DESIGN AND IMPLEMENTATION OF DIGITAL COMPUTER BASED DATA ACQUISITION AND CONTROL SYSTEM

S. H. Khan, T. Yasser and H. N. Mondal
Department of Chemical Engineering
Bangladesh University of Engineering and Technology

Abstract

Conventional control systems lack the ability to incorporate complex mathematical and control algorithms available to the control engineer today, which includes system identification, fuzzy logic, neural networks robust and predictive control etc. They also generally lack the ability to maintain historical data. This makes studying and refining a process difficult either for debottlenecking/optimizing or accident/fault diagnosis. Stricter safety and environmental requirements demand high speed, fast-response control systems, which conventional systems either cannot provide, or is very expensive. Looking for a way to improve these limitations in process control, a digital computer based control system was developed using revolutionary new software technologies and state-of-the-art programmable SCADA hardware. The developed system has extensive data logging capability, a nearly flat operator learning curve, and features auto-tuning PID control algorithm. It is also capable of broadcasting data to remote clients using TCP/IP networks, and has configurable audible alarm and trip subsystems. The computer-based control system was tested on a test rig with level and temperature control capabilities. Commercial, off-the shelf technologies were used for building the system. The system that resulted is a convenient, flexible and cost effective solution to some of the critical limitations of traditional pneumatic or PLC based control systems. Industrial automation is no longer limited to corporate giants. Even small and medium scale industries can use this technology for chemical process control.

Introduction

The concept of microcomputer based process automation is not merely a modern trend in instrumentation. It is a paradigm shift in focus of effort among leading professional bodies in the field of control, instrumentation and automation engineering. Today, it is possible to create extremely complex control systems using dedicated instrumentation programming software that takes advantage of the extraordinary number crunching capabilities of 21st century PC hardware. These systems can be easily modified and tuned for optimum performance. Hot swappable, plug-and-play hardware and software now allows modification to control objectives to be implemented on-line as process/market demand changes. This reduces overall plant downtime and allows adaptive production planning, leading to increase in profit and reliability of a plant[1,2,3]. Moreover, when it comes to using smart control systems based on novel techniques like fuzzy logic, neural networks, predictive and decisional control, using digital computers is usually the only way forward.

Industrial control usually comes through as very expensive solutions that include proprietary components. The package usually consists of industrial standard (but still patented/proprietary) hardware components integrated with control logic that is hidden into compiled or embedded machine-specific code. This code is stored in an EEPROM or flash memory. The embedded control logic cannot be modified at the users end if and when required. As the control logic within the software is machine specific, non-reprogrammable and non-transferable, the control system cannot be modified even though the sensors and actuators communicate via open communications standards like HART, ProfiBus, Foundation Fieldbus, CAN, Ethernet/IP or 4-20mA current loops. On top of that, every major player in DCS and process automation has their own packages and product lines that are generally incompatible with each other. This makes PLC-based, distributed and computerized control systems very expensive to install, maintain and upgrade[1]. Such integration bottlenecks and incompatibilities among control solution providers' results in poorly optimized plant operation, increased production cost, and reduced reliability that directly translates to increased risk to health and the environment. The stiff resistance of conventional and modern control systems toward full programmability, and the high cost of process-specific intelligent systems have led to end users being reluctant to explore into the optimization issues of chemical process control. This situation is shared among chemical process industries in the developed and developing countries to almost the same extent. One estimate is that over 80% of the control loops of the world's chemical process industry are poorly tuned[2].

In light of these realities, the focus of the authors was on building a control system with PID control loops where the fully programmable control logic will be implemented in a digital computer. Communication with a process that it is designed control will take place via hardware and software interfaces such that the internal complexity of the control system will be transparent to the operator. As such, the limitations of the conventional and PLC based systems can be overcome at an affordable cost.

Development Tools and Equipments

Once the control logic can be built from the ground up for a specific process, the overall fulfillment of control objective and process performance improves significantly at a nominal expense. This was achieved by the authors using fully programmable SCADA hardware components and LabVIEW application development software from National Instruments, USA. National Instruments (www.ni.com) is one of the world's leading manufacturers of control and instrumentation hardware and software that have product application in telecom, automotive, semiconductor, biomedical and chemical fields; its products are used by NASA[3], Ford, E.I. DuPont in the industry and Texas A & M University, CalTech[4], U.T. Austin[5] in the academia to name a few. Its SCXI line of signal conditioning and instrumentation equipment, and a multifunction PC interface adapter board, were used to build the hardware layer of the control system.

