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Communication system for a distributed intelligent controller☆

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Abstract

New emerging standards are having an impact on the development and use of industrial controllers. But such developments need a formal approach to design an appropriate device, system or equipment that will cover an industry segment. Communication network design is becoming increasingly complex as more requirements are imposed on them. This paper presents the current status of a joint development project between the Automatic Control and Computer Engineering Department of the Universitat Politècnica de Catalunya, and DESIN Instruments S.A. After an introduction, the Fieldbus Foundation communication model, the initial prototype structure and future developments are presented. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

To create a fully automated manufacturing or processing environment, it is necessary to have communication links between all the machines, devices and computers used in the enterprise. Corporate computers, engineering workstations or process controllers in such an environment have to transmit orders, programs and supervisory data to factory devices, robots, machines, transmitters, valves and other plant or cell devices. However, no single vendor actually supplies all the factory devices, and proprietary vendor components cannot easily communicate with other vendor equipment. Establishing the communication links environment is not an easy task, because the machines have to be well conditioned for powerful communication tasks, and such tasks should be well organized in a global factory management, control and supervision strategy.

In the field of manufacturing systems, the distributed computation technologies motivate scientists and industry to develop modular architectures, distributed and linked through specific networks in contrast to centralized and rigid organizations.

Industrial automation users are moving into a technological era in which integrated, multivendor control systems are a daily reality, while proprietary software and hardware interfaces have become history. Advances in software technology transforms the world of integration into compatible systems and devices by establishing an open connectivity standard, agreed by manufacturers, which should provide plug-and-play communication and interoperability between field devices, control systems, and enterprise-wide business applications, all using general-purpose computer technology in the automation industry. As more systems take advantage of the open software and hardware architecture, manufacturing systems become increasingly open, flexible, and of lower cost. New technologies based on standards now give us a great opportunity to create an integrated software and hardware environment that permits the development of reusable, plug-and-play objects that are interoperable across corporate-wide manufacturing and business applications.

On the factory or plant floor more and better connectivity is needed as more and more intelligence goes to the sensors and actuators, while the whole system needs to be co-ordinated and managed. In a distributed system, there is a co-operation between many devices that are geographically distributed. Designing a distributed system requires dealing with the real structure of the industrial site where it will be applied. The site interconnected subnetworks are usually independently designed and controlled, resulting in a complex application with many difficulties for accessing, controlling and for even having visibility of data, events

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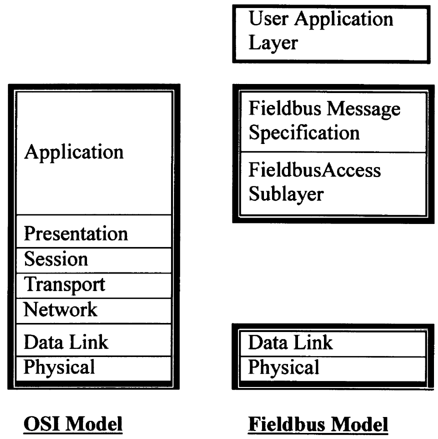

Fig. 1. Fieldbus layered structure.

and general communication objects. For a given implementation, some kind of homogeneity in terms of response times, synchronization, data coherency, and temporal consistency should be considered. In particular, the restrictions imposed by the real-time characteristics of such systems [1–4] configure the main limitations of industrial networks.

The development of control distributed system requires a multidisciplinarity, where different methodologies and knowledge can bring together the best use of hardware and software platforms presently in the market, together with the emergent paradigms and technologies seen in the most advanced theoretical and applied research. Some of the new abstract concepts that appear under such architectures are known as holonic and fractal systems, scalable, bionic fabrication, extended and virtual manufacturing, etc. All of them reflect their autonomous and modular character, similitude with living organisms, flexibility in their dynamic reconfiguration and also operation ability under degraded conditions and fault tolerance.

The common propriety of these systems, referred to as technical aspects, is based on topological considerations, real-time operation, distributed intelligence and microcontroller module's design, with the ability to operate in mutual co-operation. The topological considerations refer to devices and equipment shared in a working area, which can be extensive and in difficult environments. The real time operation is characterized by strict reaction and response time constraints in a fast changing environment. The ability to operate in mutual co-operation refers to information distribution and sharing, with real time constraints, between the plant devices.

