DISTRIBUTED CONTROL SYSTEMS BASED ON COTS COMMUNICATION DATA BUS

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Abstract: This paper deals with the distributed commercial off the shelf (COTS) data bus based on Controller Area Network (CAN) used as a communication data bus for Autonomous Locomotion Robot (ALR) and a System of Avionics Modules (SAM) that is used in civil aircraft Ae270. This article describes main characteristics of CAN communication data bus and its higher layer protocol CANaerospace that are used in communication system of ALR and SAM. The basic idea of distributed control systems are described and their main characteristics are presented. Developed control systems proved that the CAN with HLP CANaerospace is efficient and reliable communication data bus that can be used in safety critical applications like mobile robots, automotive, and avionics systems.

1 INTRODUCTION

The Controller Area Network (CAN) adapted by Bosch is known as a protocol for high performance and high reliable serial communication links between electronic control units in the field of automotive and industrial control applications. Design of CAN data bus enables distributed system control in real-time with a high degree of transmission security.

Since that prime manufacturers of integrated circuits already implement CAN protocol support into their product, rapid exploitation of this protocol with other applications, e.g. robotics and aviation will take place.

Distributed control, or distributed problem solving, involves the use of decentralized, loosely coupled controllers or problem solvers. The system is decentralized, so that both the control and the data are functionally and often geographically distributed.

Multiprocessor control systems that are characterised with high independence comprise very important area of automation resources. The spine of these systems must include a powerful communication system. Maintenance of the multiprocessor system priority requires a fast, safe, and reliable communication channel. Based on these requirements, the CAN communication device was used (CAN).

2 CAN COMMUNICATION SYSTEM

The distributed control system based on CAN communication data bus allows nondeterministic control in real-time. Matching rate and access method of CAN data bus is specifically adapted for distributed control systems. CAN is based on broadcast communication mechanism which is achieved by using a message oriented transmission protocol. Stations and their addresses are not defined, CAN only defines messages. The message is identified by a message identifier which is unique within the whole network and it defines not only the content but also the priority of message.

2.1 Higher Layer Protocol CANaerospace

CANAerospace (see (CANaerospace)) is an extremely lightweight protocol/data format definition, which was designed for the highly reliable communication of microcomputer-based systems in airborne applications via CAN. The purpose of this definition is to create a standard for applications requiring an efficient data flow monitoring and easy time-frame synchronisation within redundant systems. The defi-

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nition is kept widely open to allow implementation of user-defined message types and protocols.

The data format definition specifies 6 basic message types, which are used for different network services. Each message type has an associated CAN-ID range defining the message priority. The identifier assignment within the specified ranges is at the user's discretion.

Canaerospace features:

- unique identification of message format by message transmitting device identifier and message data type,
- message numbering for identification of message drop-outs,
- critical event signaling to enable each bus-linked device to inform others of its error status
- assigning addresses to bus-connected devices and service priority,
- fixed assignment of identifiers to default data values used in aerospace technology, mechanism similar to that applied to ARINC429 bus,
- easy and unique implementation of CANAerospace protocol simplifies certification process,
- high reliability.

3 DISTRIBUTED CONTROL SYSTEM FOR ALR

In practice, a multiprocessor distributed system consists of several independent processor modules. This structure of control system has been successfully implemented and tried out on the project of autonomous locomotive robot VUTBOT2 (Szabó, 2002), (Szabó et al., 2002), (Szabó, 2003).

Conception of distributed multiprocessor system allows to easily connect next modules into the system without spurious interference to existing hardware and software parts.

The control system consists of three main, mutually relating parts:

1. Multiprocessor control system of undercarriage. The ALR undercarriage control system is divided into several function blocks.
2. ALR monitoring module. This part is used for monitoring internal and external ALR states.
3. Higher layer control module. This system represents input/output communication gate and can be used for specification and monitoring of ALR activities by a master control system.

