A Profibus-based Control System for Nuclear Physics Applications

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ABSTRACT

In this paper we present the results of implementation of a remote control system based on ProFiBus technologies used for the remote control of experimental nuclear physics apparata. Remote control makes experiment handling more flexible, eliminating any problems originating from the need for direct access to the systems being controlled. In the paper we describe two different applications. The first application of the ProFiBus is the remote control of a multidetector (made up of a bi-dimensional array of CsI scintillators) used to detect light nuclear particles, as protons and/or light ions. In the second application, we present an implementation of the control of a vacuum system suitable for a special chamber used for the development and testing of particle detectors operating in vacuum conditions.

Keywords: Nuclear physics, Profibus, sensors, vacuum system, PLC

1. INTRODUCTION

The spread of digital electronics and new networking technology has strongly modified the techniques and methodologies used in process control. Particularly today, the demand for distributed process control involves intelligent systems, control devices and measurement systems able to communicate through the network. An important requirement of these systems is the need for a reduction in connections, thus simplifying system management and decreasing maintenance problems. FieldBuses can provide a valid solution for remote control in industrial production and measurement and acquisition systems, which are widely applied in experimental research in nuclear physics.

This field of research requires distributed remote control apparatus capable of working in very hard operating environment (strong electromagnetic fields, damage by radioactive particles, low temperatures etc.) and at the same time meeting the necessary safety, reliability and simplicity requirements. The presence of a large number of devices makes it difficult to perform remote control of the whole system. Many devices must be controlled locally and this requires frequent access to the site of the experiments. Unfortunately, the environment during nuclear experiments is not safe; so it would be very difficult for a human operator to reach quickly the experimental equipment in order to tune the required parameters. For this reason, the use of a FieldBus is a valid solution since it provides tools for implementing a remote control system: the ProFiBus (Process FieldBus) is a communication system widely used in the world of industry and is highly suitable for this aim.

In this paper we present the results of implementation of a remote control system based on ProFiBus technologies used for the remote control of experimental nuclear physics apparata. Remote control makes experiment handling more flexible, eliminating any problems originating from the need for direct access to the systems being controlled. In addition, a nuclear physics experiment often requires the assembly of systems of considerable size, thus making frequent access to the many devices involved onerous and not always possible. In the paper we describe two different applications.

The first application of the ProFiBus is the remote control of a multidetector (made up of a bi-dimensional array of CsI scintillators) used to detect light nuclear particles, as protons and/or light ions. The mechanical setup has to be moved in real time, without suspending the beam operation, with very high precision in three different directions, hence requiring the remote control of three electrical motors. Through the Profibus we implemented the remote control of the mechanical setup with simultaneous on-line monitoring of the every detector's position. This application allows us to appreciate the potential advantages in terms of both reliability and simplicity which arise from the use of only one bus-based communication system. Our application shows good performance in terms of network speed combined with a sophisticated dynamic interaction between a command console and a remote slave system.

In the second application, we present an implementation of the control of a vacuum system suitable for a special chamber used for the development and testing of particle detectors operating in vacuum conditions. The overall setup includes two vacuum pumps, two vacuum sensors and a Programmable Logic Controller (PLC). The two pumps have to work in sequence since each of them operates in a specific pressure range. The PLC monitors the pressure in the chamber and decides when to switch on each pump. In this application we show how it is possible to combine the characteristics of intelligence decentralization, according to the philosophy of FieldBuses, with supervisor stations, control devices (regulators, PLC, etc.), actuators and transducers that share the same communication bus and interact in various ways.

2. REMOTE CONTROL IN NUCLEAR PHYSICS EXPERIMENTS

As mentioned in the introduction, the apparata used in nuclear physics experiments is often complex, involving a large number of measuring devices (sensors) and actuators. The possibility of handling these devices via remote control has two advantages: on the one hand it allows operators to introduce system modifications without the need to remain in the measuring area, which is often not allowed during experiments, and on the other it allows a large number of variables to be monitored in order to keep under control the progress of the experiment.

The types of information present in the system fall into two different categories of data. One includes plant supervision and control data, which is necessary for the system in order to operate correctly. This information is used to set the operating conditions that will best meet the specifications defined for the effective execution of the experiment. Its dynamic is relatively modest, therefore it can be handled via remote control by using distributed systems. The other category of information includes data obtained via measurements carried out during the experiment itself. The signals are usually obtained at an aleatory frequency and have a very short duration (generally a few nanoseconds or less) ; therefore they have to be recorded in loco by means of dedicated acquisition system and are not suitable to be transferred via Bus-Based communication systems.