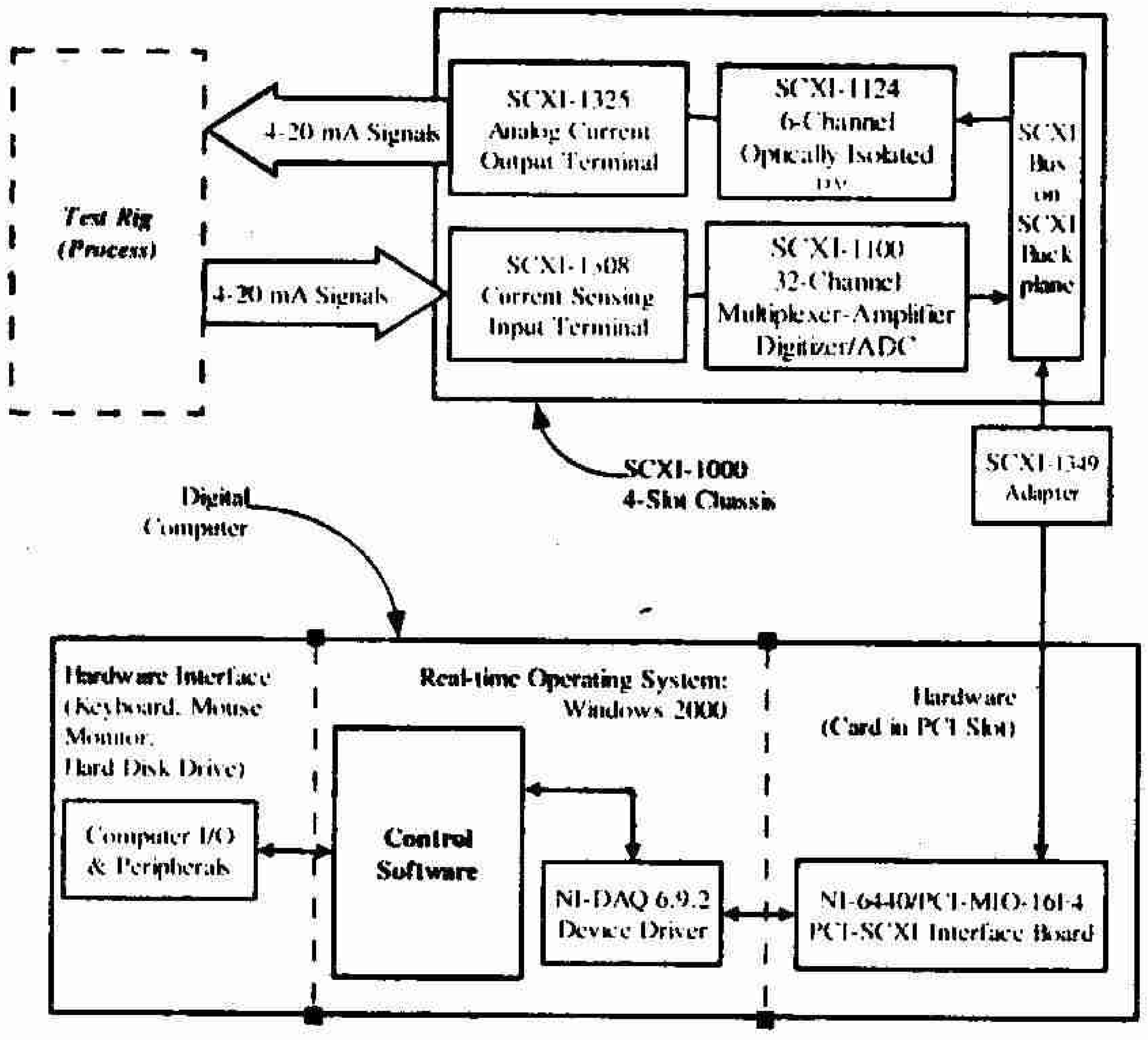

Fig 1: The Control System Schematic. The Shaded Component Contains Developed Code while other Components were Configured.

LabVIEW, the software used to develop the control program and the human-machine-interface (HMI), uses a graphical language to generate optimized code that execute at compiled speed in real time on Windows, Linux or Macintosh computers. It is a platform-independent, open-standard application development environment designed specifically for instrumentation, control, analysis and display of engineering information.

