Guidance on Design of Internet-based Process Control Systems[1)]

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Abstract Internet-based process control is becoming new generations of control systems, in which the Internet is used as a platform for global remote monitoring and control. The obvious benefit is to enable global collaboration between operators from geographically dispersed locations, data sharing and data provision for remote monitoring and control. However, connection to an open network and the use of universal technology present new problems that did not exist with the conventional design and construction of control systems, such as time delay and data loss in Internet transmission and security. This paper reviews the latest research results and presents design guidance of Internet based monitoring and control systems.

Key words Internet-based control, network latency, safety, security, user interface design

1 Introduction

Nowadays the Internet is playing a very important role in different domains. During the previous years a lot of research has been done for trying to develop applications, which make it possible to supervise and control industrial processes using the Internet. Internet based control can be described as the whole of operations performed to control or monitor a system in the Internet environment. Internet-based control system allows the process data to be retrieved by a controller, operator, and engineer at a remote location. Control action issued in the remote location can be executed in the process. The difference from normal remote control system and/or distributed control system is that the communication media is the Internet rather than any other private medias. The guidance presented in this paper covers the following design issues:

1) Requirement specification;
2) Architecture selection;
3) Time latency caused by the Internet traffic;
4) Concurrent multiple-user access;
5) Front-end interface;
6) Security.

This paper is organised as follows. In the section 2 the latest development in Internet based control research is reviewed as a short history about it. The section 3 describes the requirements specification and architecture design, which should be considered when developing these kinds of control systems. The time delay compensation is investigated in the section 4. The security problems are discussed in the section 5. The implementations including concurrent multiple-user access, user interface design and bulk data transfer over the Internet are presented in the section 6. Finally the section 7 gives some concluding remarks.

2 Review of the research on internet-based control

As a basis for the possible next generation of control systems, the concept of Internet-based process control has been introduced in recent years. To date, most research work on Internet-based process control has resulted in small-scale demonstrators[1~3] like Sun Microsystems and Cyberonix, Foxboro, and Valmet. Most of them were developed in Java. Additionally, the OPC (Open Process Control) Foundation (1998) is working on supporting XML within Visual Studio so that Internet-based process control using XML can become reality (OPC Foundation, OLE for Process Control, OPC Overview, http://www.opcfoundation.org, 1998). Intuitive Technology (http://www.aglance.com, 1999) has provided web@aGlance for feeding real-time data to a Java graphics console. The European founded

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project "web-based SCADA"[4] focuses on collecting real-time data from the Internet. Many international working groups such as Fieldbus Foundation and OPC Foundation and the major manufactures such as Invensys, Siemens, and ABB etc. are proposing standards. A few companies try to produce Internet control systems as a control device[5]. Some researchers in this area, from higher education institutions, focus on developing web-based virtual control laboratories for distance learning purposes[6~9] They allow a remotely located user to conduct experiments in their control engineering laboratory via the Internet.

The majority of the methods for overcoming the network transmission delay are based on the design of a time delay compensator to compensate for the effect of the time delay or use the predicted output of a process model to replace the actual output once a transmission delay occurs[10,11] The stability analysis of networked control systems aims to find out the condition of the networked control systems remaining stable within a pre-defined control structure and algorithm[12,13]. Most of the existing approaches are only for local networked control systems. The features of the public Internet are rarely considered in the existing approaches. Internet-based remote monitoring and control systems must be secured against attacks from outside hackers. A concerted security countermeasure has to be constantly devised for avoiding attacks[14].

3 Requirements specification and architecture design

In our previous research[15] we stated that the objective of establishing Internet-based process control systems is to enhance rather than replace computer-based process control systems by adding an extra Internet-level in the hierarchy. Fig. 1 shows a typical computer-based process control system divided into different hierarchy levels. Before designing the architecture for an Internet-based control system the requirements should be specified. The major task in the requirements specification is to identify and resolve trade-offs between goals and constraints of the system that are conflicting or not completely achievable. It should be born in mind that (a) tasks, which require a determine timing regime should be avoided because they may not be achievable due to the Internet traffic delay; (b) also direct access to a controller is not a requirement and is probably not desirable because of security reasons; (c) it is necessary to minimize the communication load between the Internet level and the existing control level. Different requirements will lead to different control structures having their own advantages and disadvantages.