The experimental setup we will refer to in this paper is a system designed to study heavy ion reactions, disposed in the ***"Neutron Hall"***. Shown in Fig.1, the structure is managed by the C.H.I.C.(Collaboration for Heavy Ion Collisions) research group and is located at the Laboratori Nazionali del Sud in Catania, property of the I.N.F.N.(Istituto Nazionale di Fisica Nucleare). The laboratory comprises a series of airtight chambers, with observation windows, in which nuclear interferometry experiments are carried out. A beam of intermediate energy heavy ions (10-50 MeV/A) is deflected in the vacuum and conveyed towards the reaction chamber by means of magnetic bending *(see the large electromagnets on the left-hand side of the photo)*. The beam impinges on nuclear targets and the collision products are recorded by various detectors *(inside the black cylinders visible in the photo)* and the data are acquired and analyzed by human operators for off-line handling.

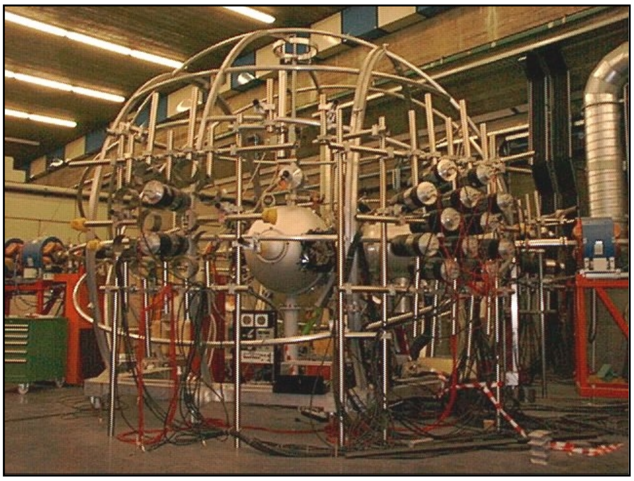

Fig.1: The experimental Setup.

After a careful analysis of the relevant information and the operating modes during the experiment, we decided to confine our attention to the problem of acquiring and distributing the monitoring and control data. We observed, in fact, that this is the part of the experiment that is generally managed in a more traditional way, often adopting oversimplified solutions. Although the approach reflects the concern of those responsible for the experiments to concentrate on measurement acquisition rather than on handling the experiment itself, it introduces a whole series of operational complications that limit the efficiency of the system. This leads to a waste of operating time, which reduces the effective data collecting.

More specifically we made the following observations:

- Currently most of the support equipment is activated manually and located close to the structure;
- During each experiment the presence of radiation that is harmful for both humans and the electronic instrumentation requires the experimental cave to be put
- under safety control; any unforeseen intervention due to faults or other circumstances, requires the beam to be cut and a certain period of time *(from a few minutes up to a few hours)* has to elapse before technicians can safely enter the cave;
- All connections between the cave and the acquisition rooms are dedicated point-to-point connections. This means that there is a large amount of cabling, passing from the experimental lab to the observation lab through shielded walls, which therefore represent a potential radiation leakage point;

On the basis of these considerations, we identified two key points in the setup where the traditional solution introduced a number of problems and prolonged measurement times:

- The support system for a multidetector apparatus comprising 13 CsI light ion detectors, which has to be moved during the various phases of the experiment in order to stay at the different best position both in the calibration and data taking runs.
- The vacuum chamber, which is an essential component of the research since the beam of particles has to move in the vacuum, and heavy ion products are degrading their energy in air. So from the experimental point of view the vacuum chambers represent an important support system for the research as they are used for the development and tuning of the particle detectors.

3. INTRODUCTION OF A FIELDBUS IN THE EXPERIMENTS.

The FieldBus is a well-established technology for process control systems [1] . It is widely used in industrial plants but, in our knowledge, only to a limited extent in experimental applications like the one being described here. Conceptually, a FieldBus is based on a very simple idea: replacing current bundles of cables with a single cable. This simple concept is, however, a great innovation in process control communications systems, providing a whole series of advantages (some direct, others indirect) which are reflected in the techniques and methodologies used to design the plants themselves. The main advantages can be summarized as follows :

