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FULL-LENGTH ARTICLE

Performance validation of a cascade control system through various network architectures

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Abstract The work analyzes the performance characteristics of a cascade control system when interconnected with various network architectures, such as Internet, mobile and wireless networks. The cascade control system consists of level and flow as primary and secondary variables, respectively. The web-enabled monitoring and control are realized using three techniques namely remote client–server, ActiveX-data socket and web publishing tool. Mobile network is established by interfacing the control system with a GSM modem which enables the monitoring of process parameters through mobile phones. The cascade control system is also monitored wirelessly from remote locations with advent of an indigenous wireless sensor node. The performance analysis proved that wireless monitoring may be considered as an effective alternate technique to the Internet-based communication especially for shorter distances.

1. Introduction

The vital role of network mediated automation has been significantly appreciated in almost all kinds of industries in the last three decades. The networking of industrial processes can be established over a small-scale network as intranet (LAN) or over a large-scale network as Internet (WAN). The makeover process of Internet communication in conventional process environment is influenced by many factors, including number of nodes, Internet bandwidth, time-delay, processing speed, amount of data, managerial policies, safety and security [1,2]. Classical control theory suggested that a delay in the control loop is an important factor causing the system instability as it increases the phase shift between the input and the output signals of the control system and this limits the maximum allowable gain [3]. Some researchers reported as today's Internet provide no real time guaranteed delivery and have essentially unbounded end-to-end latency [4]. On the other hand, reports have experimentally proven that time-delays associated with the network do not affect most of the industrial process plants because of their sluggish nature [5,14]. In general, Programmable Logic Controller (PLC) and SCADA have been widely adopted for monitoring and controlling in many

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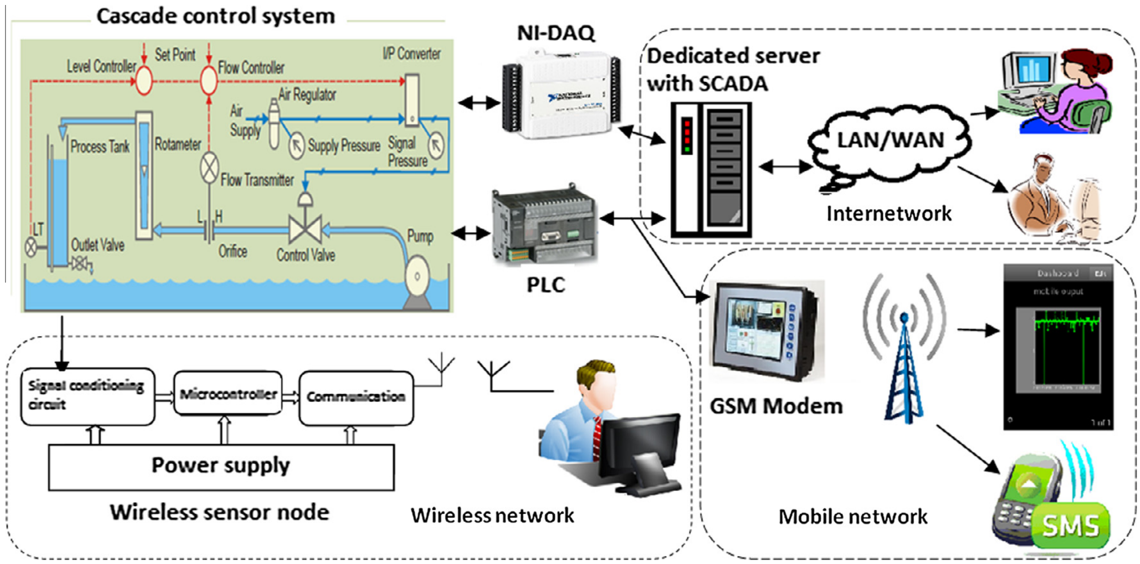

Figure 1 Functional block diagram of various network architectures enabled cascade control system.

