An X10 based intelligent gateway for Process Control Applications

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ABSTRACT

In this paper we present a new device for a remote control system based on X10 protocol and Internet technologies. This device is used in experimental nuclear physics for the remote control of various kinds of apparatus like pumps, valve and other basic systems that do not necessarily need high-speed control systems. The solution described makes experiment handling more flexible, eliminating any problem which originates from the need for cabling new systems being controlled.

Keywords: X10 Protocol, Remote Control, Internet, Nuclear Physics.

1.INTRODUCTION

The steady evolution of technologies based on digital systems has greatly modified the techniques and methodologies used in control systems. In particular, the current demand for distributed processes requires intelligent systems, control devices and measurement systems that are capable of communicating via the network. One important requirement in these systems is to reduce the number of connections, which means simplifying the handling of the systems and thus reducing maintenance problems. Over the years, various techniques have been developed for remote control and measurement in acquisition systems normally applied in experimental nuclear physics. This field of research requires distributed control apparatus that is capable of operating in particularly difficult conditions (strong electromagnetic fields, the presence of radioactive particles, low temperatures, etc..) and at the same time meets basic requirements in terms of safety, portability and simplicity. The presence of a large number of devices further complicates the design and implementation of these control systems. Many devices have to be controlled locally, which entails frequent access to the experimental measurement halls. Unfortunately, the environment in which nuclear experiments are typically performed is not safe; it is consequently very difficult and dangerous for a human operator to access this environment to modify system parameters while an experiment is being carried out. For this reason, a constant search is made for distributed communication systems that are as non-invasive of the infrastructure as possible. Communication systems based on the X10 protocol are widely used in the world of home automation; designed to meet small, low-bit-rate local control requirements, they present certain features that make them attractive for more sophisticated applications as well. The work presented contains the results of implementation of a remote control system based on X10 technology used to control experimental nuclear physics apparata. The paper presents the implementation of a system conceived to control vacuum in a vacuum chamber used to develop and test particle detection systems operating in vacuum conditions at nuclear laboratories. The system comprises two vacuum pumps, two vacuum sensors and a PLC. The two pumps work in sequence as each of them operates in a certain pressure range. The PLC is used to monitor the pressure in the chamber and contains a logic that switches the functioning of each pump [1]. This application shows how it is possible to combine the features of decentralised intelligence with a supervision station that is capable of remote manual intervention, exploiting a combination of an X10 system and a micro embedded web server with integrated Java functions representing a mini X10 gateway.

2. THE X10 PROTOCOL

Nowadays, the X10 protocol represents a "de facto" standard in home automation systems based on Power Line Carrier (P.L.C) transmission [3]. Although it is widely used for domestic applications, it has not as yet been frequently used in experimental applications like the ones described here. Conceptually an X10 system allows information and therefore data to be conveyed via an electric power line. A typical X10 system consists of several X10 modules connected to the power line used as the transmission medium. Normally a PC interface with a serial connection is used to generate the X10 commands to the various peripheral devices. The latter receive and perform the commands they are given. A generic X10 network can be represented as in Fig. 1

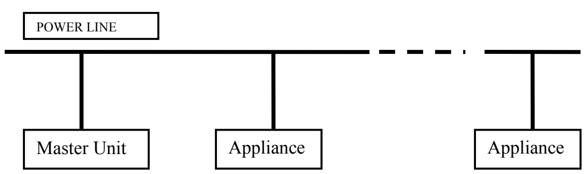

Fig. 1 – Typical Powerline Network.

The X10 transmission system synchronizes on the zero crossing rate of the sinusoid that represents the signal of a power line. The design goal is to transmit as close to the zero crossing point as possible but certainly within 200 microseconds of the zero crossing point. The system master unit provides a 60 Hz square wave with a maximum delay of 100 µs from the zero crossing point of the AC power line. A binary 1 is represented by a 1 ms burst of 120 KHz at the zero crossing point and a binary 0 by the absence of the 120 KHz. The master units modulate their inputs at 120 KHz, with a duration of 1 ms. These 1 ms bursts should actually be transmitted three times to coincide with the zero crossing points of all three phases in a three phase distribution system. (Fig.2) .