1. savings in cabling and installation costs, due to the replacement of bundles of cables with a single cable. This also reduces the number of junction boxes, safety insulation barriers and shunts.
2. easy addition or removal of system devices without the need for new cables for additional devices. This is a key point in the management of experiments which, unlike industrial plants, are continuously evolving dynamic structures where the addition or relocation of sensors is a frequent occurrence.
3. a reduction in the number of connections for devices mounted on mobile parts. This is an undeniable advantage in apparatus (e.g. the arm of a robot or mobile supports for measurement systems) which uses a large number of field devices and for which bundles of interconnection cables would make articulations heavier and more rigid. One of the two applications described here has to cope with this problem.
4. the need for fewer openings in the walls to pass cables. When a lab has to be sealed to avoid leakage of polluting particles, this may be an important point.
5. a saving in cable weight.
6. a reduction in installation errors. In complex systems the problem of human errors on field device cabling should not be underestimated. When hundreds are being used, a wrong connection (due, for example, to confusion between two different conductors) may

be made and it is not always possible to detect the error when the system is being tested. If a FieldBus is used, on the other hand, the various devices are connected in parallel, on the same bus or on different buses, and only the configuration of the system and the application software are responsible for correct routing of the information flows. It is possible to implement software modules that will control the correct setting of the system.

7. a reduction in documentation costs. Although this is not a major item in the overall costs of a plant, the documentation phase is one of the most delicate (in view of subsequent updating of the plant). When updating (as already mentioned, a nuclear physics experiment is highly dynamic) involves variations in the layout of a number of devices, previous schemes and designs require considerable modification; all this can be greatly simplified if a FieldBus is used.

FieldBuses also present typical features that have been optimized for the specific field of application, such as the following:

8. Unlike other communication networks which only provide one-to-one communications, a FieldBus also provides one-to-many (multicast) or one-to-all (broadcast) connections according to the type of information being handled. In some applications, in fact, the data produced by a device may have different uses as modules of the application process located in different places
9. but connected via the FieldBus may need to operate on the same data. The data thus has to be shared coherently by several users.
10. A FieldBus makes it possible to synchronize activities carried out by physically distinct devices connected via the Bus.
11. A FieldBus has to guarantee data quality, by indicating the presence of transmission errors and respecting suitable time windows that meet the time constraints imposed by the process being controlled in order to provide real-time control.
12. A FieldBus can operate in particularly difficult climatic, electromagnetic and radiation damage conditions.

To-day, a large number of different fieldbuses is available on the market. They use different mechanisms for the management of the communication medium. Some of them, as for example Fip [2] use a centralized access control whereas CAN [3], Profibus [4], P-net [5]use a distributed access control. Among all, Profibus has gained a large portion of the market share according to its versatility, engeenering support and marketing network.

4. THE MOTION CONTROL APPLICATION.

The first application presented here concerns the remote control of a movement system with three degrees of freedom for the micrometric positioning of a multidetector includinging 13 CsI light ion detectors. Fig. 2 is a CAD model of the positioning system: it comprises three linear tracks, arranged in the three Cartesian directions; two are of the bar type and are respectively arranged in the horizontal directions x and y, while movement in the vertical direction z is achieved by means of a platform supported by four tracks. Each track is activated by a *brushless* electric motor with a pulse encoder and a gear reduction unit; finally, at the end of each track there are limit switches to detect the maximum stroke.

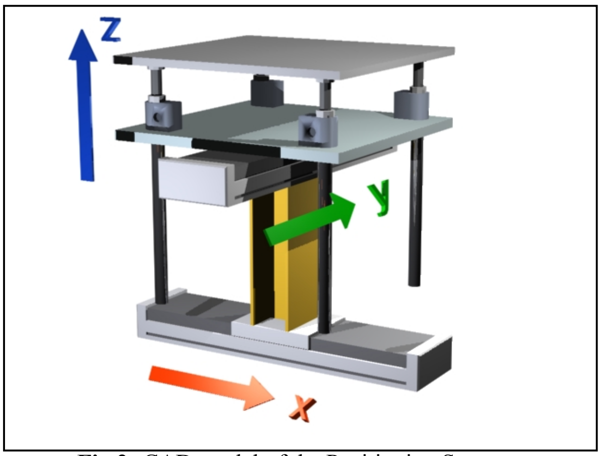

Fig.2: CAD model of the Positioning System

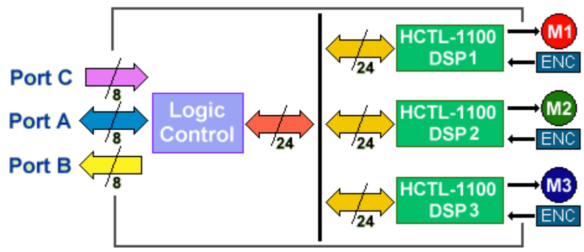

Fig.3: Architecture of the Control System.