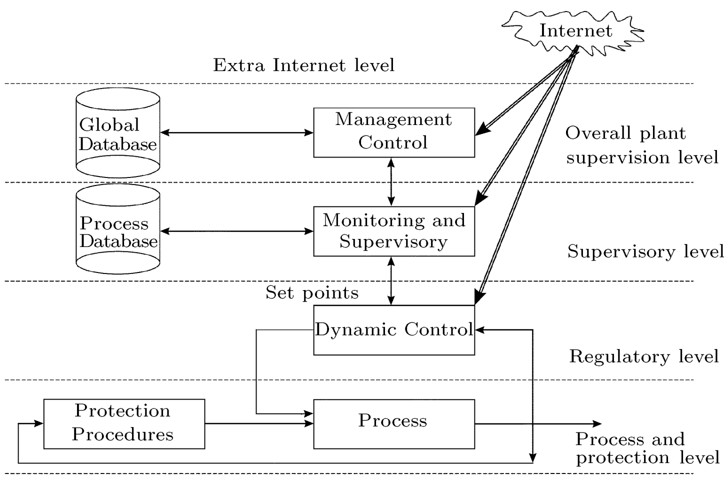

Fig. 1 Process control system hierarchy and possible links with the Internet[15]

The control system architecture can be selected in terms of the following "4R's" principle criteria to meet the requirements specified above.

1) Response time: as one moves higher in the information architecture, the time delay, which can

be tolerated in receiving the data, increases. For example, at the regulatory (control loop) level, data becomes "stale" very quickly. Conversely, information used at the management & scheduling level can be several days old without impacting its usefulness.

2) Resolution: Abstraction levels for data varies among all the levels in the architecture. The higher the level is, the more abstract the data is.

3) Reliability: Just as communication response time must decrease as one descends through the levels of the information architecture, the required level of reliability increases. For instance, host computers at the management & scheduling level can safely be shut down for hours or even days, with relatively minor consequences. If the network, which connects controllers at the supervisory control level and/or the regulatory control level, fails for a few minutes, a plant shutdown may be necessary.

4) Reparability: The reparability considers the ease with which control and computing devices can be maintained.

As shown in Fig. 2 the Internet can be linked with the local computer system at any level in the information architecture, or even at the sensor/actuator level. These links result in a range of 4Rs (response time, resolution, reliability, and reparability). For example, if a fast response time is required a link to the control loop level should be made. If only abstracted information is needed the Internet should be linked with a higher level in the information architecture such as the management level or the optimisation level.

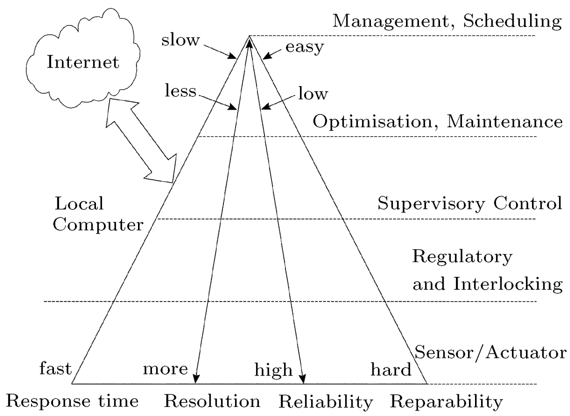

Fig. 2 Information architecture[3,16]

4 Time delay compensation

The Internet is a public transmission media, which is fundamentally different from other private transmission media used by many end-users for different purposes. The Internet transmission performance is associated with time delay and packet loss and possesses large temporal and spatial variation. In detail, the Internet time delay is characterized by the processing speed of nodes, the load of nodes, the connection bandwidth, the amount of data, the transmission speed, etc. Therefore it is somewhat unreasonable to model the Internet time delay for accurate prediction at every instant. The existing approaches mainly focus on how to design a model based time delay compensator[10,15] or a state observer[12] to reduce the effect of the transmission time delay. The majority of them are based on an accurate process model, which make them difficult to be implemented in practice. Our recent research indicates the potential of overcoming the Internet time delay from the control system architectural point of view[15,17].