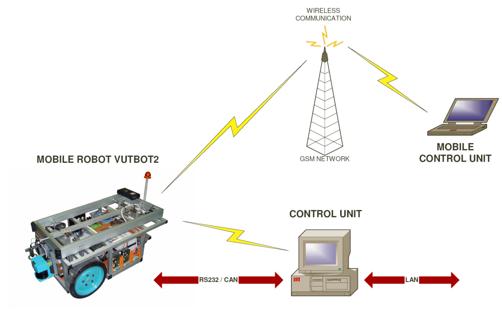

Figure 1: ALR control system.

Multiprocessor control system of undercarriage is divided into several functional blocks:

- Communication module. Module contains radio FM transceiver for wireless communication with manufacturing system.
- Sensor module. An external sensorial system and a laser distance measurement scanner PLS are connected to this module. (PLS device presents the main external sensor in movement control on the working environment).
- Locomotion module. This module supports drive and regulation of DC motors. Front wheel speed difference is calculated (electric differential) based on the required direction. The module allows manual control of motion in a critical situation.
- Control module. The module allows robot motion control according to basic commands describing optimal robot path to the goal position. This module analyses and performs these basic commands that can be extended upon additional demands.

The multiprocessor control system is connected by CAN (CAN) communication data bus with higher layer protocol (HLP) CANaerospace (CANaerospace).

4 DISTRIBUTED CONTROL SYSTEM FOR SAM

The SAM – System of Aviation Modules is a unique open distributed aviation system that performs specific functions onboard the Ae270 aircraft (see Fig. 2) and also provides internal functions for module diagnostics. Each module integrates and automatically carries out specific functions onboard the plane thus increasing the comfort of the cockpit crew when operating and controlling the aircraft. The individual modules can operate independently. Alternatively they can be extended or grouped as required by the customer via a communication bus implemented by means of the CAN (Controller Area Network) serial communications interface standard and the HLP (Higher Layer Protocol) communication protocol within the CANaerospace standard.

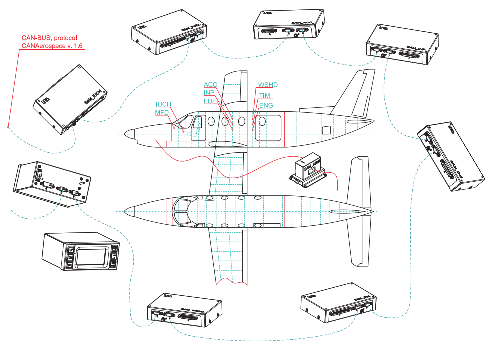

Figure 2: SAM modules onboard the Ae270 aircraft.

The hardware and software resources have been developed using elementary function blocks shared in general by the individual SAM modules. Universality and modulability of SAM system insures compatibility with other civil airborne applications.

Short description of each module in SAM is given in Table 1.

Table 1: Description of individual SAM modules.

Module	Functional description
SAM_IUCH	Electric power supply control module
SAM_TIM	Timer, fuel distribution and de-icing module
SAM_WSHD	Windshield heating module
SAM_ACC	Y–load factors monitoring module
SAM_INP	Module of inputs
SAM_FUEL	Fuel distribution control module
SAM_ENG	Engine monitoring module
SAM_MFD	Multifunctional display module

The SAM was primary developed for use in the Ae270 aircraft, but it can be used in any other avionics system. The SAM was developed in accordance with RTCA/DO-254 and RTCA/DO-178B standards. Compliance of these standards during the development cycle is required by a certification authorities for a type certification issue.

4.1 Evaluation of CAN Data Bus in Ae270 Civil Aircraft

Implementation of SAM distributed control system based on CAN communication data bus into the Ae270 civil aircraft was one of the first similar projects in the world. Therefore certification authority requires many simulations and tests to be performed to verify usability and reliability of CAN data bus as communication bus for control system used in civil aircraft.

4.1.1 Bus Load and Bus Response

For bus load and bus response evaluation the mathematical models were designed. The detailed formulation of these models can be seen in (CRI2).