Developing the Control System

The system was developed in a manner so that an operator clicks buttons and pushes sliders on a monitor to control a process. The software and hardware works transparently between the operator and the process. To test the developed system in real world, an existing three-tank temperature plus level control rig at the control-engineering laboratory of the department of chemical engineering, BUET was used as testing platform. The rig has three tanks where liquid water can be pumped and heated by steam from a boiler. It has 13 sensors measuring flow, level and temperature, and four control valves as actuators. The rig was constructed in collaboration with Training Institute for Chemical Industries (TICI), Bangladesh.

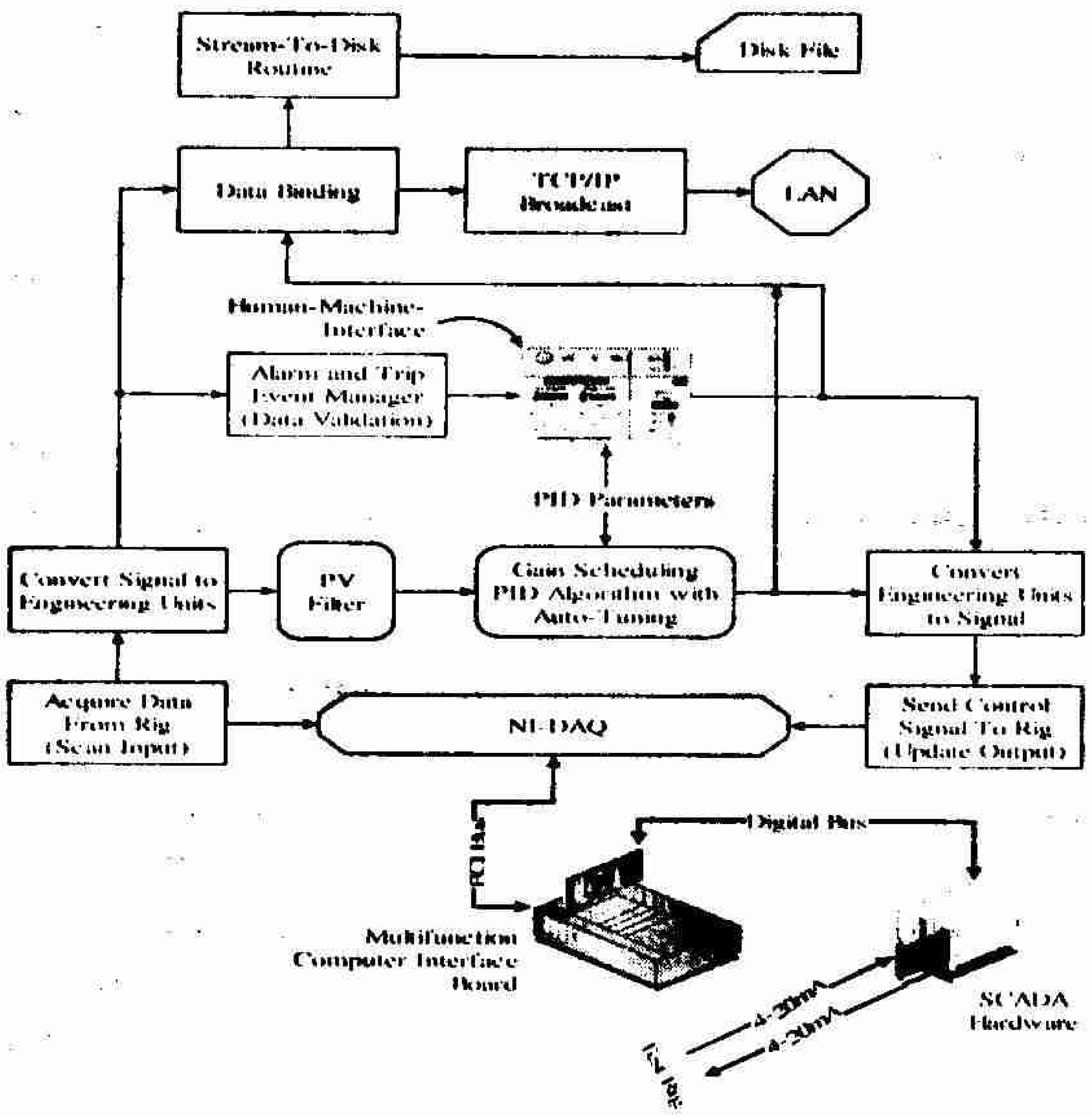

Fig 2: Functional Block Diagram of Control Software Showing Hardware and Software interfaces.