4.1 Sampling in a tolerant interval

It is arguable that the conventional discrete control structure, which uses a fixed sampling interval, is not suitable for Internet-based control systems. The conventional discrete control structure requires a predictable execution time for closed control loops. Conversely, Internet transmission time delay is unpredictable, which breaks the foundation of the conventional discrete control structure. For example, an actuator may receive a control signal from a controller after the sampling interval passes. As a result, the control system with a fixed sampling interval, T_s, potentially increases the system time delay. Our recent research investigates an Internet based control system structure, in which a tolerant time $\triangle t$ is introduced to handle the unpredictable information transmission delay. Instead of acquiring control signals at a single instant, the new structure allows the data acquisition to occur from every instant $T_s - \triangle t$ to every instant $T_s + \triangle t$, which potentially maximizes the possibility of succeeding the transmission on time. As the result of introducing the tolerant time, a sampling switch pair located at both the remote and local sides replaces a single switch in the traditional structure to facilitate the transmission action. The sampling switches are triggered and synchronized by the timers provided by the network services. Inherited from the existing approaches, two time delay compensators are employed in the new structure. Our recent research has shown an optimistic result by using this approach[15].

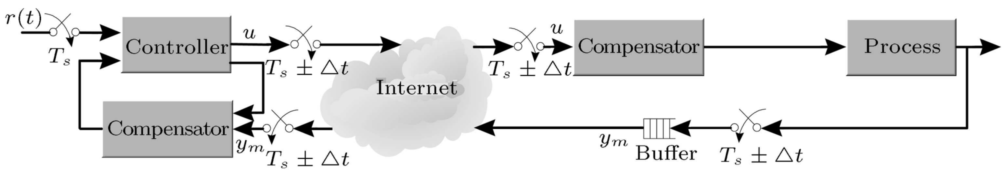

Fig. 3 Control structure with two time delay compensators and a tolerant sampling interval

4.2 Dual-rate control scheme

The dual-rate control scheme involves a two level hierarchy. At the lower level a local controller is implemented to control the plant at a higher frequency to stabilize the plant. At the higher level a remote controller is employed to remotely regulate the desirable reference at a lower frequency to reduce the communication load and increase the possibility of receiving data over the Internet on time. We designate the local controller as the fast controller and the remote controller as the slow controller. Our preliminary exploration of this approach illustrates a great potential[17].

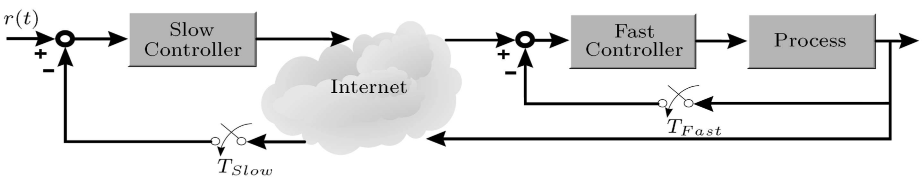

Fig. 4 Dual-rate control scheme

There are two cases that are involved in the dual-rate control scheme.

Case 1: The transmission delay is less than the sampling interval of the slow controller, T_{slow}. In this case there is no data loss during each sampling interval. Therefore the transmission delay has no influence on the slow controller.

Case 2: The transmission delay is greater than the sampling interval of the slow controller, T_{slow}. In this case the sample will be delayed to arrive at the slow controller and a compensator must be employed.

5 Security

Though introducing the Internet into process control systems have yielded benefits through an open architecture, there are various risks as the result of the connection to the open network and the use of universal technology. One typical risk is an operational trouble caused by cyber terrorist attacks. The Internet is a place where services are increasingly subject to damage from various threats, such as unauthorized access, wiretapping or tampering with private data, system failures caused by viruses, denial of service due to network and server overload. What is making this problem worse is there is no such thing as security countermeasures that are 100% perfect. The scope of the Internet-based controlled plant safety cannot be limited within the plant sites, because there are some degrees of possibility that the local control system is accessed or falsified by outsiders through the Internet.

The Internet router is obviously the first target of attack if any malicious hacker tries to get an unauthorized access into the local control system. The plan firewall (PFW) is the first protection of the control network[14]. The PFW is an application gateway. Data sent from a remote site is analyzed on the PFW and only proper data is sent on to the local control network. Naturally, because the analysis of data content creates a processing load, the PFW is used together with a packet filter type firewall to protect against denial of service attacks. In case the PFW is broken (the node A1) Figure 10 shows a possible intruding path from intruding into Intranet (the node A2), intruding into the control system (the node B2), altering control parameters (the node C3), and causing abnormal process conditions (the node D4) to causing a fatal accident (the node E5). In Figure 10 intrusion takes time from left to right and increases the degree of risk from bottom to top. Cutting off the path at any point, which starts at the node A1 and ends at the node E5, will prevent the fatal accident from happening.