The apparatus is equipped with a dedicated control system. Its architecture is shown in Fig.3, it comprises a backplane on which 3 control boards are mounted, each using a specialized chip ***(HP HCTL-1100)*** for the control of brushless or stepping motors. The backplane interface provides 3 8-bit ports: port ***A*** , which is two-way, is dedicated to the exchange of data from and to the control chip registers, port ***B*** , an input port, is used to read the limit switch , and finally port ***C*** , the output port, is used to address the chips and generate synchronization signals.

The system is completed by a suitable graphic interface, shown in Fig.4 which provides the user with some useful information. The central part of the interface provides a real-time vision of the status of the moving platform. The position and values of the three Cartesian axes are visible. The lower part of the interface provides some commands for the control of the platform according to three degree of freedom.

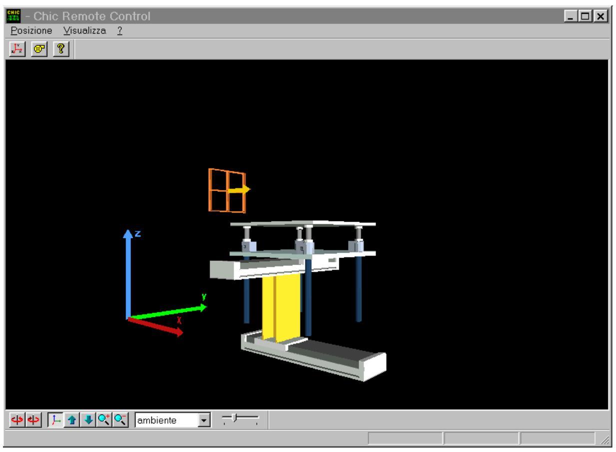

Fig.4: Graphic Interface of the Control System

5. REMOTE SYSTEM FOR VACUUM GENERATION

The second remote control application presented here is a research support system for the development and tuning of particle detectors. A complete scheme of the plant is given in Fig.5**:** it comprises a vacuum chamber, a rotating pre-vacuum pump, a turbo pump to create the vacuum, a pressure gauge, two pressure transducers for values ranging between $1{*}10^{-3} \div 1{*}10^{3}$ mbar and $1{*}10^{-9} \div 1{*}10^{-3}$ mbar , four electrovalves, two for air return and two to extract air from the chamber (pre-vacuum and vacuum).

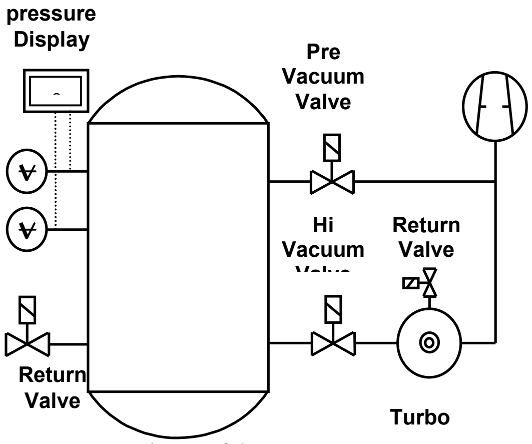

Fig.5: Scheme of the vacuum system

The remote control must perform the following tasks:

- Monitoring and automatic regulation of the pressure in the chamber on the basis of a pre-established target;
- The possibility of remote intervention on any of the activation devices .

Fig. 6 shows the portion of the ProFiBus network dedicated to control the vacuum system, including the supervisor station for parametric remote control, a PLC for local control of the vacuum system and a second slave used to acquire pressure measurement data.

information, the PLC has to carry out the correct time sequences to activate the pumps and electrovalves in order to reach the required target pressure in the chamber.

The operations performed by the control system can be described as follows: an acquisition board converts the analog pressure measurements into binary data which passes to slave unit 2; the Applicom supervisor station *(Master Unit 1)* has the task of providing the PLC with the current pressure level and to do so it cyclically scans slave unit 2 *(scan period = 100 ms)*, transforms the measurements from binary form into floating point pressure values, executes a filtering algorithm to eliminate measurement noise, and transmits the value obtained to the PLC; when automatic control is activated, the PLC uses the current pressure information obtained by Master Unit 1, together with the desired target value, to apply its control algorithm to the actuators and consequently regulate the pressure inside the chamber.

5.1 Command Interface

Fig. 7 shows the user control panel on the remote terminal for controlling the vacuum chamber.

