Design of Flexible and Cost Effective Universal DAQ Device for Remote Monitoring and Control of Industrial Processes

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ABSTRACT: There is lot of benefits for industrial process plants to adopt the ethernet to control systems. This contribution allows the systematic design methodologies for the implementation of remote monitoring and control over the Local Area Network. A web server is for such purpose where the PC located in long distance can communicate with the process through LAN. Pressure station is taken for monitoring and control over remote location. A simple pressure process where the drum pressure in psiis controlled using a PI controller. A DAQ hardware is taken for this purpose. A low cost DAQ device is designed where it can provide interfacing of the station with MATLAB or LabVIEW. Arduino (ATmega328p) controller with 10 bit ADC is used to acquire signals and communicate with the PC through USB. A current to voltage converter (RCV420) and a voltage to current converter (XTR110) is used for interfacing the process station with the Arduino UNO. This project also aims to develop remote monitoring and control environment of process station through Local Area Network. The process station for this purpose is chosen as pressure process analyser. The resulting hardware has been tested by connecting pressure process station with the PI controller developed in LabVIEW.

KEYWORDS: RCV420, XTR110, Arduino UNO, ATmega328p, DAQ, USB, Pressure Process Station, MATLAB, LabVIEW, LAN, ADC.

I.INTRODUCTION

The physical real world phenomenon is measured using a data acquisition device. The components of a data acquisition device are transducers and sensors, signals, signal conditioning, DAQ device, driver and application software. A Piezoelectric Pressure Transducer (DPT) is used to convert the physical phenomenon into an electrical 4 to 20 mA signal. Signal conditioning involves amplification, attenuation, isolation, bridge completion, simultaneous sampling, sensor excitation, multiplexing. For a process control application voltage to current and current to voltage converters are required. Controllers can process the signals in voltage form. The data acquisition is performed using an Arduino UNO (ATmega328p) controller board. This controller performs the function of converting the analog signal into a digital signal so that it can be processed in the computer. data transmission between DAQ device and PC is made through USB. The application software LabVIEW provides the possibility of control and monitor a process from remote locations. The web publishing tool allows the user to create a web server which can be used to view the front panel from any PC connected to LAN through web browser.

II.REVIEW ON DAQ AND REMOTE CONTROL

Aniket et al (2014), proposed the design of a cost effective, better resolution, simple structure and high reliability features. Data acquisition system is compatible to most of the PC and laptops and its design is interfaced to the serial port of the PC in which data converted and passed on to the computer. Laboratory Virtual Instrument Engineering

Workbench (LabVIEW) application on the computer acquires the data and plots on the appropriate graph and indicators of respective transducers.[1]

Hong Yan Li (2005), proposed that there are five essential design issues that arise from Web-related features of Internet-based remote control. Uniquely, novel network communication architecture and optimal control structure with time-delay compensator are implemented to deal with dynamic delays caused by the Internet traffic.[4]

Lita I et al (2009), Proposses that wireless technologies represent reliable and efficient solutions for remote data acquisition, supervisory and control systems. The correct selection of the proper transmission method from the wide variety of wireless radio transmission methods and standards represents an important issue. The newest and most efficient wireless technologies suitable for remote data acquisition and monitoring of environmental parameters is presented.[8]

III.PROPOSED METHODOLOGY

The process variable is measured by digital pressure transducer. This 4 to 20 mA level signal is transmitted via parallel port to current to voltage converter where the signal is converted to 0 to 5 volt. This 0 to 5 volt is given to Arduino UNO where the analog voltage is converted to digital form by a 10 bit ADC inbuilt in the board. Using a USB interface the digital data is transmitted to the PC. LabVIEW acts as a controller. The output is a percentage opening of the controller in terms of voltage which is sent to the Arduino UNO. The PWM (Pulse Width Modulation) is used to convert the digital signal to analog voltage (0-5V) signal. The voltage to current converter is used to convert the 0-5V signal to 4-20 mA signal. The converted signal is fed to the process station.