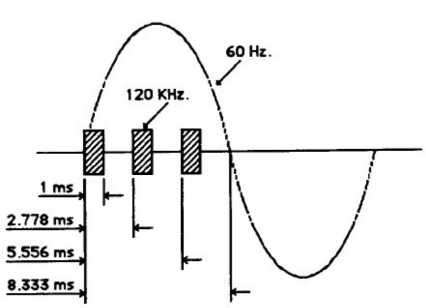

Fig. 2 Burst timing relationship relating to zero crossing.

A complete code transmission encompasses eleven cycles of the power line. The first two cycles represent a Start Code. The next four cycles represent the House Code and the last five cycles represent either a Number Code (1 through 16) or a Function Code (ON, OFF etc.). This complete block, (Start Code, House Code, Key Code) should always be transmitted in groups of 2 with 3 power line cycles between each group of 2 codes. Bright and dim are exceptions to this rule and should be transmitted continuously (at least twice) with NO gaps between codes. (Fig. 4).

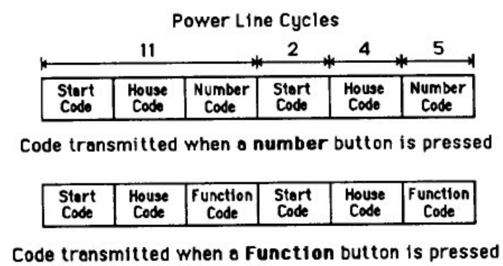

Fig. 4 – Code transmitted when a Function or Number button is pressed.

The tables in Fig. 5 show the Binary Codes to be transmitted for each House Code and Key Code. The Start Code is always 1110, which is a unique code and the only one which does not follow the true-complement relationship on alternate half cycles.

House Code and Key Code Tables.

House Codes	H1	H2	H4	H8	Key Codes	D1	D2	D4	D8	D16
A	0	1	1	0	1	0	1	1	0	0
B	1	1	1	0	2	1	1	1	0	0
C	0	0	1	0	3	0	0	1	0	0
D	1	0	1	0	4	1	0	1	0	0
E	0	0	0	1	5	0	0	0	1	0
F	1	0	0	1	6	1	0	0	1	0
G	0	1	0	1	7	0	1	0	1	0
H	1	1	0	1	8	1	1	0	1	0
I	0	1	1	1	9	0	1	1	1	0
J	1	1	1	1	10	1	1	1	1	0
K	0	0	1	1	11	0	0	1	1	0
L	1	0	1	1	12	1	0	1	1	0
M	0	0	0	0	13	0	0	0	0	0
N	1	0	0	0	14	1	0	0	0	0
O	0	1	0	0	15	0	1	0	0	0
P	1	1	0	0	16	1	1	0	0	0
					All Units Off	0	0	0	0	1
					All Lights On	0	0	0	1	1
					On	0	0	1	0	1
					Off	0	0	1	1	1
					Dim	0	1	0	0	1
					Bright	0	1	0	1	1
					All *Lights* Off	0	1	1	0	1
					Extended Code	0	1	1	1	1
					Hail Request	1	0	0	0	1 ①
					Hail Acknowledge	1	0	0	1	1
					Pre-Set Dim	1	0	1	X	1 ②
					Extended Data (analog)	1	1	0	0	1 ③
					Status = on	1	1	0	1	1
					Status = off	1	1	1	0	1
					Status Request	1	1	1	1	1

Fig.5 – House Code and Key Code Tables.

A hail request is transmitted to see if there are any other X-10 transmitters within listening range. This allows the O.E.M. to assign a different Housecode if a "Hail

Acknowledge" is received. X-10 Receiver Modules require a "silence" of at least 3 power line cycles between each pair of 11 bit code transmissions (no gap between each pair). The only exception to this rule is bright and dim codes. These are transmitted continuously with no gaps between each 11-bit dim code or 11-bit bright code. A 3-cycle gap is necessary between different codes, i.e. between bright and dim, or 1 and dim, or on and bright, etc..

