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Distribution diagnosis of networked embedded system

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Abstract: The progress in microelectronics allows to integrate, in embedded systems, both digital computation and communication network capabilities. During the last years, smart sensors and actuators, then embedded systems and network sensors have appeared. They lead to development of networked embedded system. These systems have to comply with safety requirements but they are constantly under cost pressure. In introduction to the session on "Low-Cost Safe Embedded Control System", the paper is interested to these news architectures and poses the problem of the fault detection and isolation. It gives different points of view which are considered in the literature for studying the origin of the failure : some works concern only sensors, actuators and physical process, some works focus on monitoring of the network, others sum up the networks in estimated delay, then some problems that are not yet treated are given. (copyright IFAC 2008).

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1 - INTRODUCTION

Scientific and technological progress have widely contributed to the realisation of competitive industrial systems, in various domains such as: energy, automobile, aerospace, chemical processing, …. These systems are becoming more and more complex and their behaviour is difficult to evaluate when they are subject to disturbances. Disturbances that can lead systems to a failure state, or a non-sedentary state, have a considerable impact on socio-economic stakes related for example to the security of men and materials, the environment and the productivity profit.

These last years, the research works were carried out on the control of the systems and the limitation of the consequences following a failure. A part of these works is devoted to the dependability evaluation and the design of complex systems by respecting constraints on some dependability parameters such as reliability and availability (Maza *et al.*, 2006). Another part of research works concern the Fault Tolerance Control (Åström *et al.*, 2000), (Blanke *et al.*, 2003). The main objective of FTC in automated systems is to equip them with a robust and reliable capability of tolerating process malfunction in order to prevent that simple faults become more serious failures

The technological developments of real-time and distributed control systems, of embedded systems and networked control systems make on the one hand, the systems more and more complex at the level of the Fault Detection and Isolation, but also offer more and more possibilities of reconfiguration and thus, allow to improve performances of FTC. Complexity is due to the need to consider software and hardware aspects of the distributed system, and to take into account fault, as well from physical system, from the devices (smart sensors and actuators), from the communications system, or from the data processing units (microcontroller, PLC, automata...).

This paper is organised as follows. In the next section a short resume of the evolution of automated system from centralized to distribute one is given. This evolution allowed the development of "smart devices" which led to smart sensor and actuator, then to embedded system and to network sensors which are detailed in section 3. Different architectures of distributed automation system are given in section 4. The FDI difficulties of these systems are introduced in section 5 and some conclusions are given on the multidisciplinary requirements.

2 - EVOLUTION OF DISTRIBUTED SYSTEM

The automation engineering has seen several fundamental developments over the last two decades. From a centrally structured architecture where the process controller is coupled with sensors and actuators via link such as 4-20 mA, the automation system evolved during two major stages: The first one is due to the arrival of standardised field bus communication, and gives rises to decentralised automation system in which simple devices communicating by fieldbus. The second one is consecutive to the development in microelectronics and communication systems. The field devices have evolved into intelligent devices producing a shift of automation function to the field devices themselves. The decentralised automation led to distributed systems with local intelligence in field devices (figure1).

The distributed architectures are currently a satisfactory solution to face the improvement of technologies and the development of new equipments. Indeed, the use of networks to allow the components to communicate in the new architectures, offers a best flexibility in design at the functional level (modifying or extending system's capabilities) as well as the hardware level (change or addition of elements in the physical system). Such architectures are now in current use in control applications (fig. 2)