A. Signal Conditioning Unit

The current to voltage converter converts 4 – 20mA current signal to 0 – 5V voltage signal. The amplifier output is offset to an amount, $VOS = –(4mA)(0.3125V/mA) = –1.25V$ to get the desired output (0V for 4mA and 5V for 20 mA). +In or –In pin is used as input for the current signal. Depending on the polarity, the signal is returned to ground through the center tap, CT. The sense resistors are used to convert the input current signal into a corresponding voltage, where the differential amplifier amplifies it. The voltage gain of the amplifier is given by, $AD = 5V/(16mA)(75\Omega) = 4.1667V/V$. according to the amplifier's common-mode signal capabilities, the input resistor network provides high-input impedance and attenuates common-mode input voltages to suitable levels.

In voltage to current converter, the pins 3, 4, 5, 9 and 10 specifies the ranges of input voltages that can be converted to specified ranges of output current signals. RSPAN is the total impedance that can be seen at the emitter of the internal NPN transistor. According to the configuration of pins 8, 9 and 10, the impedance varies. QEXT or P-channel MOFET is the external pass transistor that conducts the output current signal. QEXT could fail if the supply voltage, +VCC, exceeds the gate-to-source breakdown voltage. To protect QEXT, the gate-to-source breakdown voltage is lower than +VCC with a 12V zener diode connected from gate to source.

B. Analog to Digital Conversion

Arduino UNO consists of an inbuilt 10 bit ADC. Pin A0 to A5 in Arduino UNO represents analog inputs. The 10-Bit ADC in Arduino has the ability to detect 1,024 (2^{10}) discrete analog levels. The ADC assumes 5V is 1023 and anything less than 5V will be a ratio between 5V and 1023. The formula to calculate ADC resolution is given in the.

$$\frac{\text{ADC resolution}}{\text{Board voltage}} = \frac{\text{Obtained digital binary value}}{\text{Measured analog voltage}}$$

C. Digital to Analog Conversion

Digital to analog conversion is performed by Pulse Width Modulation (PWM). To get analog results with digital means, PWM is used. Using digital control a square wave signal is switched between ON and OFF. By varying the portion of the time the signal during ON versus the time that the signal during OFF, The on-off pattern can simulate

voltages in between full ON (5 Volts) and OFF (0 Volts). The ON time duration is called the pulse width. The output of a PWM channel is either 5 volts during the pulse or zero volts otherwise. If this signal is supplied as input to a device that has a response time much larger than τc, the device will experience the signal as an approximately DC input with an effective voltage of Veff = Vs $\tau o \tau c$. The ratio $\tau o/\tau c$ is called the duty cycle of the square wave pulses. The effective DC voltage supplied to the load is controlled by adjusting the duty cycle.

D. Virtual Lab

LabVIEW networking involves monitoring and control of remote of the process remotely through internet and LAN. The station being virtually presented. DAQ is a part of embedded system. There is one server and multiple clients. Server has over all control over all the clients that is connected to it. Server decides which client can control and monitor the station. Only one client is active at a time. The DAQ hardware which is designed using Arduino UNO or MEGA is interfaced with the LabVIEW using Maker hub LINX tool kit. This allows the user to run a firmware wizard to initiate LabVIEW and Arduino communication. Web camera is used to view the changes happening in the pressure gauges and valve stem position when a set point is given.

IV.CONTROLLER DESIGN

An open and closed PI controller tuning is designed for the pressure process. The PI controller consists of proportional and integral term. The proportional term changes the controller output proportional to the present error value. Large values of proportional term make the system unstable. The Integral term changes the controller output based on the past values of error. So, the controller attempts to minimize the error by adjusting the controller output. The results obtained from open loop response is used to determine parameters for PI controller tuning using Cohen Coon method is taken to design the controller.