The hardware layer of the control system was built using a SCXI chassis housing a DAC and an ADC module. Analog signals arrive as 4-20mA currents from transmitters at the plant into a terminal where the currents are sensed in 250Ω 0.1% precision process current resistors as voltage. The voltage signals at the terminal are digitized on the ADC module, which controls communication with a PC interface board over an adapter and cable. The analog control signals are sent to the process from another terminal. Programmed 4-20mA current is sent to this terminal from a digital-to-analog converter module. The DAC module is controlled serially over a back-plane bus on the SCXI chassis. Control signals arrive at the DAC as digital data from the PC-interface board over the path to the ADC and via the SCXI back-plane bus.

The low-level communication with PC adapter board over the computer's PCI bus is maintained by NI-DAQ, which is a device-driver software by function. Configurable by the NI-MAX software NI-DAQ acts as a high-level software interface between front-end software and the hardware. The adapter board in turn provides a transparent hardware interface between NI-DAQ and SCXI devices that it controls. This way, the whole data transaction process is transparent to the human operator.

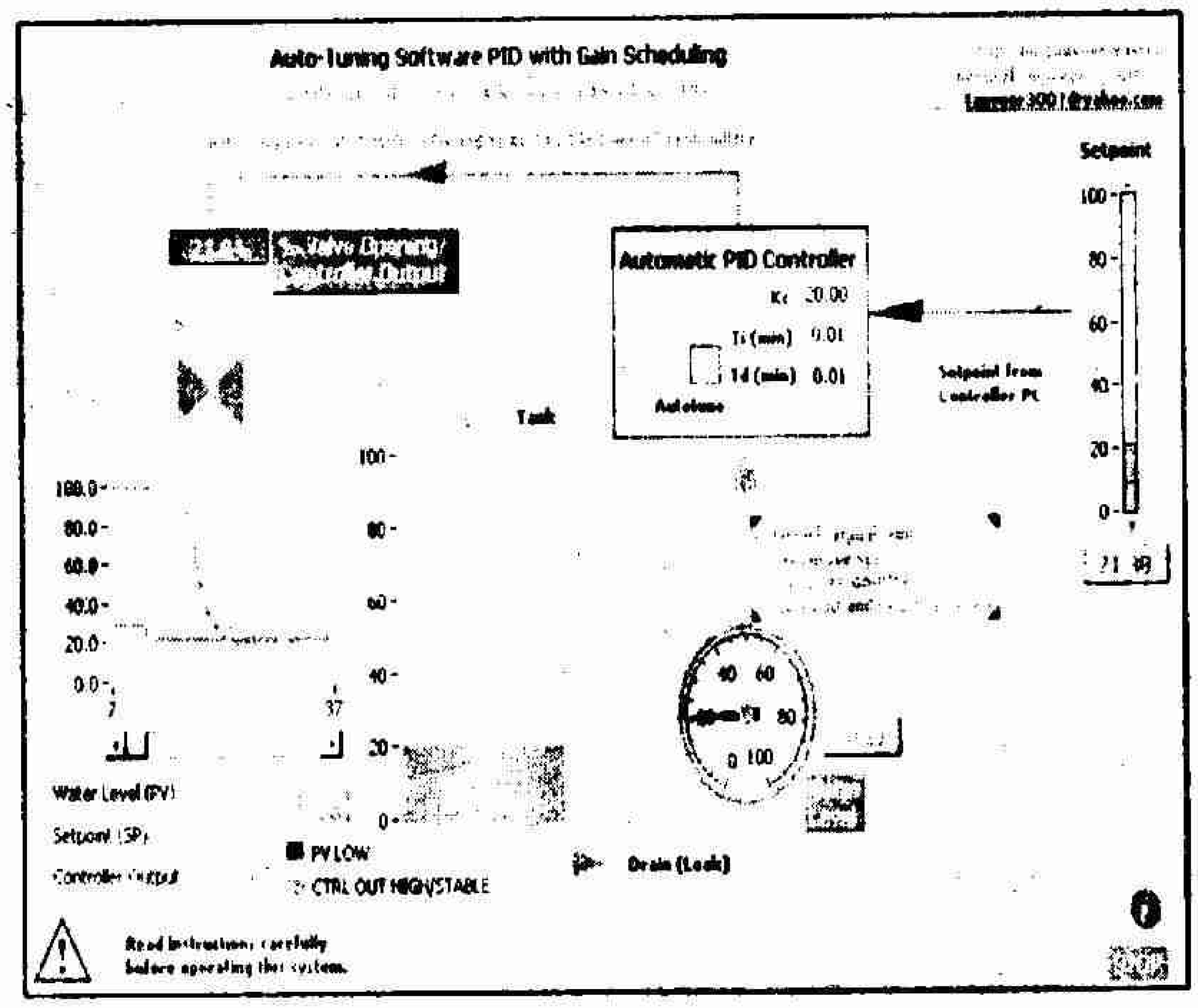

Fig 3: HMI (Operator Window) for a Level Control Loop

The front-end software constitutes the human-machine-interface and interacts with human operator to communicate test rig information. It also performs data logging (stream-to-disk) functions, TCP/IP broadcast functions, alarm and trip event handling and PID loop control functions. The PID algorithm has options for direct/reverse action, proportional band, gain scheduling (setpoint, process variable or controller output) and process variable averaging filter. The auto-tuning subsystem employs a modified setpoint-relay tuning algorithm.

Fig. 1 shows a schematic diagram of the control system. Fig.2 shows the functional block diagram of the system software. Fig. 3 shows a typical operator window displayed by the developed software. The complete system hardware assembly is shown in Fig. 4. Input/Output process data generation pattern is shown in Fig.5. Controlled Output, Set point and Process Variable data from a single tank level control loop while it was responding to a step change in set point is shown in Fig.6.

In a broader context, this work is the first step toward vertical integration of a plant's information-management system, from the device to the enterprise level. To achieve this end, a control application incorporating a human-machine-interface (HMI) was developed that streams plant data to a storage device and broadcasts it on a TCP/IP network. In an actual chemical plant, when this is done plant-wide, it becomes possible to use the data in an integrated plant information-management system, which is essentially plant automation.