3. IMPROVED PROTOCOL

As the X10 protocol is very simple and implements only a few commands for appliance management, it would be unfeasible to use it in nuclear physics experiments. Consequently, by exploiting its capacity for modification, we implemented a master unit based on a microprocessor which integrated normal X10 commands with other, more advanced functions, thus extending the range of available functions.

The characteristics of the master system are as follows:

- Bidirectional X10 communication;
- Serial RS-232 interface;
- 80 byte FIFO buffer
- Collision avoidance and detect, automatic retransmission;
- Compatible with standard and extended X10 code, extended functions;
- Support custom protocol up to 127 bit length messages;
- Automatic power line frequency detection;

This unit (called PLI, Power Line Interface) allows us to interface appliance equipment with computers or other CPU systems, equipped with a serial input RS-232. It is able to receive and to send all the X-10 codes, standard and extended. The extended functions are up to 127 bits in length. The large buffer eliminates microprocessor wait states for X10 transmissions. Some features, such as collision avoidance and detect, automatic retransmission improves a great reliability like as confirmation after a right transmission or failure.

The serial protocol is very simple and it allows some internal PLI functions to be controlled, such as enable/disable triphase transmission, enable/disable twice transmission, power line frequency and others. Moreover, the automatic power-line frequency set-up allows this device to be installed on a 50 or 60 Hz system. In addition, we provide a serial/TPC/IP interface able to manage the Java Applet in order to provide the system with all network capabilities .

Message format
A message is made up of a sequence of bytes. The 1st nibble of message indicates the type of message. PLI manages two types of message. A sample of possible codes and their meaning is shown in the following tables.

Data to/from PLI
The format of the messages sent by PLI is shown in Fig. 7

Type	Length	Data	CheckSum
1st nibble	2nd nibble	N Bytes (max 14 bytes)	1 byte
Type of message	Number of bytes in Data field –1	Data	Sum of all previous bytes

FIG.7 - PLI message format.

PLI sends on the power line the number of bits indicated in the length field, starting from the last bit of the 2nd byte of the message.

The extended MAC protocol will now be described.

Standard Code (X-10)
The X10 protocol uses a technique based on the following statement "Ensure that the system is not receiving". To do this it is necessary to check that there are 4, 5 or 6 zero crossing rates, chosen at random, with no signal, corresponding to the bit "0". If an error is detected during transmission, i.e. if 0 was being transmitted and 1 is read, or if the power of the signal received is greater than that of the signal transmitted, the transmission must be stopped immediately and resumed after a time randomly chosen between the 4,5 or 6 zero crossing rates with no "1". Between one message and another there has to be a gap of at least 4 cycles. The standard X10 protocol does not indicate whether the transmission is to be completely cancelled if errors occur n consecutive times. If errors occur 8 consecutive times it is advisable to cancel the transmission.

Extended Code (X-10)
Use of the Extended Code requires the transmitter to be capable of preventing collisions whenever possible, and if a collision does occur it has to be detected and the conflict resolved. To achieve this the following access protocol was used. First of all, all messages have the same priority. To access the transmission line, the transmitter has to wait 8, 9 or 10 z.c. during which there must be no transmission of "1s". If a "1" is detected, the count starts again. If a conflict is detected during the transmission, a collision is detected, the transmission is cancelled and the cycle is resumed, that is, the transmitter waits for 8, 9 or 10 z.c. with no "1s" and then starts to transmit again. If 8 consecutive errors occur the transmission is cancelled.

Extended Function
There are two levels of priority: Normal and Absolute.
Messages with normal priority follow the rules outlined above. Thee specifications for messages with absolute priority still remain to be defined.

Procedure:Address
The basic predefined address of a new unit is P16 and the extended address 0. Upon insertion into the network the Automatic address setting with master procedure is followed.
Each time it re-enters the network the unit will notify its arrival with the NewGuest function.