A. Open Loop Response

The open loop response is done by disconnecting the controller and feedback loop. The control valve stem position is adjusted according to 0 to 5V for its corresponding 0 to 1 duty cycle. 0 to 5V is converted to 4 to 20 mA and its corresponding 3 to 15 psi pressure signal. By setting particular voltage (eg: 2V), the process variable pressure is made to settle at a particular value from 0 to 100 Kg/cm^2. The data viewed in the form of waveform chart. The data can be exported to spreadsheet.The saved data is imported in the system identification tool box and the transfer function is obtained or by using Cohen Coon method the proportional gain and integral gain is calculated.

The calculated values are,
Proportional gain, $K_P = 0.6022$
Integral gain, $K_I = 0.162$

B. Closed Loop Response

The feedback loop and controller is included in the LabVIEW model of closed loop response. The controller is set to PI mode and the gain values are provided. Set point is given from 0 to 100 Kg/cm^2. The set point and pressure sensor reading are given to multiplexer and the output is fed to scope to view the closed loop response of the pressure process. Using waveform chart the response is obtained.

V.RESULTS

In Fig 1, the proposed hardware blocks are shown. The I to V and V to I converters are interfaced with the Arduino UNO. The hardware is interfaced with the station. The DAQ device is connected to the PC through USB 3.0 port since this port allows full duplex high speed data transfer. Once it is connected the PC device manager shows the port number such as COM 3. This port number is specified while initialising LINX in LabVIEW. In the LINX firmware wizard from the tools menu, the type of Arduino board and COM port is specified so that wizard uploads server program in the Arduino for its communication with the LabVIEW.
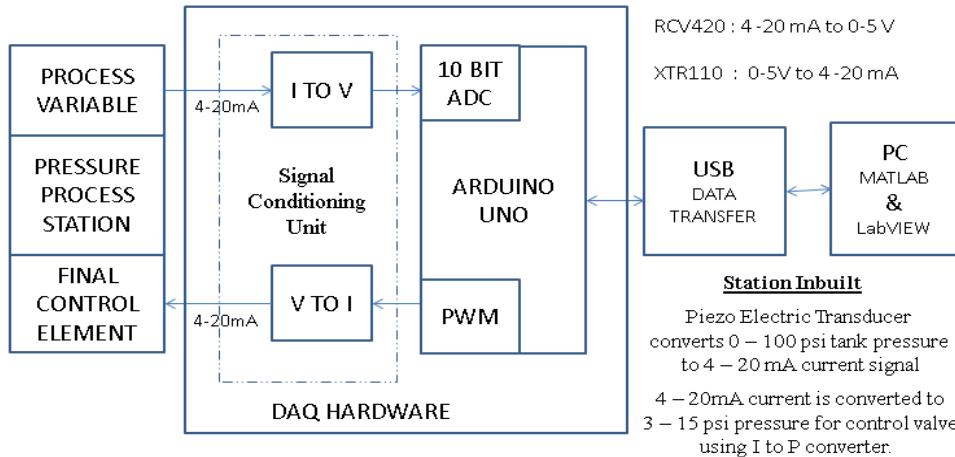
Fig. 1 Block diagram of DAQ device