The existence of different Fieldbuses caused a conflict for designers and users of industrial automation systems. A Fieldbus is a complex communication system for industrial use that is optimized for specific application demands. There are already many standardized factory and plant floor networks like CAN, Fieldbus Foundation, HART, Interbus-S, P-Net, Profibus, WorldFIP, and some others, with a crude competence in between, due to the high commercial interests involved. Even when a fair specialization with these networks exist, the frontiers are far from clear, and services and characteristics are mixed and sometime less understood. However, in the area of Instrumentation for Process Control there is some consensus in that the International Electromechanical Commission (IEC) will produce an industry communication standard in which the competing Fieldbuses will migrate to (mainly lead by Fieldbus Foundation, with strong links to Profibus-PA, HART,and WorldFIP) [5–7].

This is the main reason why we chose the Fieldbus Foundation as the Fieldbus communication network for the ongoing project. Up to now, only two of the "three plus one" layers of the communication stack are internationally approved, those that represent physical communication and node link. As these are the layers that require hardware development, while the other layers can be developed just by software, it will be a matter of re-programming some firmware for migrating to the expected future standard.

2. The Fieldbus Foundation communication model

The IEC Fieldbus standard [8], from which the Fieldbus Foundation was inspired, is designed as a three compliant International Standardization Organization/Open Systems Interconnection (ISO/OSI) layers: (Physical layer, Data Link layer, and Application layer), plus an additional User layer that facilitates the abstract transactions of the nodes into a distributed control environment.

Fig. 1 shows that the Foundation Fieldbus layered structure specifies the physical, data link, and application layers, corresponding to the ISO/OSI Reference Model, while also includes a new User layer, special for process control. Layers 3–6 of the ISO/OSI RM are left empty, as usual in Fieldbus communication systems.

The physical layer receives encoded messages from the upper layers, adds or removes preambles and converts messages into physical signals on the transmission medium and vice versa. Fieldbus Foundation H1 specifications are a proper subset of ISA SP50.02 and IEC 1158 Fieldbus standards [9]. H1 was designed explicitly for interfacing smart field instruments to a DCS. It implements the slow speed (31.25 Kbps), intrinsically safe, bus-power options of the Fieldbus standard's Physical Layer. The H2 option will be used for high-speed communication among PLCs. Line signal codification uses a trapezoidal waveform that is less susceptible to noise interference than the more traditional square wave. The encoding method is Manchester II, that permits the clock in the receiver to be extracted from the incoming signal.

The Data Link Layer (DLL) is responsible for allowing all the communication nodes to share control of the network. The DLL uses a deterministic centralized scheduler, the Link Active Scheduler (LAS) which controls the node access to the bus. It supports the deterministic cyclic communication (control loop execution) and acyclic communication (alarms, events). The cyclic communication is driven by a list of transmit times maintained by the LAS and by compelling messages at these appropriate times. Acyclic communication is done after LAS grants permission, by passing a token to a device requesting its usage.

The Fieldbus Application layer (AL) encodes and decodes the user layer commands. The services and communication objects for the operation of the protocol are defined in such layers. The defined communication objects consist of data (attributes) and services. Accessing such objects is through an object oriented hierarchical device model. Such structures were inspired directly from Manufacturing Message Specification (MMS) of the Manufacturing Automation Protocol (MAP) project and, in general, we found that AL provided a group of communication services for remote transfers of individual or grouped data, events, status or files, all encapsulated under the Object Orientation formalism. Most of the MMS functions that are associated with data processing were left out, but additional real time functions were added.

The User layer, above the common communication stack, implements a fundamental part of the distributed control strategy by including Function Blocks (FBs) [10,11], Device Description services (DDs), and System Management (SM). To facilitate the use of standardized devices there is a provision for the support of Device Profiles (DP), which describe the typical behavior of common industrial equipment and devices. The user layer acts as an Application Programming Interface (API), between the customer application and the communication protocol. It represents the implementation of the specification of the protocol software and provides the user with an interface for using the services and exchanging data among subsystems.

Function Block specifications define a set of inputs and outputs as well as a node structure and an alarm/event subsystem for common control system functions. There are software structures that combine data, commands, configurations and programs, for obtaining encapsulated objects. Examples of FBs are: Analog or Discrete Input and Output, PID Controller, Ratio Selector, etc. FBs have one or more principal inputs and outputs, an executable function, and some configuration parameters. Each FB processes input parameters according to a specified algorithm and an internal set of control parameters. They produce output parameters that are available for use within the same FB application or by other FB applications. We can see FBs as standardized encapsulations of control functions that are built into the field devices to achieve the desired device functionality. In this way a Fieldbus device can obtain data from sensors and communicate it to other devices as FBs variables [12].