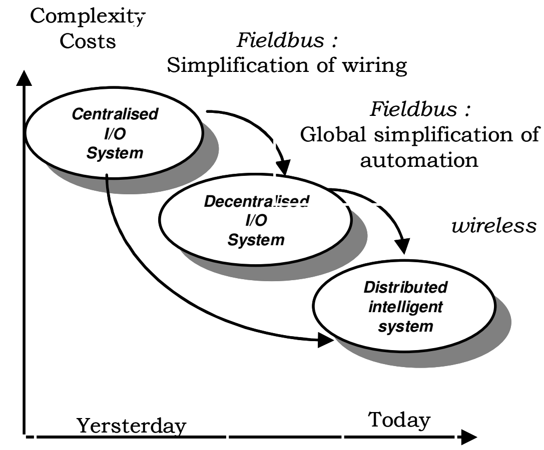


Figure 1: evolution of automation system

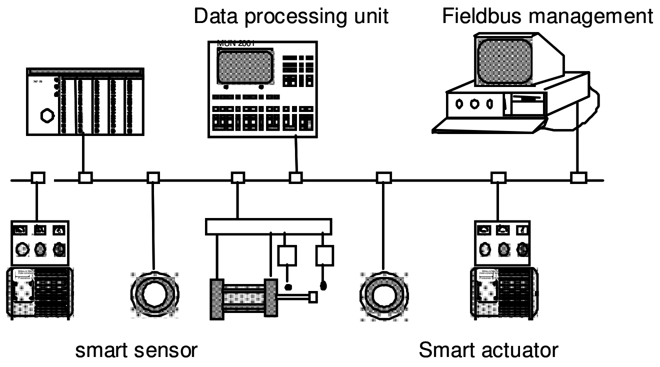


Figure 2. Distributed Architecture with field bus

In parallel, the technology of the office automation based on Ethernet was developed. Little by little, it gained interest for the industrial systems of automation.

The today distributed automation system are characterized by the distribution of hardware, software, and physical components for the control and automation systems implementation, following the trend to distributed intelligence into the controlled plant and to integrate Information and Communication Technologies into automation systems.

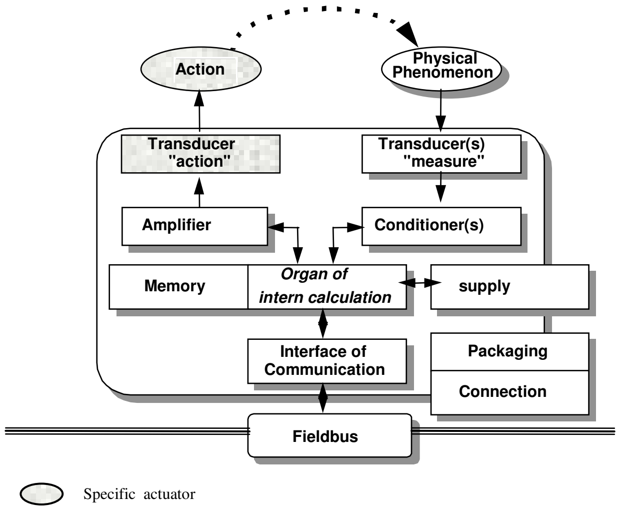
The distributed automation systems are functionally divided into various levels. At the lowest level, the input/output level (I/O level), the network devices (for example, Interbus, CAN, Profibus, …) are in direct contact with the process via the sensors and the actuators, and communicate measurement data to the control level, or receive control signals from the control level.

In the higher-ranking levels, standardized LAN (local area network), such as Ethernet are used to communicate between the control and the management level.

3 - FROM SMART SENSORS TO NETWORKED SENSORS

3.1 Smart sensors

The evolutions of control system due to the development in microelectronics and communication systems lead to the setting up of distributed systems. In the Eighties, sensor and actuators have benefited of these progress. Smart devices were born, their local processing power allows the processed information to be more numerous and increases the possibilities of the global system by giving them new functionalities to process.



The generic architecture of smart device is given on figure 3.

Figure 3: Hardware architecture of smart instrument

At the most basic level, smart sensors and actuators have the ability to communicates information beyond the basic feedback signal. The mean of communication can be a HART signal (superimposed on a 4-20 mA), or a fieldbus, or a wireless arrangement. Because of the need for developing interfaces adapted to each network, various solutions were found:

- a family of smart transducer interface standards intended to give plug-and-play functionality to sensors from different makers has been developed (IEEE 1451).
- to gather some local sensors and actuators on a same interface of communication. This solution is also used to improve the self-diagnosis of sensors, or of smart actuators. “Intelligent” valves for example, include pressure sensors, and debit sensors.

