lamp) if the temperature is too low, or the fan if the temperature is too high, according to the control message received from the master.

5. CONCLUSIONS

In this work we have described a short range wireless network, developed for remote sensing and actuation, providing wireless communication for a simple greenhouse control application.

The utilization of wireless technology and consequent elimination of data cables removes some constraints verified on other solutions and adds flexibility to the system..

Furthermore, the low power consumption of the nodes of the system is appropriate to applications where long battery is required, such as this case.

The Round Robin scheduling algorithm, together with an application oriented software design and a proprietary operating system, results in an efficient behaviour with low computational power.

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