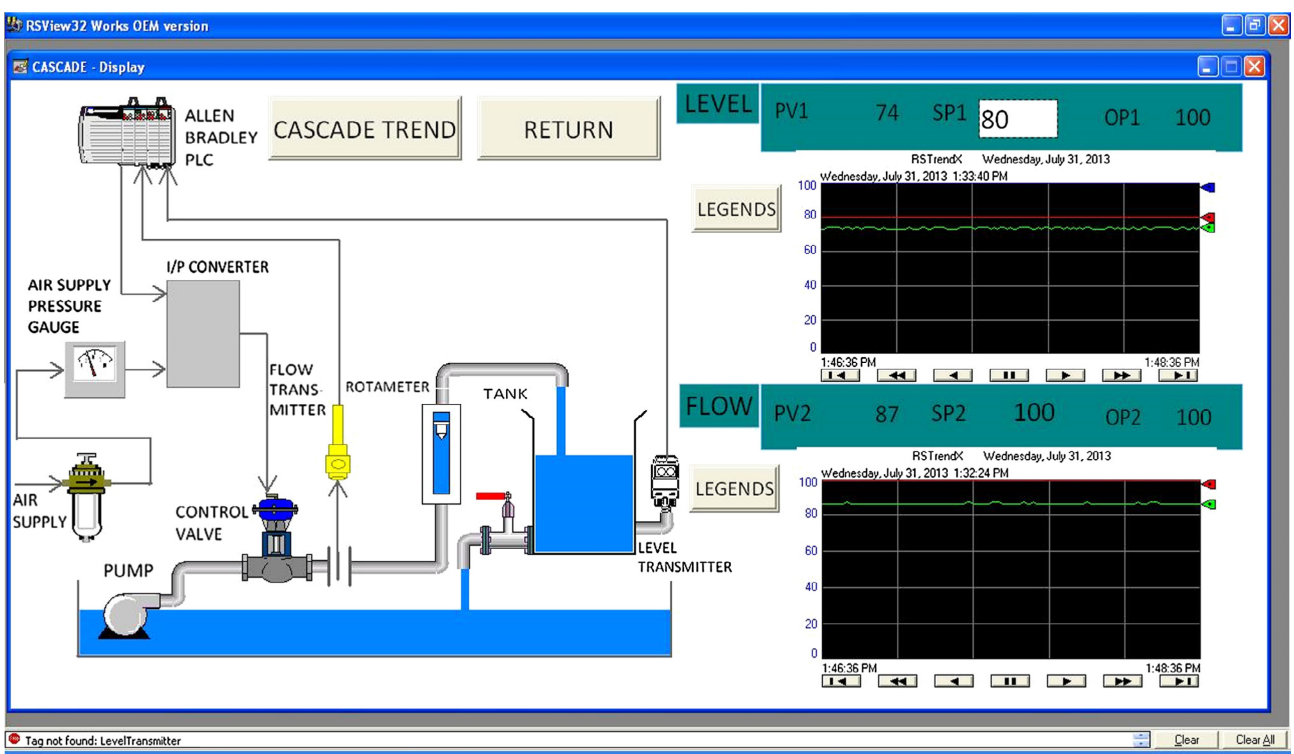

Figure 2 SCADA representation of cascade control system.

process industries. They have great features, including flexibility, reliability, low power consumption and ease of expandability [6,7]. SCADA stands for Supervisory, control and data acquisition which offers graphical visual representation of process parameters even from the remote places [7]. It is understood that the efficiency of plant automation can be further improved by integrating PLC with SCADA through tags of information [8–11]. The Internet based engineering laboratories are seen as revolution in technical education which not merely brings the equipments to the student's home but also ensures sharing of resources among universities [12,13]. All the leading PLC manufacturers including Siemens and Allen-Bradley have started to adapt the web-enabled automation in order to increase the productivity.

Most of the industries prefer to use wireless communication as it scores better than the wired to monitor the process parameters from remote locations. The mobile and wireless network requires minimal effort for the installation and maintenance

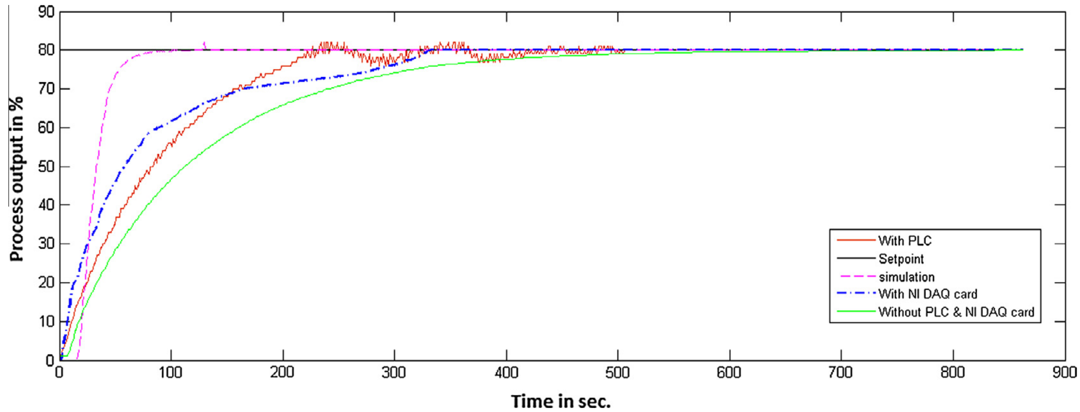

Figure 3 Performance characteristics of cascade control system.

since both not involve messy and lengthy cables [16,17]. Generally, a wireless sensor node consists of a computational module, communication module, power supply and appropriate sensing system [18,19,26]. Both wired and wireless technologies are extensively used for monitoring and controlling [16,20]. In future, both wireless sensor network and mobile communication may assume an indispensable part of our lives due to their flexibility, deployment and low cost [21].