The inputs and outputs of individual FBs can be connected to specify the communication of data on the bus, while function execution and data transmission can be precisely scheduled to optimize control and communication efficiency. The sequential passing of dynamic time critical function blocking the input and output data is called operational traffic. This traffic and the execution of the FB is scheduled by the system so as to occur on a periodic basis with a minimum delay, thereby achieving optimum closed loop control performance. Scheduling allows the user to control the order and also the frequency of execution of a block. Then it is possible to execute FBs functions at defined intervals of time. The user can combine the executions in the correct sequence using time synchronization. The System Management is responsible for the communication of the universal time throughout the Fieldbus devices. For this reason and, to allow the system control data interchange between them, it is necessary to have an assignment of device addresses.

Device Description services are mechanisms for reading and interpreting the functions and capabilities in a device, under the DD information. Such an information is stored in a prescribed DD language and can conform to a particular Device Profile. Profiles are structured databases with accepted or standardized functions, behaviors and capabilities of device families, e.g. temperature transmitters, electrovalves, angular detectors, etc. With a DD a user can use software tools to learn characteristics such as vendor name, software revisions, available function blocs, diagnostic capabilities, etc. of a given device connected to the Fieldbus.

The Fieldbus specifies management interfaces (system and network management). Network faults and performance are monitored so that problems can be corrected before they become progressively worse. System management is necessary to establish the choice for each network layer. The combinations of these choices are grouped together as “Profiles” (e.g. “process control”, “factory automation”, “SCADA”).

Some characteristics and benefits are derived from the communication model that we have described. The time required for engineer and operator training can be reduced, as with the use of the functional blocks, they will be able to solve problems and to program the control equipment in a standard way. Another key point in Fieldbus is the interoperability. The interoperability allows a host application to be purchased from a manufacturer other than the field device; all devices can be monitored and controlled using a single application and the user can change or add a new Fieldbus compatible device to the network, independent of the manufacturer. Other benefits of Foundation Fieldbus include reduced wiring, using multiple variables from a single field instrument, simpler integration and easier maintenance, greater manufacturing flexibility and productivity, higher quality products and improved regulatory compliance.

3. The distributed intelligent controller

The general structure of the FCS 8000 distributed

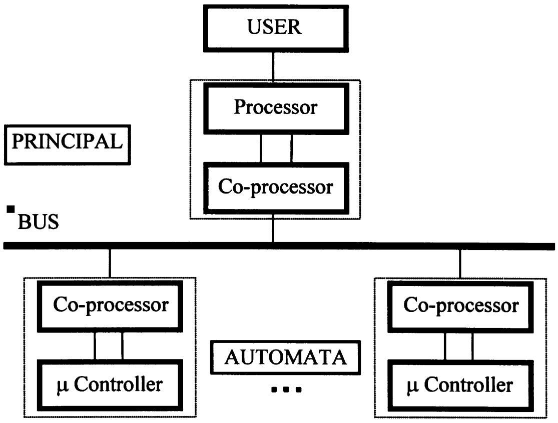

Fig. 2. Structure of the distributed system.

intelligent controller is based on an autonomous industrial controller or automata with capabilities for configuring, accessing analog and digital I/O process data, intelligent multiloop algorithmic processing (PID, etc.), auto-tuning of internal operational parameters and some other distributed functions. Here we will concentrate on the description and guidelines of the development of the FCS 8000-system communication model.

The general structure of the distributed system is shown in Fig. 2, where there is a Principal node with a user application (p.e. MMI, SCADA, etc.), and remote nodes linked through a communication media driven by a communication co-processor. The different interfaces between each one of the communication subsystems is also shown.

The development of the previous model has different alternatives as the possibilities and performances are becoming complex. Fig. 3 shows three ways for connecting the Principal node to the network, depending of the system demands. The lowest performance is for the RS-232 to Fieldbus external adapter, while the highest performance is by designing a proprietary PCI design. The intermediate performance is obtained by using a commercial PCI as a PC communication co-processor. In the field side of the design, we devise an adapter for the Fieldbus communication that takes advantage of the Modbus (Modicon) communication channel of the standard FCS 8000, while at a later stage

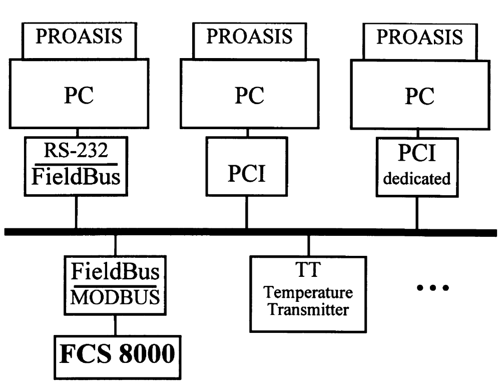

Fig. 3. Communication system alternatives.

