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Distributed Sensing and Actuation over Bluetooth for Unmanned Air Vehicles

Ezequiel T. Coelho, Paulo Carvalhal, Manuel J. Ferreira, Luís F. F. Silva, Heitor Almeida, José A. Afonso, Cristina Santos

Dept. Industrial Electronics, Minho University, Guimarães, Portugal

Email: cibertech@portugalmail.com, {paulo.carvalhal\mjf\jaa\cristina}@dei.uminho.pt, {lffsilva\heitor}@dem.uminho.pt,

***Abstract* – A short range wireless network platform, based on Bluetooth technology and on a Round Robin scheduling is presented. The objective is to build an application independent platform, to support a distributed sensing and actuation control system, which will be used in an Unmanned Aerial Vehicle (UAV). This platform provides the advantages of wireless communications while assuring low weight, small energy consumption and reliable communications.**

***Index Terms* – Bluetooth, Wireless communications, Control Architecture and Programming, Aerial Vehicles, Sensor Networks**

I. Introduction

In this work, we describe the implementation of a short range wireless network, based on Bluetooth [1] technology and on a Round Robin scheduling algorithm.

The developed network provides wireless communication to a distributed control system of a model-sized aircraft. The final goal is to have an autonomous flight able to carry on different flight missions. We propose a novel approach by mixing a classical control problem with a distributed sensing and actuation platform. The network comprises one network master station, containing also the flight controller, and up to seven slave stations, spread along the aircraft structure.

The developed software builds a logical architecture which accesses the system's hardware through a set of built-in primitives. Basically, we have designed a proprietary and application oriented operating system. We have formulated, designed, specified and implemented the logical structure which supports two state machines acting in the system. Further we have also projected and implemented all the hardware. The state machines interact hierarchically, within two levels. The state machine for the hierarchy's first level is hardware dependent and application independent. It acts as a bearer for data traffic, granting packet transportation on wireless medium. Through an efficient signaling and buffering scheme, this machine communicates with the higher level state machine. At the second level, the state machine is hardware independent but application dependent.

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.

Control algorithm may be distributed or centralized as required. Another innovative aspect of the work is that each of its elements may perform sensing, processing and actuation tasks. Similarly, the proposed solution has various desirable properties. Firstly, the communications nodes provide some management functionalities for their connections, which enable to neglect some of the protocol Bluetooth layer's complexity. 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 [4] [5]. Finally this Bluetooth based system enables a higher transfer rate relatively to the other sensor networks [2] [3].

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

II. The Platform

Fig. 1 shows node distribution of 7 nodes on the aircraft structure. Nodes can be Master Modules (MM) or slaves modules (Sensing & Actuation Modules - SAM). The MM is placed at the body of fuselage and acts as both the network and flight controller. The other six remaining network nodes are SAM. On each wing, there is a node for an electric propulsion motor, and a node for control surfaces like ailerons and flaps. At the tail, there are two more modules for elevator and rudder control. Further, each slave node has allocated other functions not related with the aircraft mechanical devices, for instance, reading GPS and Inertial units, among others.

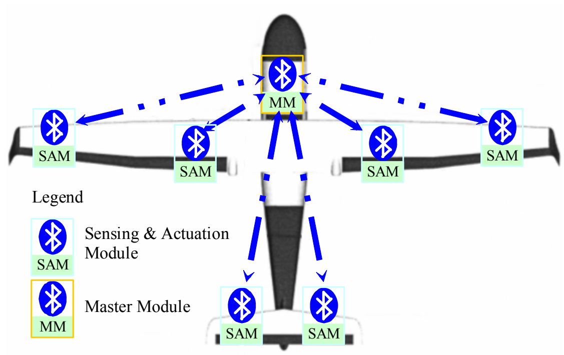

Fig. 1 Node distribution on the aircraft structure

The fact that sensing and actuation control is distributed along the aircraft structure provides some desirable properties.

Firstly, global electronics weight is spread by several points, instead of being confined to a single point. Further, mechanical transmissions for control surfaces, which are servo controlled, are eliminated reducing the overall weight. In fact, mechanical transmissions become local, as the actuating device is located in the vicinity of control surfaces. The same occurs with the sensing elements that are located where required thus reducing some design constraints. Finally, cables along the structure are eliminated, also reducing overall weight.

III. Basic Communication Services

We have chosen to interface with the Bluetooth stack at an application level, such that all Bluetooth implementation details are ignored. Other alternatives exist, that are functionally richer, but expensive in terms of computational effort and design complexity. At this level of interface, all communication services are built on top of a Virtual Machine (VM), but the available functionalities are limited by the Bluetooth modules' manufacturer. 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 [6], implements a wireless multidrop access scheme (see Fig. 2), where all slaves are able to listen to the frame sent by the master, in a point-to-multipoint strategy. The master node builds a frame with information pertinent to all slaves, freeing one time slot for each of the slaves, if compared to a point-to-point strategy. Therefore, time is more efficiently used.