The objective of this study is to analyze the changes in performance indices, such as peak time, rise time and settling time of PLC–SCADA enabled cascade control system when it is operated through various network architectures namely, Internet, mobile and wireless networks. The error values such as Integral Square Error (ISE) and Integral Absolute Error (IAE) are also calculated [22,23]. The cascade control system is the combination of level (primary process) and flow (secondary) processes. The web-enabled monitoring and control are realized through three techniques namely remote client–server, ActiveX-data socket and web publishing tool available in LabVIEW software [15]. The effectiveness of mobile and Zigbee communication is also practically examined. The sensor node performance is also validated by its power consumption, wireless range and throughput analysis.

2. Experimental overview

The architecture of a cascade control system integrated with various network architectures is shown in Fig. 1.

The description about the cascade control system and its performance characteristics are validated and described elsewhere [24]. In brief, the conventional cascade control system consists of a serial dual loop PID controller which has level transmitter as a primary measuring device and flow transmitter as a secondary measuring device. A dedicated communication is established through MODBUS (ADAM-4022T, M/s Advantech, Germany) with a personal computer and it is automated using SCADA based software architecture. In this study, PID is implemented on Micrologix-1200 PLC and RSView-32 SCADA has been used with RSLinx communication software. The PLC–SCADA control loop is implemented with real time data analysis, set point modifications, automatic report generation and integration of data with MS-Excel and MS-Access [24]. The controller produces controller output in the ranges between 4 and 20 mA and the same is given to I/P (current to pressure) converter which produces equivalent pressure in the range of 3–15 psi. The pressure actuates the pneumatic control valve which opens or closes and eventually the error value is brought to zero. Generally, the experiments are conducted in run-time mode and visualization and modification done in the development mode.

The cascade process is considered as the product of the transfer functions of primary loop (level process) and secondary loop (flow process). The transfer function for the cascade control system is obtained using two time constant method [25]. The transfer function is given in Eq. (1) as obtained from the experimental data.

$$\text{Transfer function } T(S) = \left(\frac{0.604}{158s+1}\right)\left(\frac{0.4}{4.2s+1}\right)e^{-6s} \qquad (1)$$

The web-based architecture of cascade control system is created with four functionalities, such as publishing process variable over the Internet, sharing of data, remote control and distributed execution. An industrial standard GSM modem (M/s Horner GSM 0308) is programmed using CSCAPE software to monitor the live status of cascade control system. The modem is operated at 900 MHz with the power transmission of 2 W. The modem has been configured to deliver the alert message that can contain up to 20 variables to the registered users for every one minute. This duration can be reprogrammed for any minutes, for seconds and for hours depending on the requirement.

A wireless sensor node that has been constructed using PIC18LF4620, a nano-watt microcontroller is used along with Zigbee wireless communication module (MRF24J40). The sensor node operates at 2.5 GHz frequency with the data rate of 250 Kbps [26,27]. In this study the wireless sensor node described in [26] is successfully interfaced with cascade control system.

2.1. Interfacing of wireless sensor node with cascade control system

The microcontroller in wireless sensor node has been programmed as a full function device (FFD) and is responsible for operations such as computation, conversion of sensed information into respective engineering unit and to perform the execution of Zigbee protocol stack for wireless communication [28,29]. After immediate initiation, the node is

Table 1 Performance characteristics of cascade control system.

System characteristics	Simulation	Without PLC and NI DAQ card	With PLC	With NI DAQ card
Integral Square Error (ISE)	1.60E+05	3.70E+05	2.60E+05	1.95E+05
Integral Absolute Error (IAE)	2541.43	9185.6	6277	5766.44
Peak time (t_p in sec)	–	–	234	–
Rise time (t_r in sec)	41	186	129	59
Settling time (t_s in sec)	107	838	406	332