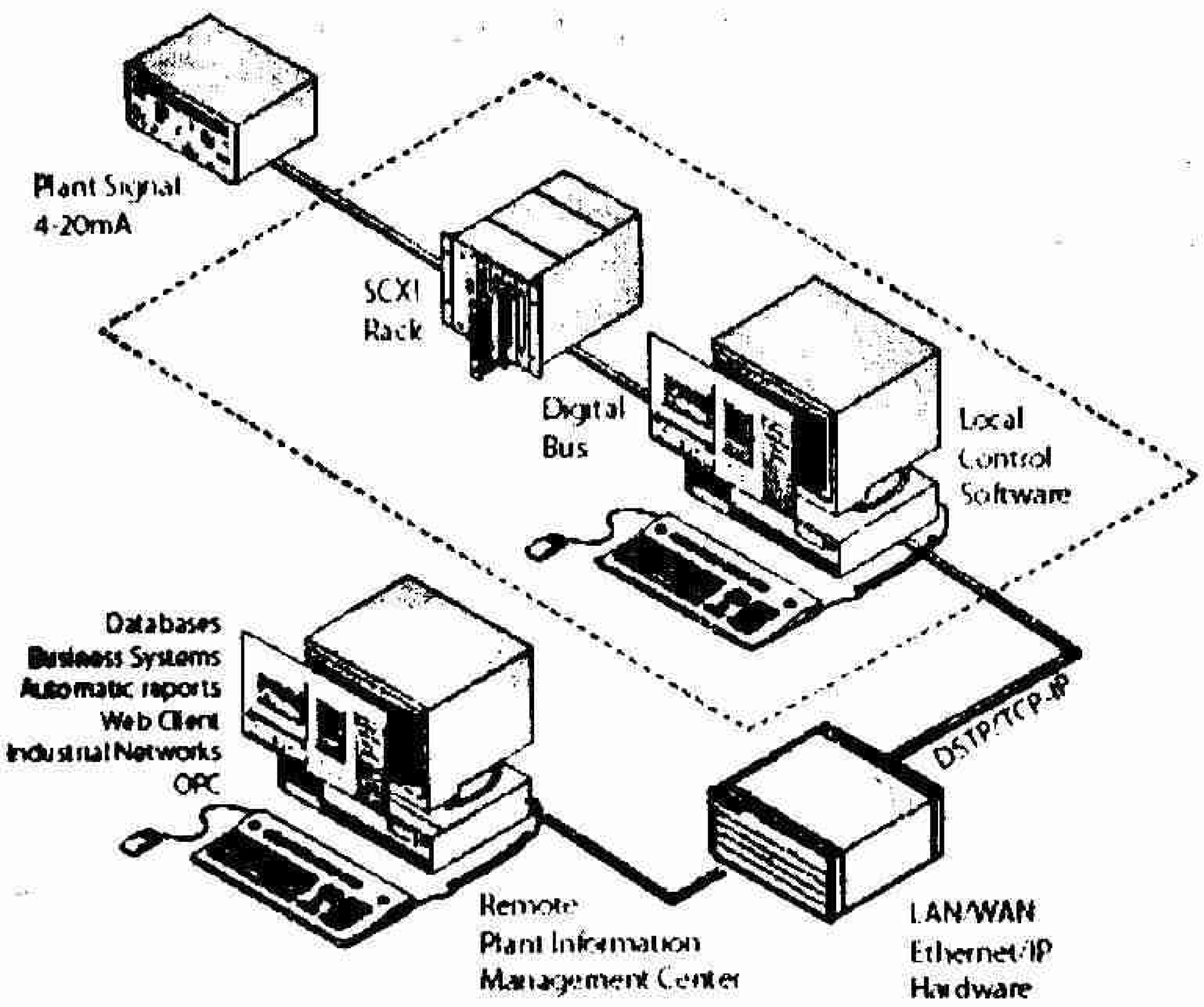

Fig 4: The Complete System

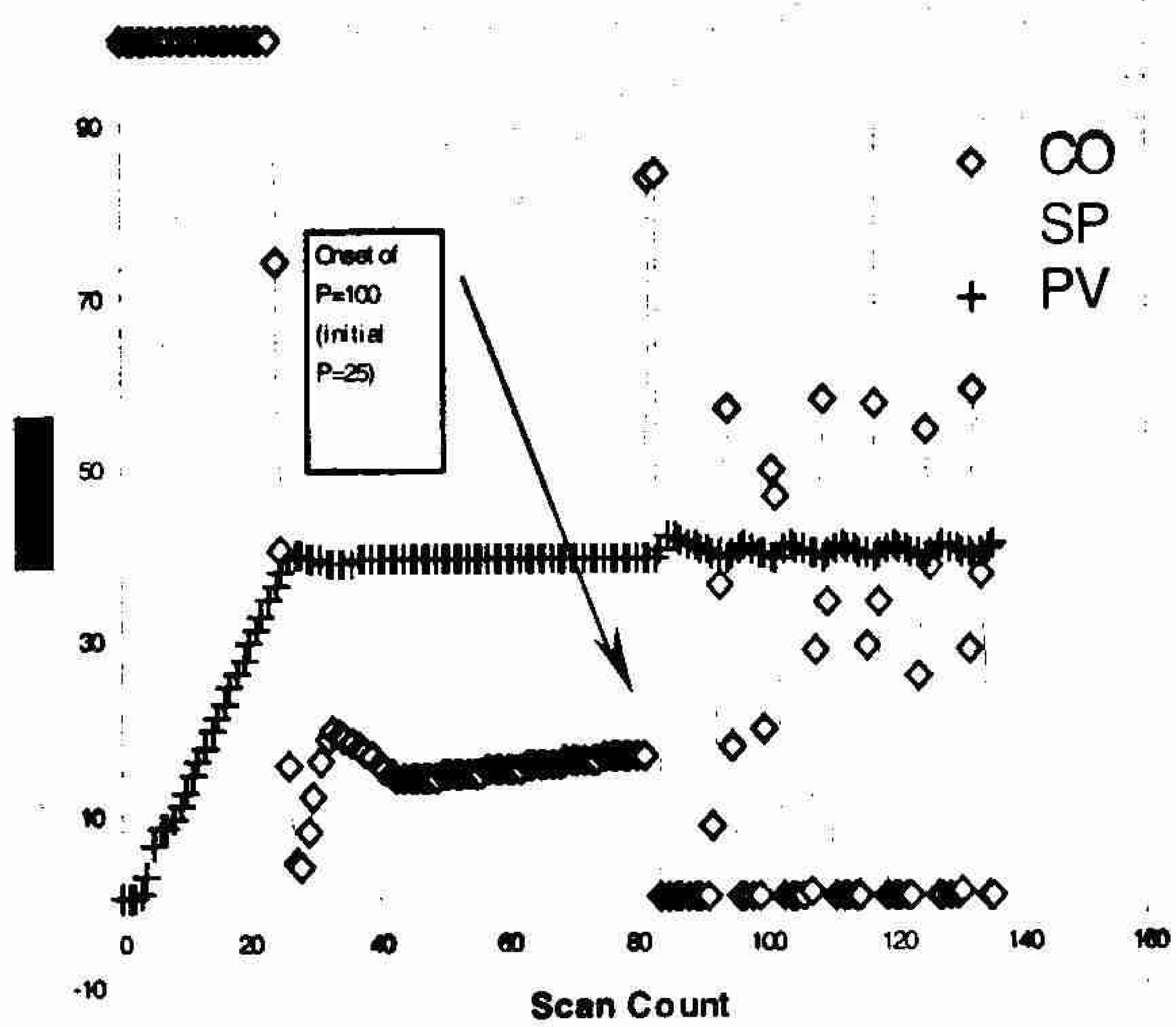

Fig 5: **Input output process data from the test rig for a change in Proportional Gain of the PID control algorithm at a scanning rate of one sample per second.**

Validation of the System

The Control Software was developed with options for logging all process data and PID control parameters to the local hard disk drive. An add-in for Microsoft Excel was developed to import the ASCII data from the SCADA system directly into an Excel workbook. However, it should be emphasized at this point that the data can be exported to any program, such as Matlab, MathCAD, Mathematica, HiQ, Maple etc.