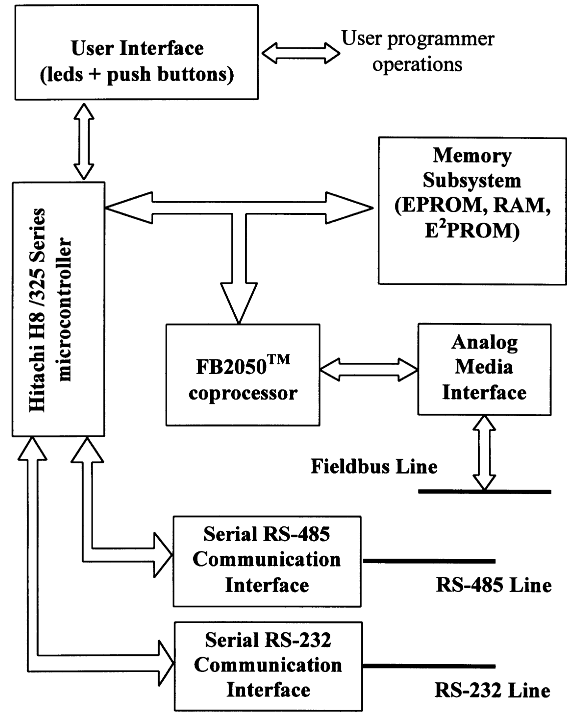

Fig. 4. Fieldbus–Modbus prototype.

such an adapter could be implemented as an internal co-processor.

Actually a prototype of the Fieldbus–Modbus communication system is present at the department laboratory, which is shown in Fig. 4. Such a module has some interesting properties as it includes scratch RAM and ROM memory and alternating modes of operation depending on the particular development and test objectives. The system can perform different types of tests as it is connected already to a Fieldbus Foundation complete system. Such a Fieldbus Foundation network has a Master station running a FbView bus explorer and some other network nodes as Temperature Transmitters (TT, Fieldbus device with Fieldbus communication capabilities).

The communication software for the three upper layers is being developed and tested under Hitachi microcontroller programming language for the Fieldbus–Modbus gateway. Next step is the design and test of the complete FCS 8000 distributed system options.

The main characteristics of the Fieldbus physical layer interface correspond to layer 1 of the IEC model. It receives encoded messages from link layer and converts them, after adding a preamble and two delimiters to the data message, to physical signals on the Fieldbus transmission medium. The communication controller auto-detects frames coming from the network and checks them to ensure that there is no error in the Manchester coded signal. An Analog Media Interfacing acts as a Network Interface in order to electrically isolate the circuitry and correct the symmetrical wave form into valid signals for transmission and reception. In

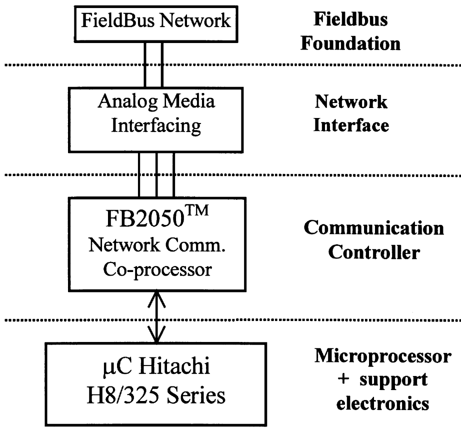

Fig. 5. Prototype structure.

addition to the use of the FB2050™ [13] Network co-processor, the microcontroller Hitachi H8/325 (Fig. 5) manages the data link communication protocol and application layer capabilities.

4. Conclusions

Over the past generations industrial networking has edged out of the pure networking arena to support application needs more closely. Even when the different industrial networking technologies coexist, maturation of competing protocols will allow only those systems to survive that are best adapted to advanced distributed intelligent systems with intelligent end nodes and high level, flexible and modular industrial networking schemes.

The technological approaches discussed in this paper are those of the IEC Fieldbus standard and Fieldbus Foundation system. At the lower level of the layered structure, the IEC 1158 is used, while at the highest level the Device Description and Function Block models based on distributed object oriented technologies are used. By using these object models, a class of hierarchical structures for the components of the distributed system is developed, enabling the preparation of device profiles accessible through remote messaging, whilst also allowing for structure remote settling and programming of intelligent end nodes.

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