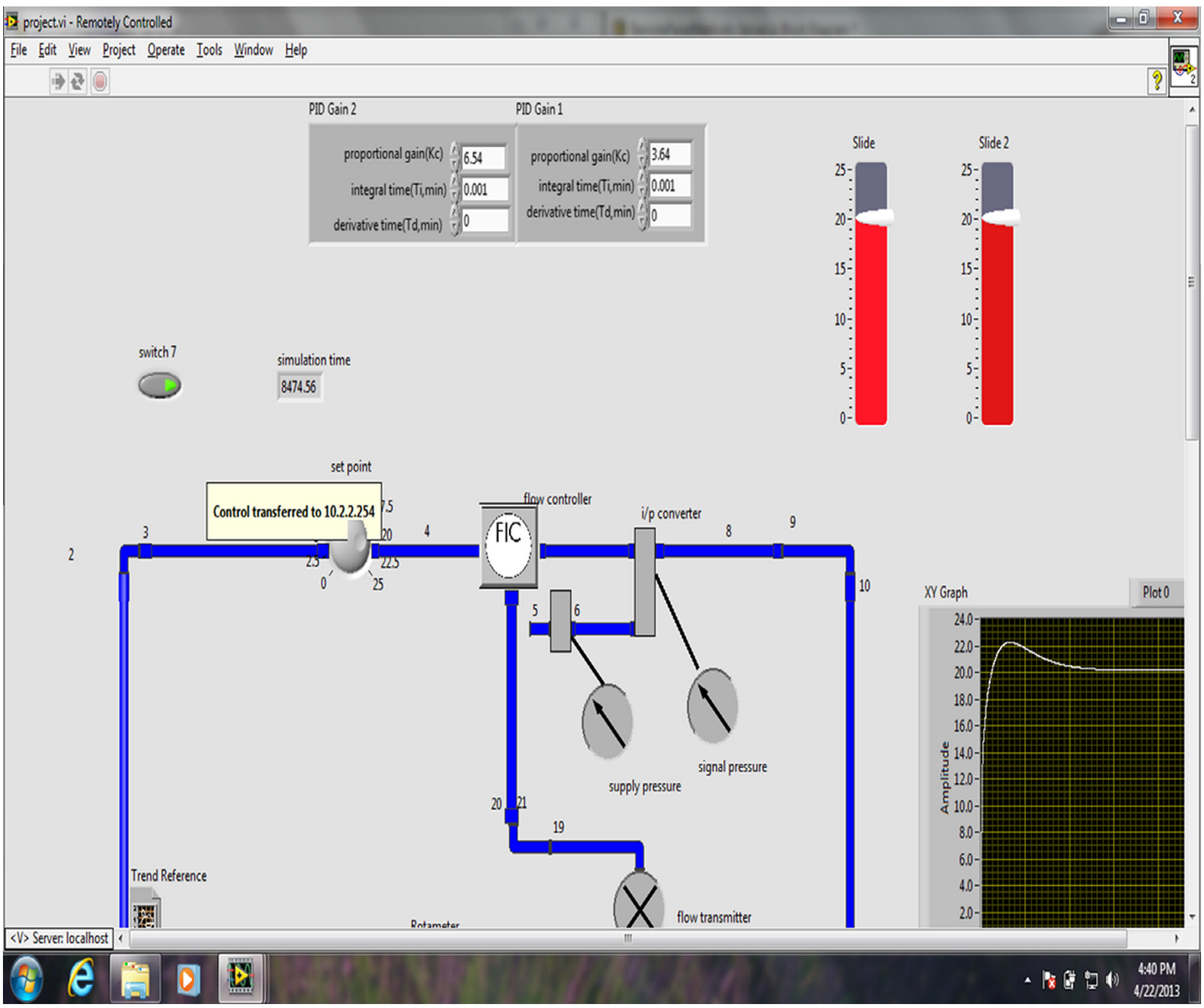

Figure 4 Monitoring and controlling over the Internet using remote client–server method.

programmed to read the corresponding sensor port, performs computation and eventually transmits the signal before it goes to sleep mode. The software design of Zigbee protocol specifications is implemented in medium access control layer (MAC) [30]. The hardware configurations are initiated and the Zigbee processes are invoked to establish the wireless network. After establishing the network, the primary process variable (level) is collected and eventually the computational analysis is performed. After successful transmission of message the sensor node is entered into sleep mode for every 2 min and the above procedures are repeated [26,27]. The present study compares the performance of wireless sensor network with mobile communication as an extension of previous work described elsewhere [27].

3. Results and discussion

Fig. 2 shows the SCADA representation of cascade control system and its operational sequence. The process can be monitored either by individually (flow or level) or concurrently both at a time. It has been configured to have history of data by linking it with Ms-Excel.

The performance characteristics such as peak time, rise time and settling time of cascade control system when it is