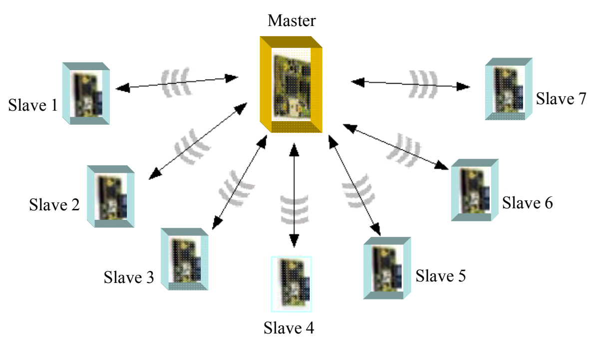

Fig. 2 Wireless multidrop access scheme

This scheme efficiently implements a Round Robin scheduling that simultaneously updates information in all slaves.

IV. Node Architecture

Each network node (see Fig. 3) is microcontroller based, with local storage capacity, especially at the master station, where a solid state disk is built using non-volatile ferroelectric RAM for log and buffering purposes. Interfacing logic for local sensors and actuators is available on board. A serial connection is used for Bluetooth radio module local communication [6].

A. Physical Details

The physical part of the platform, Fig 4, 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.

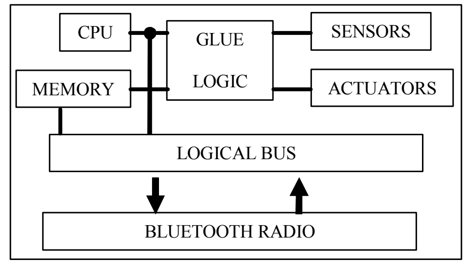

Fig. 3 Architecture of each node of the network

Besides its low power profile, which uses about 280µA 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.

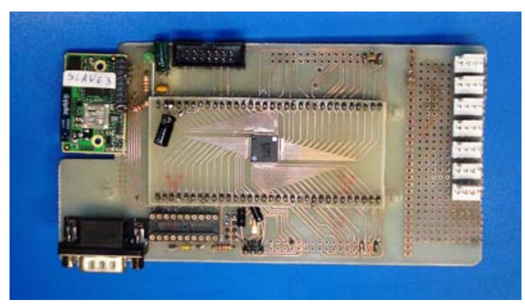

Fig. 4 Layout of experimental prototype physical platform

Relating Bluetooth module, Fig 5, we use a ConnectBlue OEM series device. The master unit is an OEMSPA33i module and the slave units are all OEMSPA13i modules, both including an integrated antenna.

Fig. 5 Bluetooth slave module from ConnectBlue

The Bluetooth's frequency hopping spread spectrum mechanism and its frequency agile capabilities are paramount in order to grant reliable communications by adapting to dynamic spectrum usability conditions during aircraft operation.

In order to communicate with a ground based station, an additional narrow band radio link is installed at the master node. However, because of the current link short range characteristics, that only fulfil this prototyping design phase, it will be upgraded with different technical solutions in future developments.

B. *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. 6.

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.

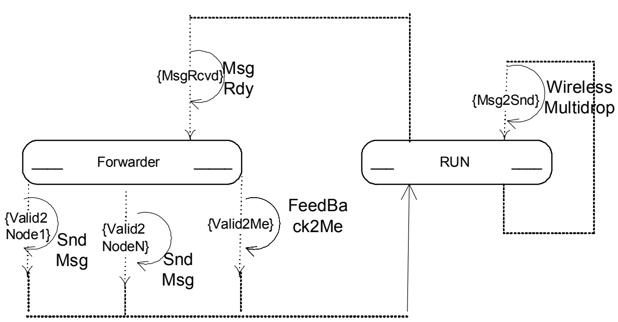

Fig. 6 Basic structure of the master's state machine

Fig.7 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 aircraft application, its main goal is to replicate a system table among all network nodes. This system table maintains all critical system values, describing the several actuators and flight status parameters.

Each network node is mapped to a table's section, where all related variables from sensing, actuators and metering are located. This layer is responsible for cyclic refreshing the respective table contents (based on local status), and also for cyclic actuation according to data sent from the master node (flight controller orders). This way the whole system is viewed as a resident two dimensional array located at master, with different partial copies distributed among slave nodes.

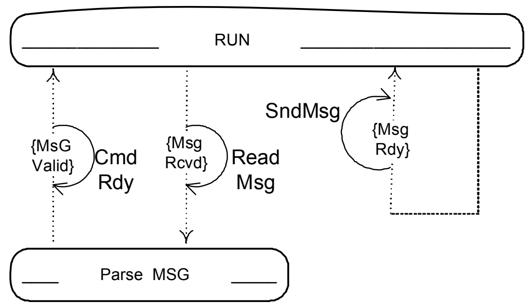

Fig. 7 Basic structure of the slave's state machine

V. Conclusions

In this work we have described a short range wireless network, developed for data acquisition and remote actuation, providing wireless communication for a distributed control system of an UAV.

The utilization of wireless technology and consequent elimination of data cables removes some aircraft design and construction constraints and also lead to a distribution and reduction of overall weight.

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. We are currently performing experiments in a real model-sized aircraft, which provide more rigorous tests of the proposed solution robustness.

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