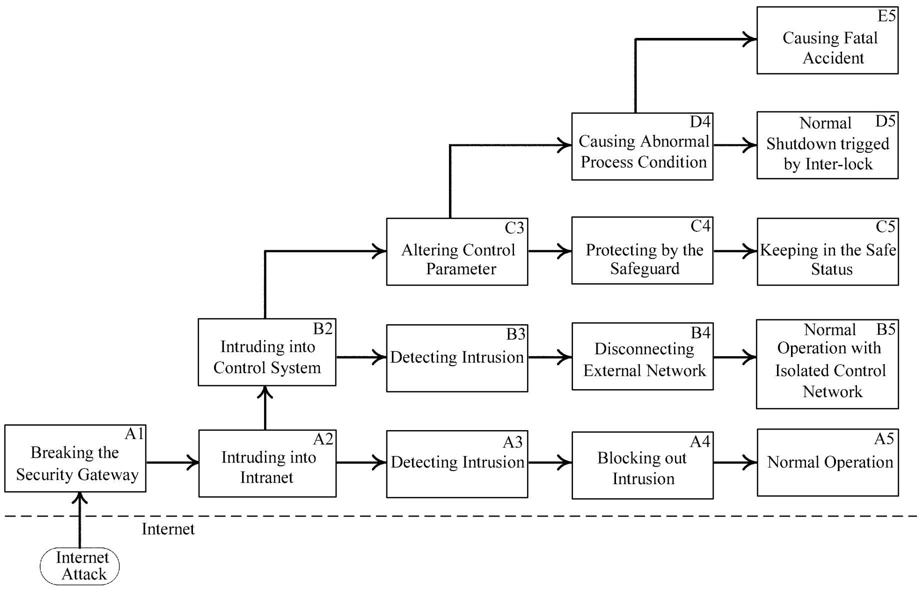

Fig. 5 Security risks from malicious hackers

6 Implementation

6.1 Concurrent multiple-user access

Compared with the traditional distributed control system (DCS), the special feature of the Internet-based control system is multiple-user and the uncertainty about the users. The number and location of the users keep changing. Although the DCS system allows several operators to operate the system at a same time, they normally sit in a same operation room. Therefore, coordination amongst them is not a real problem. In the Internet-based control system, the operators cannot see each other, or may never have met. It is likely that multiple-users may try to concurrently control a particular process variable. If more than one authorized users have the same opportunity to fully control the whole process some problems could arise. Assume that user 1 sets a setpoint for a controller, and then the setpoint is sent to the local controller. If user 2 sets another setpoint for the same variable before the variable achieves the setpoint, the second setpoint will overwrite the first setpoint even if it is unsuitable for the current situation. The setpoint of the controller fluctuates from point to point. Coordination among multiple-users becomes very important. Some mechanism is required to solve control conflict problems between multiple-users, and coordinate their operations. There are three steps for dealing with multiple-user concurrent access[15].

1) Assign users with different priorities, for example the integer values 0 to 6. The user with a high priority can immediately pre-empt the commands issued by users with lower priorities. Generally, the easy way to identify a user is the user account. When the user logs in, a dynamic identity (ID) will be generated for the client. The control command issued by the user will be combined with this ID, so that the server can identify the command issuer, work out the priority of the issuer, and decide whether the command is acceptable or not.

2) After a new command is accepted, the system will be blocked for a certain period of time and refuse to accept any further command from users with equal or lower priorities. The time will vary from case to case. Normally the time could be chosen as the time constant of the system. It ensures that the command has been fully executed before the new command is carried out.

3) Only allow a single user to operate the system in the tuning operation. There are two typical operation scenarios. One is the tuning operation; the other is the normal operation. The tuning operation covers start-up, shutdown, and emergency handling. Normally, the tuning operation is handled by a senior control engineer. In this case, the operation should be continuous, exclusive, and not be interrupted. Therefore, the system will be hold for only a single user until this user logs out or releases the right to another. The other users only can monitor operations during the tuning operation.