Smart equipment embed in their intelligence, self learning and self diagnosis functions.

Intelligent sensors have numerous advantages. As the cost of embedded computing power continues to decrease, "smart" devices will be used in more and more applications. Internal diagnostics alone can recover the investment quickly by helping avoid costly downtimes. The interest of smart sensors is well known: to provide information that can be gathered from the process to reduce downtimes, to increase operational efficiency, to reduce maintenance costs and to improve quality.

The smart devices include a data processing unit more or less complex, and are able to communicate. They must monitor their behaviour and the one of their surroundings and then, make a decision to compensate for the changes automatically or to alert somebody for needed attention.

The interoperability of a set of sensors and actuators in a distributed application is a real problem : each device can produce or consume data so compatibility between the smart sensor and actuator is required in order to be able to exchange the data contained in the different local data bases. The semantic has to be defined to insure for example that the data contains in a smart sensor memory are those that the actuator requires, the conditions under which an intelligent actuator enters in safe mode must be the same for actuators of same type but from various providers, ... Generic models have been developed to provide a formal representation of intelligent sensors and actuators, they give the basic of a rigorous modelization of the intelligence of the functional model as well as an external view (Staroswiecki et al., 1996).

The syntax has also to be defined. One of major problem is that for the manufacturers of sensors (or actuators), the design of intelligent devices is quite difficult according to the variety of fieldbuses, and the needs of flexibility and standardisation because each fieldbus has each language. In order to give a solution, a standard interface (IEEE Std 1451.2), (Lee K. et al.) has been defined for some fieldbus. In parallel, development tool for design smart devices has been conceived. In (Bayart, 2001), a tool based on the IEC 1131-3 norm (IEEE 1131-3) is used to describe the functions, and a C program is automatically generated. It allows easily realising the software of an application, which will be implemented in a micro-controller in order to obtain smart devices.

External model of smart instruments is also interesting for the software design of these devices. In (Imhemed et al., 2007) a tool is proposed to describe the wanted behaviour thanks to a set of services. According to this behaviour, the final code is generated by a tool that uses a description written with an XML format and produces a corresponding code in a C language. This code aims to be implemented into the instrument after being compiled.

According to the domain of use (robotic, automobile, aeronautic …), the needs of miniaturization and of autonomy, smart equipment evolves towards embedded system.

3.2 *Embedded sysem*

Embedded systems are often described as systems designed to perform one or a few dedicated functions. They are conceived with objectives to optimize these functions, in taking account the constraints allowing to reduce the size, the consummation, and cost of the product, or to increase the reliability. Some embedded systems also have real-time performance constraints, others characteristics can be founding (Albertos, 2007). Their architecture includes limited computer hardware resources, little memory (Hristios-Varsakelis, 2005). They are separated of the devices or sometimes physically built-in to the devices they control. W. Yong, L. Quanli, W. Wei, Z. Zili propose a low-cost Embedded Control System of Step Motor based on ARM7 microcontroller (Yong *et al.*, 2008)

3.3 *Smart sensors networks*

Real time operating system has been developed in order to be integrated in embedded systems. Progress in communication and miniaturization of the data processing system permit the development of new smart sensor, and more specifically of network sensors.

A communicating object is "a physical object interacting directly (i.e. by the means of sensors/actuators) or by the means of communication networks of nature unspecified, with its physical environment, other communicating objects and/or possible human users, equipped at least with numerical storage capacities of state, and, if necessary of digital processing. (Kintzig *et al.*, 2002).

In regarding the preceding definition, one can note that there are a great number of common points between smart devices, embedded system, and network sensors. We will see, in the next paragraph that they correspond to different points of view at the level of distributed architectures.

4 - DISTRIBUTED SYSTEMS

The great advancements in the development of intelligent sensors, powerful microprocessors, and communication protocols led to the development of distributed system that they can have for names: distributed automation system, Distributed Intelligent Automation System (DIAS), Networked Control System (NCS), …. The basic components of these architectures are similar.