The circuit of Current to Voltage convert is shown in Fig 2. The converter converts 4 to 20mA current signal to precision 0 to 5V. A supply +15V is given to the IC for functioning.
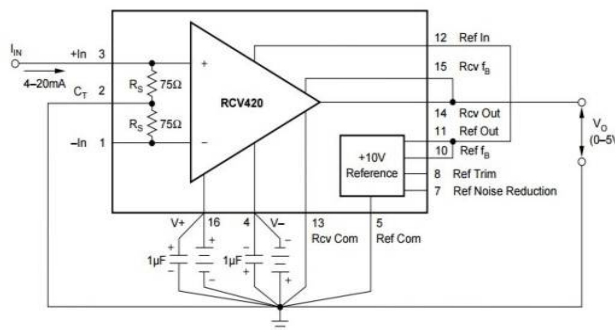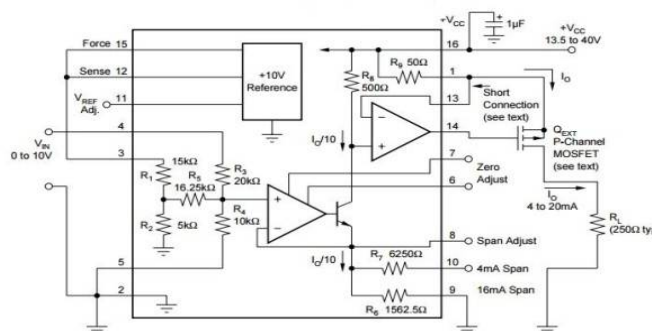

Fig. 2 Current to voltage converter circuit

In Fig 3, a Voltage to Current converter circuit is shown. The circuit converts 0 to 5V analog signal to 4 to 20 Ma current signal. A 15V supply is given to the IC.

INPUT RANGE (V)	OUTPUT RANGE (mA)	PIN 3	PIN 4	PIN 5	PIN 9	PIN 10
0–10	0–20	Com	Input	Com	Com	Com
2–10	4–20	Com	Input	Com	Com	Com
0–10	4–20	+10V Ref	Input	Com	Com	Open
0–10	5–25	+10V Ref	Input	Com	Com	Com
0–5	0–20	Com	Com	Input	Com	Com
1–5	4–20	Com	Com	Input	Com	Com
0–5	4–20	+10V Ref	Com	Input	Com	Open
0–5	5–25	+10V Ref	Com	Input	Com	Com

Fig. 3 Voltage to current converter circuit

Fig 4 shows the waveform of pulse width modulation. According to the percentage of duty cycle from 0 to 1, an analog signal from 0 to 5V is generated in the Arduino PWM pins.
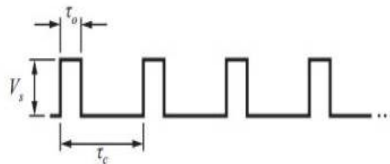

Fig. 4 Pulse width wave

Fig 5 shows the architecture of virtual lab. Virtual lab enables a person to monitor and control the pressure station from the remote locations through Ethernet communication. The communication latency is negligible.
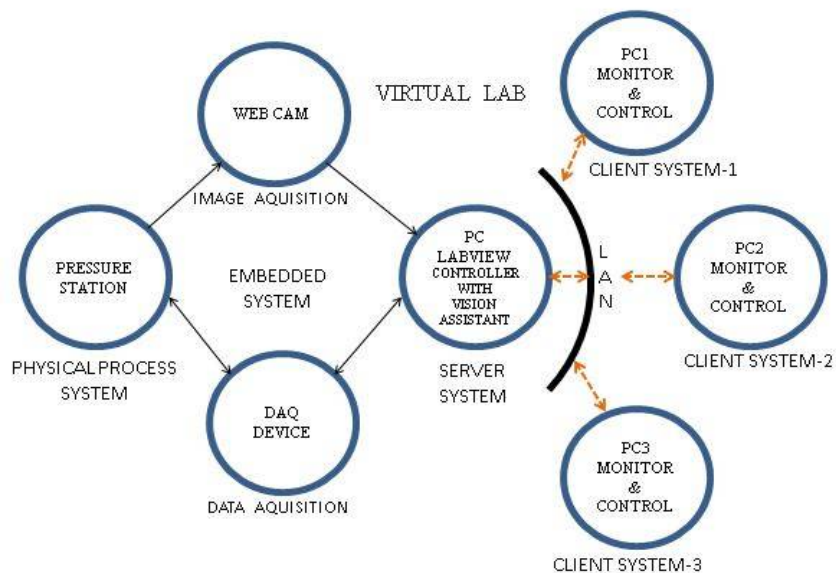