Bus load evaluation was performed for three basic screens of the SAM_MFD module. These screens are labeled HOME1, HOME2, and HOME3 and results are shown in Figure 3.

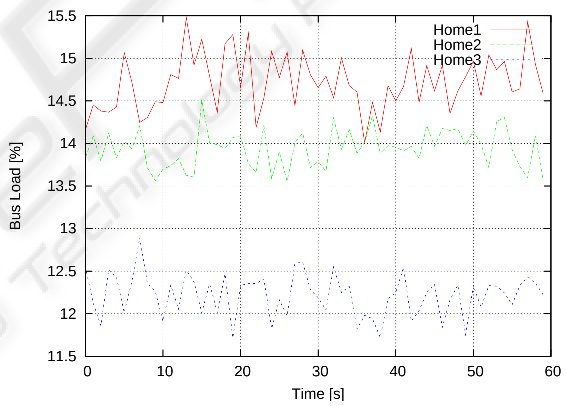

Figure 3: Bus load for three basic screens of SAM_MFD module.

Mathematical model was verified by measurement during real operation using CANalyzer (CANalyzer) and measured results match theoretical results well. From presented data results that average bus load is less than 15 % even during the occurrence of error messages on the bus, thus bus capacity for SAM is more than sufficient.

Bus response means time that pass from data insertion into the queue to their receiving by a receiver.

The results obtained from mathematical model are shown in Figure 4. The figure describes relation between CAN identifier, which designates the message priority transferred on CAN bus, and calculated time response.

From the given findings results effect of message priority identifier on prolongation of bus response, but

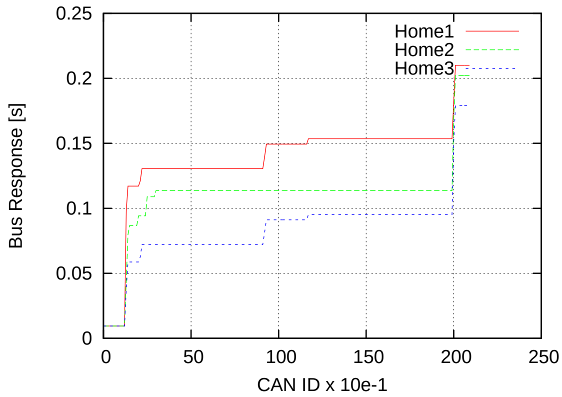

Figure 4: CAN bus response.

during normal operation of SAM modules the maximum theoretical response time can not be achieved.

4.1.2 Bus Characteristics

The basic characteristics of CAN data bus used onboard the Ae270 aircraft are:

- transfer rate 27.7 Kbps,
- average load of CAN bus on Ae270 is 33.9 %,
- probability of undetected message corruption in a CAN network is around $1 \cdot 10^{-13}$,
- probability of undetected failures per flight hours is $2.7 \cdot 10^{-8}$,
- length of CAN data bus is 13.5 m,
- the number of nodes (SAM units) is 8.

System of Avionic Modules SAM was awarded the Gold Medal of 43th International Engineering Fair in Brno, Czech Republic, 2001. In December 2005 the Unis company obtained an approval from Czech aviation authority (CAA) for its System of avionics modules (SAM). Next in December 2005 the European Aviation Safety Agency (EASA) issued a type certificate for an Ae270 civil aircraft produced by Aero Vodochody. Specific functions onboard the Ae270 aircraft is performed by SAM developed by Unis. The type certificate for US market was issued by the Federal Aviation Agency on February 24, 2006.

5 CONCLUSION

During the development project the CAN communication data bus was successfully implemented into the mobile robot and avionics control system. Its performance and reliability satisfy requirements of individual systems and their standards.

The next step for the future will be implementation of CAN communication data bus into more complex robotic systems like a manufacturing robotic system. Performed tests on SAM proved CAN suitability in advanced avionics systems.

Type certification issued for avionics system with described communication data bus for use in civil aviation represents one of the first realisation of similar project in the world.

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