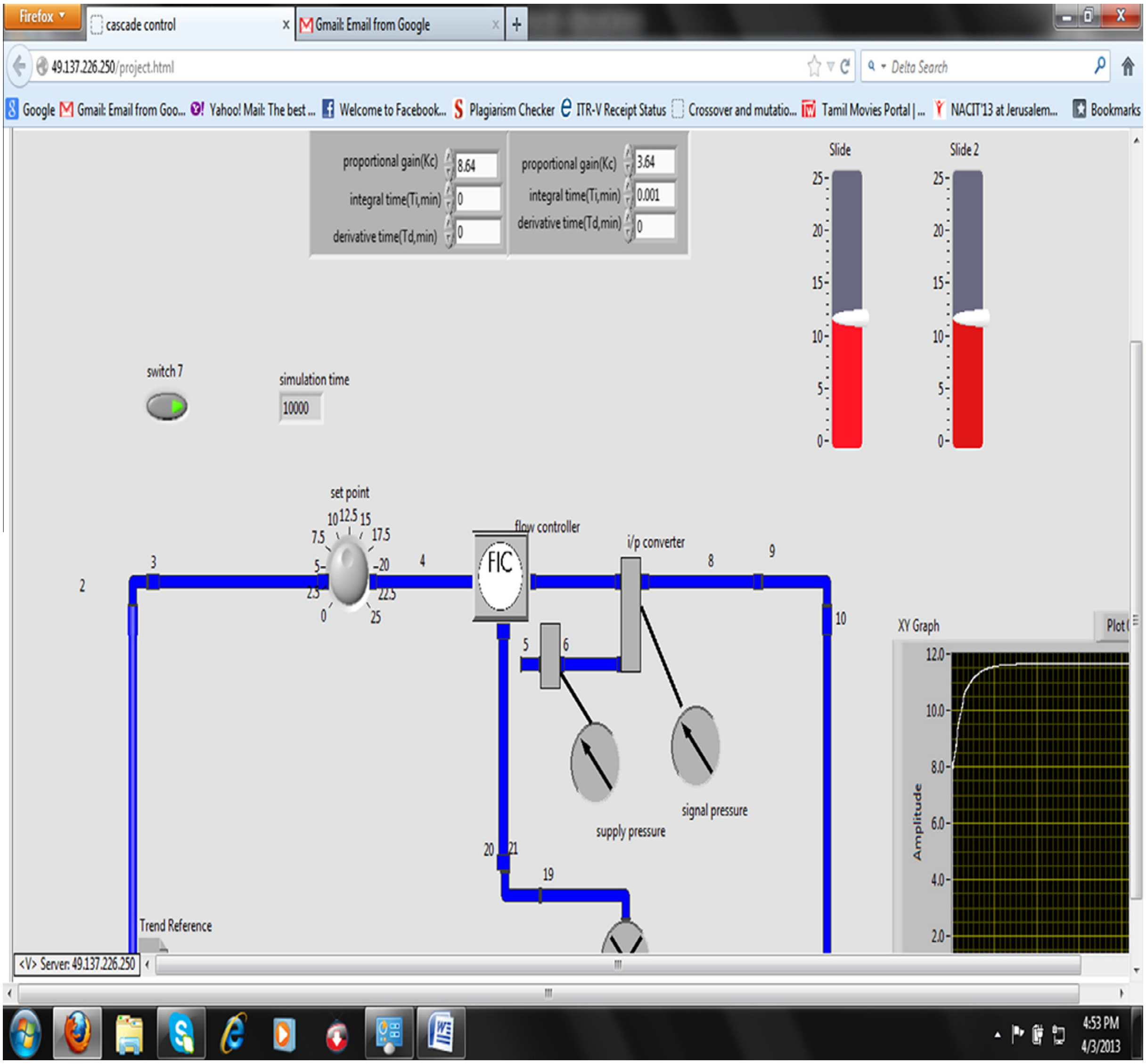

Figure 5 Monitoring and controlling of process parameters using web publishing method.

interfaced with NI-DAQ card are evaluated. It is found that, the system when it is interfaced with NI-DAQ card shows minimal rise time and settling time with minimal error than it is interfaced with PLC which is shown in Fig. 3 and in Table 1. Also, the overall performance of the system significantly improves and eventually becomes more stable. Such improved performance can be attributed through data acquiring speed of NI-DAQ.

The cascade control system that integrated with NI-DAQ card is successfully made available in Internet by using three methods, namely remote client–server, ActiveX-data socket and web publishing tool.

3.1. Details on remote client server method

In the remote client–server method, it is presumed that both client and server machines are installed with similar version of LabVIEW software. To establish a connection, three components, such as IP address of server, name of program and port address are required. The connection will be established after server machine acknowledges the connection request from client by providing the IP address, program name and port address. The client must enter the IP address of the server and the name of program to be controlled with port address. Once the connection is established, the client machine is allowed to monitor as well as to change the process variables from remote location which is shown in Fig. 4. The server machine regains its control over the process whenever the connection has been terminated.

3.2. Details on web publishing tool method

In this method, LabVIEW software needs not to be installed in all client machines. However, a LabVIEW runtime plug-in engine called web server has to be added with web browser at the client side. The initial access control over the process from server is transferred to the client when client invokes the connection by accessing the URL of the Internet server