6.2 User interface design

Advances in control and information technology have shifted the operator role from being the key element in the control loop to the new function of plant supervisor and trouble-shooter. Internet-based process control will speed up this shift since many routine control functions have been taken over by computer-based control system at the regulatory level in the process control hierarchy. The web-based user interface should be designed to suit this shift. The central design objective for a web-based user interface in Internet-based process control is to enable the operator to appreciate more rapidly what is happening in process plants and to provide a more stimulating problem-solving environment outside the central control room. It should be born in mind that media available in the Internet environment outside the central control room will be very much limited compared to those in the central control room, and a web browser like Netscape or Internet Explore is the most logical way for accessing control and monitoring systems via the Internet.

The technologies from the areas of "multimedia" and "Virtual Reality" show considerable potential for improving yet further the human-computer interfaces used in process control technology[18], and different media can transmit certain types of information more effectively than others and hence, if carefully chosen, can improve operator performance[19]. The irrelevant information may obscure important information by attracting the attention of a user. Choosing the best media for different interface tasks and minimizing the amount of irrelevant information in the interface[20] are two main guidelines, which should be adopted. The human interface tasks are classified into two types of functions according to operational goals: process monitoring functions and process operation functions. The first type needs process flowcharts indicating current process status, historical trend displays, and visual information of the plant while the other one asks for controller window displays.

6.3 Bulk data transfer and communication over the Internet

An Internet based process control system consists of two parts, a client side and a server side. Whilst the client side interacts with users, the server side is not only a web server, but also includes data acquisition and local control programs to carry out the control tasks. A direct TCP (transfer control protocol) connection between the client and the server can be made to build the communication channel between a remote user in the client side and the process via the server. This does not break the security rules of popular browsers because the rules permit a socket connection between a client site and a process on the server from which the current web page came. But this is not preferable, because a general firewall of an Internet site does not permit the socket connection from outside, and such a connection must suffer from unpredictable delay time of the Internet. A better alternative is the employment of the standard common object-request broker architecture (CORBA), whose specifications are given by the object management group (OMG, http://www.omg.org, accessed in 2004). A client and a server can communicate via the Internet InterOrb Protocol (IIOP), which is expected to be a standard protocol of the application layer on the Internet for securely going through firewalls.

An efficient way of organizing and providing bulk real-time data for a remote client is essential in Internet based control systems. We are investigating the structural data block such as HDF5 (hierarchical data format version 5) (NCSA, HDF5 - a new generation of HDF, http://hdf.ncsa.uiuc.edu/HDF5, accessed in 2004) with XML (eXtensible Markup Language) semantic wrappers for organizing bulk real-time data, and the web query technology for providing a proper subset of the bulk real-time data. HDF5 defines a feature rich data format for structural datasets as well as groups of data. Our research use HDF5 for storage of enormous datasets, and use XML for description of the meaning of data. While HDF5 has an attribute facility for storing "name=value" pairs, the use of XML allows us to easily support various enormous data format on the Internet. In order to reduce the communication load enormous datasets will be transferred through the Internet from the server side only if these data are requested by a remote client. The web query determines the optimal amount of datasets over the Internet, and therefore reduces the communication load.

7 Conclusions

Internet-related features such as the Internet time delay, concurrent user access, web-based interface and security, present new problems that did not exist with the conventional design and construction of process control systems and make the design of Internet-based process control distinctive.

In this guidance the scope of Internet-based process control has been clearly specified: Internet-based control is only an extra control level added into the existing process control hierarchy. The objective is to enhance rather than replace computer-based process control systems. Six essential design issues have been investigated which form the guidance on the design of such Internet-based process control systems. These design issues include requirements specification, architecture selection, web-based user interface design, Internet time delay, concurrent user access, and security. Only those requirements, which are achievable through the Internet, are suitable for the Internet control level. The Internet can be linked with the existing process control system at various levels in the hierarchy in order to meet various control requirements. In addition, limited media are available in the Internet environment for web-based user interface design. Also, since the Internet time delay is affected by both the number of nodes traversed and the Internet loads, it is unreasonable to model the Internet time delay for accurate prediction at every instant. Overcoming the Internet time delay from the control system architectural point of view indicates great potential. Concurrent user access is acceptable only if the conflict between multiple-users is properly solved. System security should be protected by a plant firewall and other countermeasures.

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