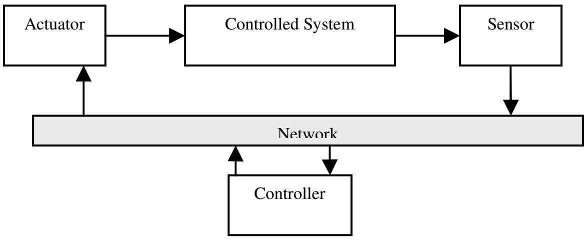


Figure 4: Networked Control System

Another form of distributed system is wireless networked sensors. Such system is composed by hundreds to thousands of elements, communicating by wireless networks and has the objective of data collecting, processing, and disseminating to a point of interest.

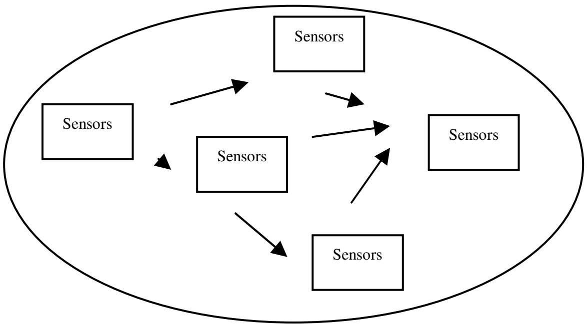


Figure 5: wireless networked sensors

The future networked automation system will integrate the two networks. On the one hand, in production systems, smart equipment with wireless communication can be implanted to obtain complementary measures on difficult access points by limiting cost . On the other hand, in removed control of mobile system, with a wireless communication system to communicate control to a distant system which owns itself an embedded network.

The paper "Embedded Implementation of Mobile Robots Control" of A. Valera, M. Vallés, P. Albertos, R. Simarro, I. Benitez, C. Llácer, illustrates this architecture (Valera *et al*.., 2008).

5 - FDI OF NETWORKED SYSTEMS

Differences are observed on the communication systems in dependability point of view.

Wireless network imposes channel errors, delays, packet losses, and power and topology constraints. However, the research works concern principally the effect of the distributed algorithm on the use of networking resources. The effects of lost or corrupted messages on the performance of the detection or estimation algorithm are often neglected. There is no physical process, because it is often considered that these networks make measurements of the environment.

In distributed automation system, the local processing power brings by the smart devices allows the distribution of the intelligence among all the components of the automation system. The control of distributed automation system, or networked embedded system is the subject of many research works. The control algorithms are adapted to take into account that the feedback loop is closed via a real-time network.

One common point is that network introduces a delay during exchange of information. The types of delay can be classified in two groups: computing times often considered as fixed and delays due to the communication. The times of transmission are a function of the number of connected nodes, of the type of network or of scheduling.

Each smart device generates information about its actual state and about the system, or the environment according to the application. Communication between components can be subjected to two types of initialization: either an initialization on clock, periodical (T-initialization) or an initialization on event or interruption (E-initialization).

In general, delay times are considered between sensors and controller, and between controller and actuators. Three types of times can be considered:

- time related to the network between the sensor and the controller tksc,
- time of calculation for the element tkc,
- time related to the network between the controller and the actuator tkca.

and robust control algorithms are proposed.

The same approach is considered for fault detection and isolation algorithms, and proposals are done with Kalman filters (Zhang *et al*., 2006), (Zhengm *et al*., 2004), (Fang *et al*., 2006).

But one major difficulty is due to the fact that, unlike centralised control architectures, smart instrumentation integrates various parts: physical part, hardware/software part and communication part.

The design of the FDI algorithm as well as its implantation is one of the important problems to be addressed. The FDI studies are often made, on a part of a global system. Indeed, some studies consider only the plant with instrumentation, other ones are interested only in real-time control system, without considering the physical devices, etc.

Few works are carried out FDI methods with the integration of the two aspects i.e., the fault detection and isolation of plant with its instrumentation and the FDI of the distributed control system integrating software and hardware.