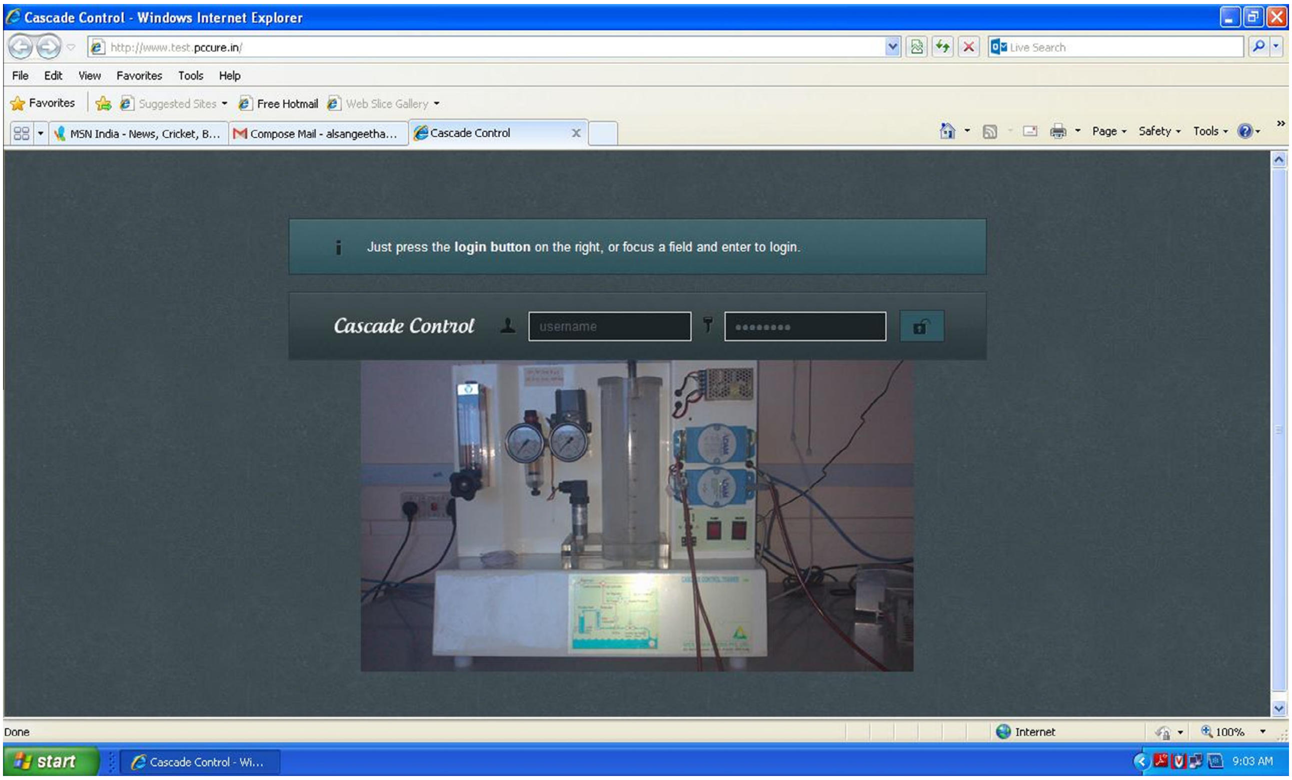

Figure 6 Screen shot of web page created for cascade control system.