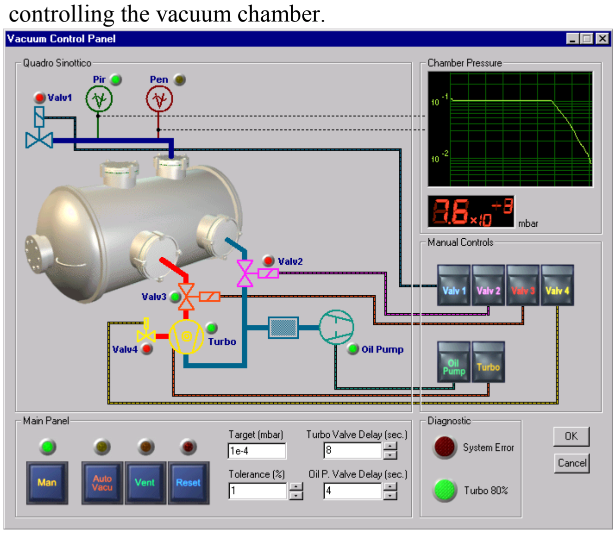

Fig.7: Control Interface of the Vacuum System

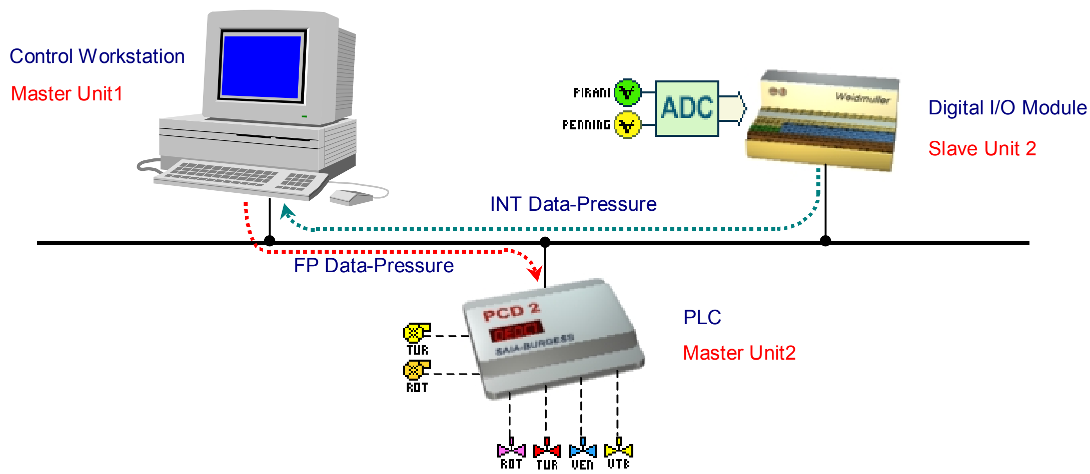

Fig.6: Profibus Network for the control of Vacuum System.

The task of the PLC is to receive information from the supervisor station concerning the type of control to be applied *(manual or automatic)* and, in the case of automatic control, the target value for the pressure; on the basis of this

The central part of the control panel reproduces a scheme of the plant, together with the operating indicators: any colored in green indicate that the associated device is active, i.e. a pump or electro-valve is open; red indicates the remaining states.

The two pressure sensors have two indicators; the one switched on indicates which of the two devices has currently

been selected to acquire the pressure measurements. On the top right-hand side there is a panel with two displays:
the first is a sliding display on a semi-logarithmic scale showing the trend of the pressure in the chamber; the second displays the current pressure in mbar.

The Main Panel contains a number of buttons, one for each control state of the local algorithm. The Diagnostic panel has two indicators: *System Error* , which indicates the presence of malfunctioning of the instrument feeding the pressure transducers, and *Turbo 80%* , which informs the user that 80 % of the maximum turbine speed has been reached.

6. CONCLUSIONS

In this paper we presented the results obtained through the use of the Fieldbus Technology in Nuclear Physics research. In particular we have studied how to integrate distributed control systems through the Profibus for two specific applications:
the first application concerns the remote control of a complex detector (made up of a dimensional array of detectors) used to detect flows of light ions. This system must be moved in real time, with very high precision in three different directions, requiring the control of three electrical motors that move the detectors. The second application, concerns an implementation of the control of a vacuum system suitable for a suitable chamber used for the development and testing of particle detectors.

The results we obtained encourage us to continue in this direction. The system can be expanded easily and it is possible to integrate new devices without any modification in the communicating system. Moreover, it is also possible to improve the network speed (the data rate of Profibus can be increased up to 12 Mbps) and in this way a wider bandwidth is available, in order to accommodate a larger number of devices.

7. REFERENCES

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