FDI algorithms are adapted to take into account the delays, but other failures that can be introduced by fieldbus are not considering. Few works integrate the failures induces by the network, as missing information, silent sensors, … These failures are studied in fieldbus of low level, which have only three layers as represented figure 6, [Ghostine *et al*., 2007).

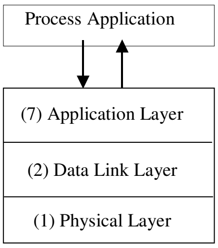


Figure 6: Fieldbus management

For each layer, an inductive approach based on a Failure Mode, Effects Analysis (FMEA) has been carried out. (Cauffriez *et al*., 2004). The FMEA of the failure modes of these three components and their possible causes allows to understand the communication function Let us give some results extracted from this analysis :

a) Physical layer

Failure mode	Possible causes	effects
Non reception of signals by one or several consumers (transmission error)	Perturbation on the medium External aggression	Loss of information
Continuous emission on the network (excessive dialog)	Internal failure of a component	Network overload

b) Data link layer

Transmission of an erroneous frame	-Internal failure of the data link layer -disturbance due to the environment	Information not valid
Arrival of temporally erroneous information	-Non respect of production deadlines -non respect of transmission deadlines	Temporally invalid information

c) Application layer

Non detection of the appearance of a station	Error of configuration	Loss of all the produced information

A framework to enable the analysis of the influence of the transmission faults on the reliability of a networked control system is given in (Ghostine, 2008). The use of networked cascade control structure is proposed in (Galdun, 2008) in order to increase reliability.

Another aspect that is not considered in study of Fault Detection and Isolation is the load of communication network caused by the distribution of FDI algorithms.

The distribution of the automation system among all the components allows considering them as a connexion number of intelligent objects which produce or consume information via a communication system associated with global objectives, and thus global management rules.

The exchanges between components require the validation of the transmitted and received data. Several levels of validation of the information are defined:

- The first one is a technological validation .In this level, we have to distinguish two parts :

- the technical validation links to the device; it concerns the conditions under which the information has been produced. Smart sensors can easily integrate this level.

- the technical validation of the communication, which concerns the condition, under which the information has been transmitted.

- The second one is a functional validation which interests in the content of information and uses Fault Detection and Isolation software.

The real problem is thus to define how the FDI algorithms have been implemented?

In each intelligent unit connected to the network, we can distinguish three sets of variables:

- a set of local variables, those that are produced and consumed on the inside of the device
- a set of produced variables, among those variables, some are transmitted to other smart devices.
- a set of consumed variables, i.e.; variables which are transmitted to the device i.e. by the communication network.

The distribution of the Fault Detection and Isolation procedure among the various local units, (smart sensors and actuators, embedded system, …) has an impact on these sets of variables, and consequently on the load of the network and so, on communication. Consequently, performances of FDI algorithms have to be evaluated according their implementation.

6 - CONCLUSION

Advances in hardware and network technologies have created low-cost, low-power, multifunctional miniature sensor devices, and have considerably improved automated systems from the performances and the productivity of industrial and automated systems, but have also introduced additional constraints about FDI/FTC, due to more complex architectures associating to the physic layout, smart devices and communication networks.

This paper aims at making a short review of the evolutions in automation system. Numerous works and results are available on FDI techniques by considering only a part of the system, namely the process and its instrumentation,or the network, or the calculators dedicated to control. However, actual industrial systems are too complicated to be considered only as one process with its instrumentation (sensors and actuators), and a failure of the system (or a part of it) can have many origins. Consequently, there is a need to develop tools and new approaches in order to consider all of those system's entities and the interaction between them.

Efforts are made in the automatic community and computer community toward each other, in order to answer to the problems to which the designers are confronted nowadays. The research works should progress in this direction, i.e., in considering the whole complex system, in order to improve its performances and the factors of dependability . The first step must consist to unify the used vocabulary in the different research communities, and then, to combine the various manner of thinking in order to obtain global methods for the design of safe intelligent distributed automation system.

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