Procedure:Automatic address setting with master
At start-up the NewDevice unit sends a Request(Address) 3 times at 5-second intervals (over a 100 bps connection). The request is answered by the AssignAddress function. If a reply is received, confirmation is sent to the master via the SendOldAddress function; the master confirms reception of the SendOldAddress by sending an Ack. The following is a scheme of the functions (N=New unit, M=Master)
N: Request(Address) a maximum of 3 times at 5-sec intervals until AssignedAddress is received
M: AssignAddress
N: SendOldAddress a maximum of 3 times at 5-sec intervals until an ACK is received
M: ACK
If no reply is received, the unit will execute the procedure every time it is activated until it loses the NewDevice property. The NewDevice property is equal to False after the arrival of an AssignedAddress.
The master can recover an address setting session by using the Request(OldAddress) function.

4. CHARACTERISTICS OF THE X 10 GATEWAY

The system proposed comprises two units: a module to handle the X10 signals (master unit) and another which is an embedded web server, produced by Intellisystem Technologies, developed for fast, easy and reliable management of professional remote control applications in a TCP/IP environment (Fig. 8).

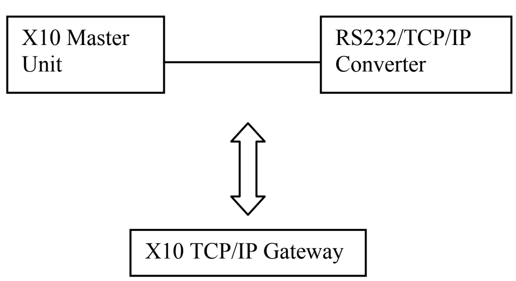

FIG. 8 – X10 TCP/IP Gateway functions.

The two systems interface via a serial connection based on the RS232 protocol. Once connected to an Ethernet, the whole system offers a hardware and software platform that can be programmed using a high-level language like Java. This means that the user interface can be managed by a parametric Java Applet: in this way the end user can develop his own control application in a fast and safe fashion without the need to be able to program in Java. Using the support of any Internet browser, for example Internet Explorer or Netscape, the system provides remote control of any device or apparatus.

5. CASE STUDY: A REMOTE SYSTEM FOR VACUUM GENERATION

The application presented here represents a test configuration for a support system in developing and tuning of a particle detector. A complete scheme of the plant is shown in Fig. 9; it comprises a vacuum chamber, a rotating pre-vacuum pump, a turbo pump to create a vacuum, a visual pressure gauge, two pressure transducers for values set between $1*10^{-3} \div 1*10^{3}$ mbar and $1*10^{-9} \div 1*10^{-3}$ mbar, and four electrovalves, two for air return and two to extract the air from the chamber (pre vacuum and vacuum).

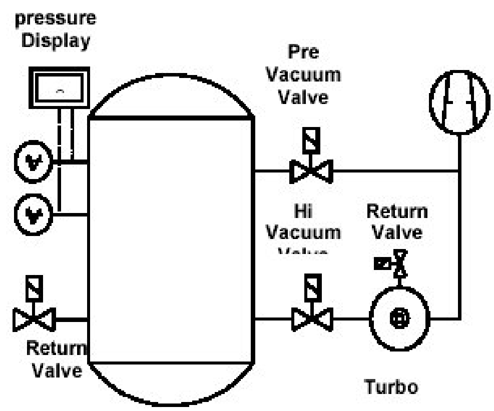

FIG. 9 Scheme of the system for vacuum generation.

Remote control of the vacuum has to carry out the following tasks:

- Monitoring and automatic regulation of the pressure in the chamber according to an assigned value;
- Possibility of remote action on any of the devices activated.

Fig. 10 is a block diagram of the vacuum control system developed. A PLC is dedicated to automatic control of the vacuum by acquiring information regarding the state of the system and automatically regulating the vacuum in the chamber. The PLC has a TCP/IP interface that integrates with the one proposed in our X10 system.