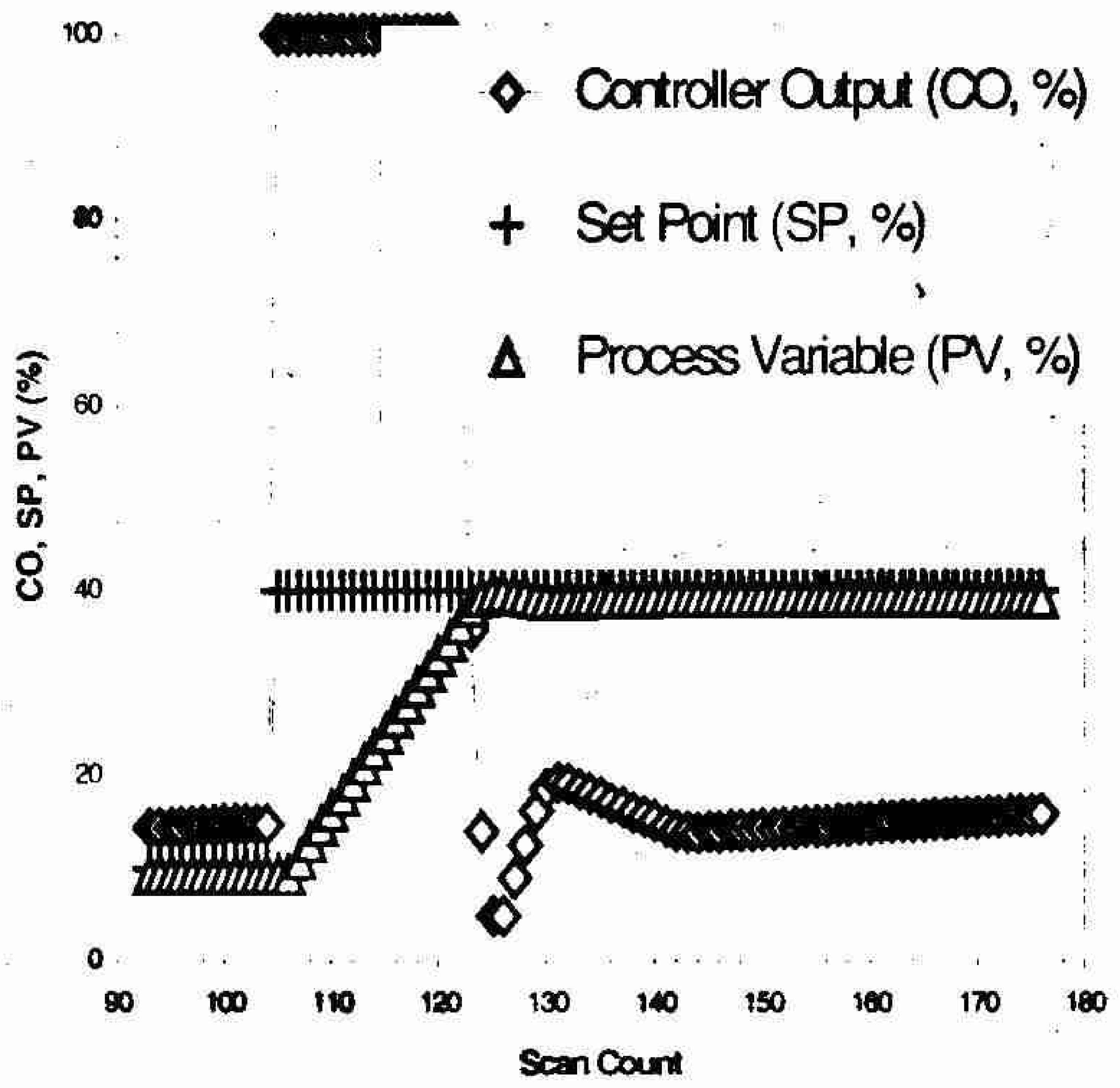

Fig 6: Controlled Output, Set point and Process Variable data from a single tank level control loop while it was responding to a step change in set point at a scanning rate of one sample per second.

The data from the next two plots show one of the PID loops of the developed system in action. To reduce unnecessary valve movement, the signal sources from the rig are filtered using an averaging filter. This is done to reduce control valve jitter and consequent drop in the valve's useful life without compromising data quality that is necessary for safety, alarm and trip event handlers. The alternative, reducing scanning rate, has the potential of anti-aliasing the incoming data.

Conclusion

When a process plant is developing its own control software and implementing control strategy in-house, vendors of control systems and hardware have less work to do. The cost of labor is very high in countries where these package providers develop their systems. This makes a difference in cost between a packaged control system from solution providers and building the control solution in-house. Most development software that can be used to develop control applications in digital computers has no royalty constraint. On the other hand, almost all package solution providers charge for using each copy of their proprietary software. The story goes and on. The digital computer based system that was developed and studied on the test rig successfully removes some of the critical limitations of conventional control systems. Although this is not a total solution, this is a technology preview, an important stepping-stone to the more robust arena of plant automation.

The work done have shown that using computer based, distributed automation, it is possible to develop total solutions across the entire value chain of a chemical process plant. Only such a vertically integrated industrial information management system can ensure safety and survival of a chemical plant in today's marketplace.

Future Development