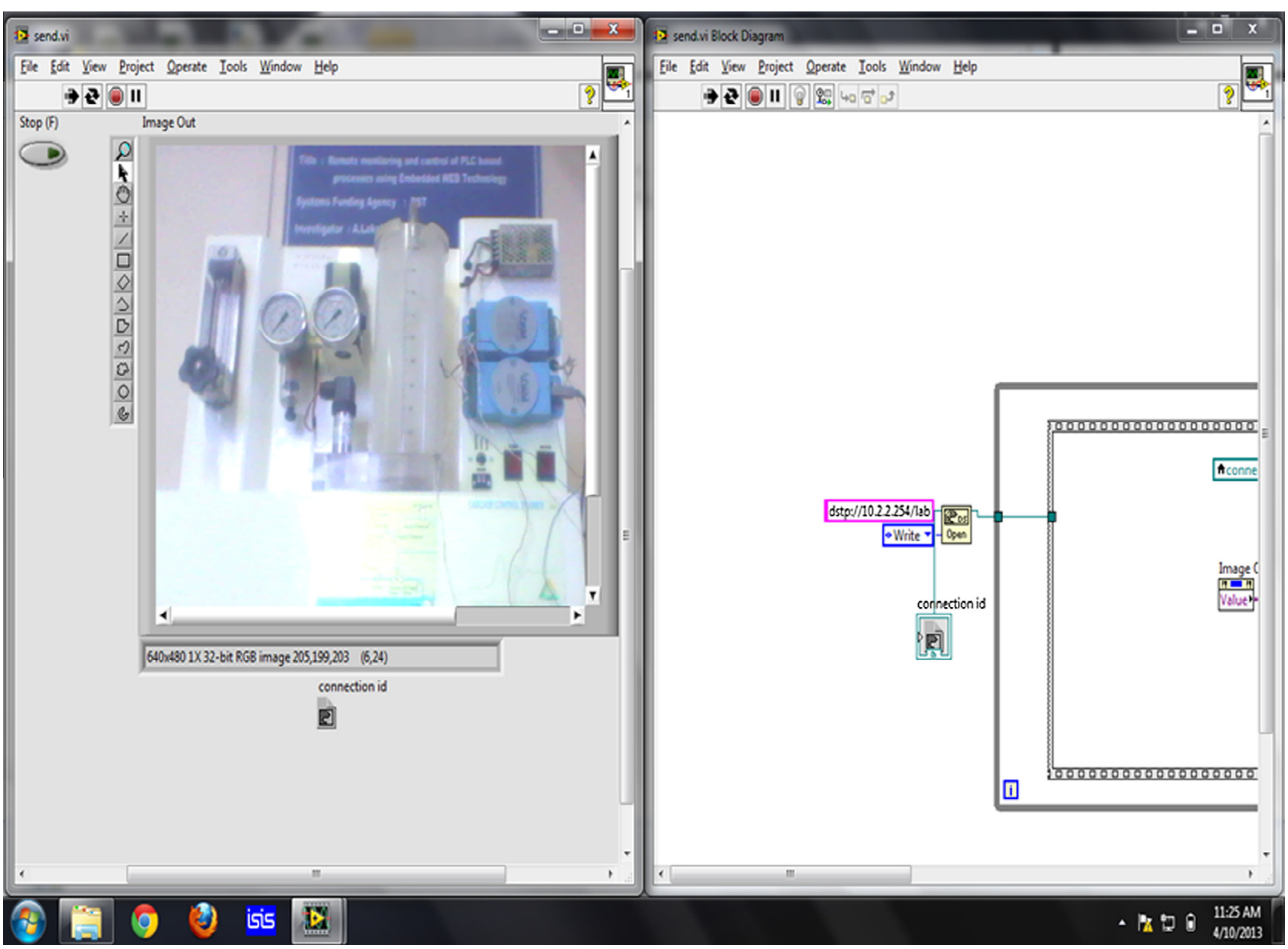

Figure 7 Accessing remote application using data socket method.

Table 2 Functional differences between various methods available in LabVIEW for web applications.

Methods	Range of applications	User interaction	Security	Cost	Additional software
Remote server client	Within LAN	Very good (no lag)	Good	Requires LabVIEW in client side	None
Web publishing tool	No restriction	Depends upon Internet bandwidth (0–2 s)	Good	None	LabVIEW Run Time Engine (Web Browser Plug-in)
Data socket-ActiveX	No restriction	Depends upon Internet bandwidth (0–2 s)	Minimum	Additional LabVIEW Software	NI Vision Acquisition NI Vision Run Time Engine

through web browser. The client is now able to view and change the set point through web browser which is shown in Fig. 5.

A URL http://test.pccure.in has been created using PHP (Hypertext Pre-processor) and to evaluate the performance of process control system over the internetwork. A minimum level user authentication mechanism has been provided using CGI scripts to ensure an authenticated user by prompting to enter username and password as shown in Fig. 6. The web page is configured to be accessed by many clients simultaneously. The user can view the response as graphical chart which is uploaded at server side.

3.3. Details on data socket and Active X method

The ActiveX-data socket is used to build interactive Internet-based process automation. It allows the user to broadcast as well as to receive high content live data as shown in Fig. 7. To access this method, the LabVIEW software has to be installed with ActiveX controls. Both client and server should have similar version of LabVIEW environment and the output of data socket can be viewed through web publishing tool. The functional and performance characteristics of all three methods are compared and given in Table 2 [31].

3.4. Details on mobile and wireless sensor network

For the mobile-based applications, the GSM modem is configured to display both primary level value and secondary flow values. The screen shot of message appeared on a mobile phone is shown in Fig. 8.

The message is delivered for every 1 min. to the mobile user. Fig. 9 shows the corresponding value of process output against the time period.

The wireless sensor node is programmed to capture the process parameters at a regular time interval of 2 min. It is clearly observed that the sensor node is able to track the process variable continuously which is shown in Fig. 10. From the results, it is understood that the integration of wireless and mobile network creates the possibilities of tracking the process variables from remote locations, very efficiently. The performance comparison between mobile and wireless network is evaluated based on the settling time of cascade control system. The wireless sensor node has a less settling time of 240 s. compared to mobile network which has a settling time of 300 s.

The cascade control system is interfaced through NI-DAQ and the communication is streamlined to match the data rate

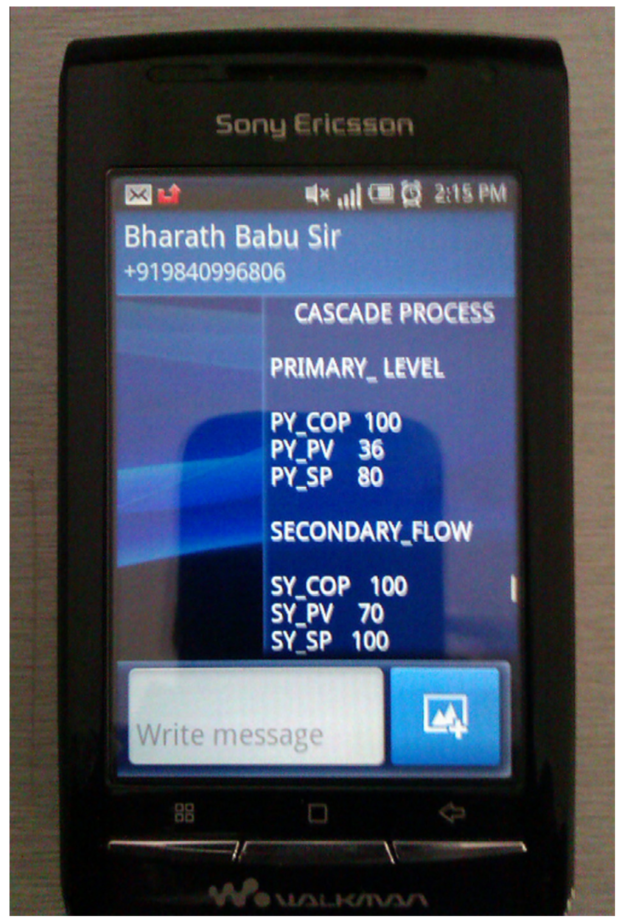

Figure 8 Short message in a mobile phone.