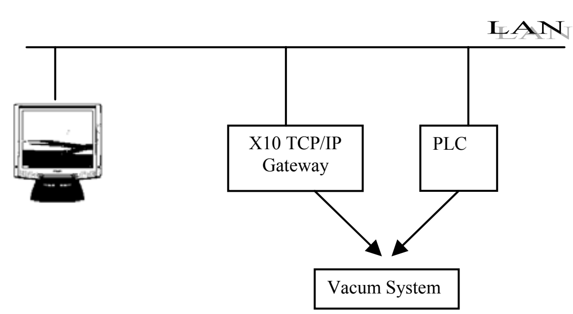

Fig. 10 – Block diagram of vacuum control system.

The task of the X10 system is to allow control of the main components of the plant, that is, the pumps and valves regulating the air flow. To this end, dimmer and on/off modules were used. The former interfaces with the valves and regulate partial opening/closing. The latter activates the pumps to create the vacuum.

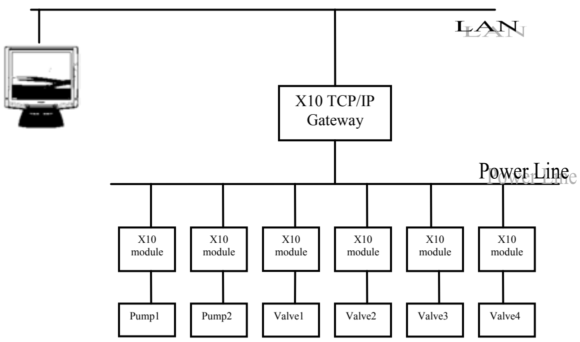

Fig.11 Scheme of remote vacuum control system.

Fig. 12 shows the control interface via which the operator performs remote control of the whole vacuum system. The central part of the control panel reproduces a scheme of the plant together with indicators of the operations performed: each indication coloured green indicates that the associated device is active, for example a pump or an electrovalve is open; red indicates the remaining states.

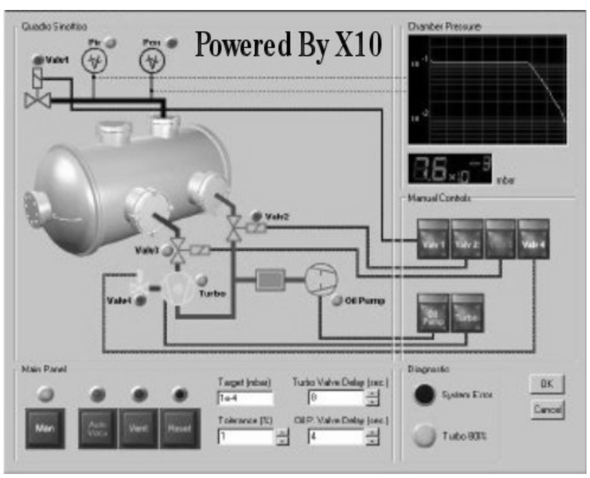

Fig. 12- JAVA GUI interface for vacuum control.

The two pressure sensors have two LED indicators; when one comes on it indicates which of the two devices is currently selected for acquisition of the pressure measurements. On the top right-hand side there are two displays: the first is a sliding graph on a semi-logarithmic scale showing the evolution 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 state of control of the local algorithm. The diagnosis panel has two indicators: system error, which indicates the presence of malfunctioning of the instrument providing the transduced pressure, and Turbo 80%, which informs the user that 80% of the maximum sped of the turbine has been reached.

On the bottom left-hand side there is a button to switch the system from automatic to manual functioning.

6. CONCLUSIONS

In this paper we have presented the advantages obtained by using X10 technology in a typical nuclear physics environment. We have investigated how to integrate distributed control systems via the X10 protocol with particular reference to implementation of a system to control the vacuum in a special chamber used to develop and test particle detectors.

The system can easily be expanded and it is possible to integrate new devices without modifying the communication system. By interfacing with a TCP/IP network the system becomes a gateway for the remote control of systems and applications.

The flexibility of the graphic interface written in Java, by virtue of its parameterisation, drastically reduces the time required to develop it, thus allowing the system to be put into operation very rapidly, even when substantial modifications have been made to the plant being controlled.

7. **REFERENCES**

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