For high reliability, it is possible to embed the control software code into a dedicated SCADA computer in a PC adapter board running an embedded operating system that continues to operate even if the host operating system fails. Even with an embedded adapter, the cost is significantly lower than any similar capability package offered by control solution providers. All this is without taking into account the fact that there is no need for any data logging hardware (pen-chart recorders etc.) on a per-channel basis. The control application can be programmed to log process data and stream it to a storage device connected to the digital computer (Tape drive, MO drive or RAID).

Computer-based real-time process optimization is an area of control engineering that will see active growth in the future. High-speed, inter-operable hardware will accelerate the development of control systems that is more economic than any in the past. Safety and reliability of process plant will continue to increase to even higher levels, and this will save money as well as lives. The field of plant automation is the new frontier of process control. Modern digital computers give the control engineer an unprecedented level of computational and analytical power, which is limited only by his/her knowledge and ability. The integration of business information networks with plant information networks means that a plant is no longer an isolated island of data. It is indeed a world that is getting smaller everyday.

Bangladesh Perspective

Modern process control in Bangladesh is largely limited to PLCs and distributed control systems, mostly in the private sector. Although Bangladesh produces a good number of high quality chemical engineering professionals each year, there is surprisingly little effort to utilize them. Investing in in-house development of control systems has the potential of utilizing the engineering expertise of the country's chemical engineers, as well as saving the local industry large sums of money. At a time when Bangladesh is facing increasing economic adversities, building a knowledge-based economy where it is developing its own technology, can be extremely beneficial.

The work done has demonstrated that it is possible to develop viable technology in a developing country that is as good as anywhere in the developed world. As world's economic scenario becomes more and more competitive every day, this is sure to be the key to survival.

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