to ethernet connectivity. For the wireless network, the data rate of wireless Zigbee communication is 250 Kbps, so the packets are sent as much higher speed to the coordinator node. The effect of time-delay in both wireless and Internet communication on the process parameters is noted insignificantly. In other words, there is no significant time delay and its impact on the monitoring of process parameter of system is observed. Further experimental analysis is required on the obtained resultant data for the effective usage of combined NI DAQ-PLC–SCADA-Wireless network–Mobile interface in industrial applications. In addition, intelligent controllers need to be adopted to make the control system compatible to the operators. Security systems also need to be strengthened and

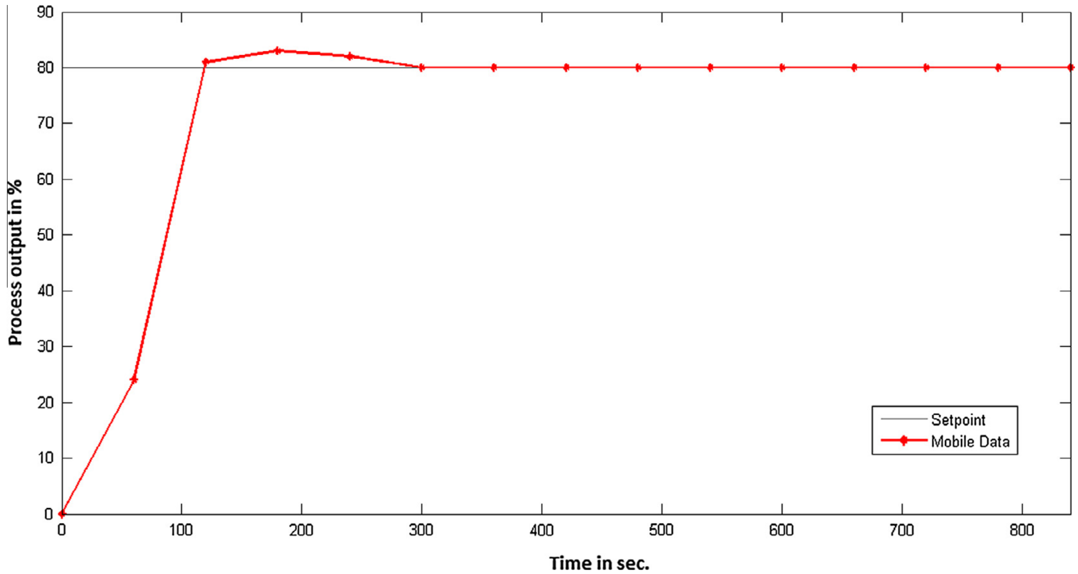

Figure 9 Process output received at mobile phone at an interval of every 1 min.

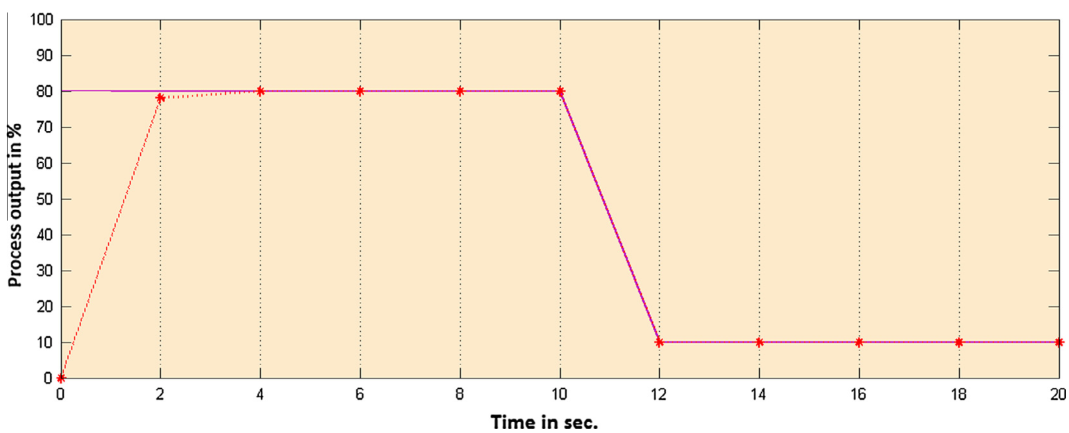

Figure 10 Process parameters received through wireless sensor node.

eventually safety of operators should be ensured. In the near future, miniaturization of components used here is envisaged.

4. Conclusions

A stand-alone cascade control system is made available in Internet and the process variables are published, shared and controlled. The web publishing tool method is found very useful for the web related applications as it does not require any additional software to be installed in the client machines. Further, it provides good security and can be accessed through most of the available web browsers. The performance indices of cascade control system are analyzed and it is found that the control system is operated very efficiently when it is interfaced with NI-DAQ card. The compatibility of sensor node is verified and it has been successfully integrated with cascade control system. The results obtained create the possibility of using wireless and mobile networks for other industrial process monitoring applications.

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