Fig. 5 Virtual lab architecture

Fig 6 shows the open loop LabVIEW model of single input single output pressure process. LINX analog read reads the analog input from Arduino and acuire in digital form. LINX set duty cycle block allows Arduino's PWM pin to generate the analog 0 to 5V.
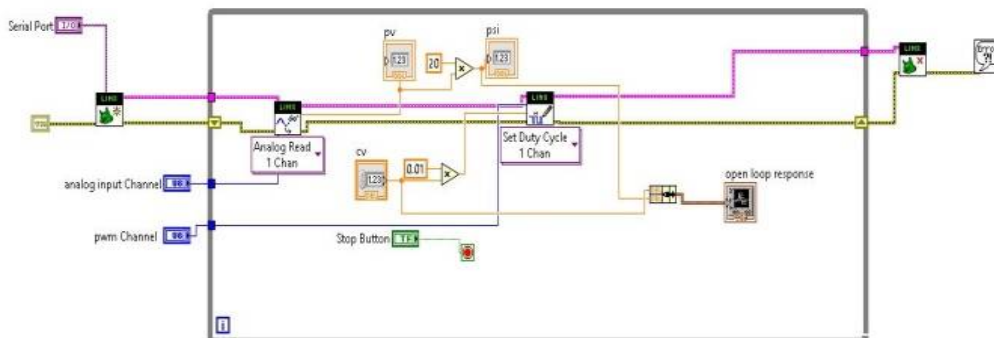

Fig. 6 LabVIEW model of open loop pressure process

Fig 7 shows the closed loop LabVIEW model of single input single output pressure process. The controller percentage output is converted to corresponding duty cycle percentage and given to LINX set duty cycle block. This block allows Arduino PWM pin to generate analog 0 to 5V signal.
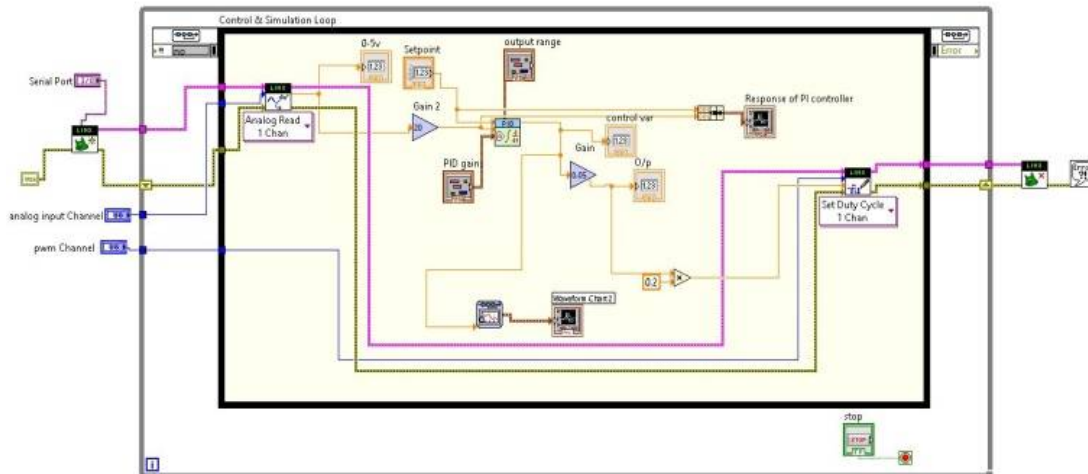

Fig. 7 LabVIEW model of closed loop pressure process

From the designed DAQ device the response curve of the pressure process is obtained using LabVIEW with Arduino. Response curve is shown in Fig. 8.The open loop response is done by setting 2V to the analog write, the process variable rise and settles at a particular pressure. The waveform chart is used to view the response curve.
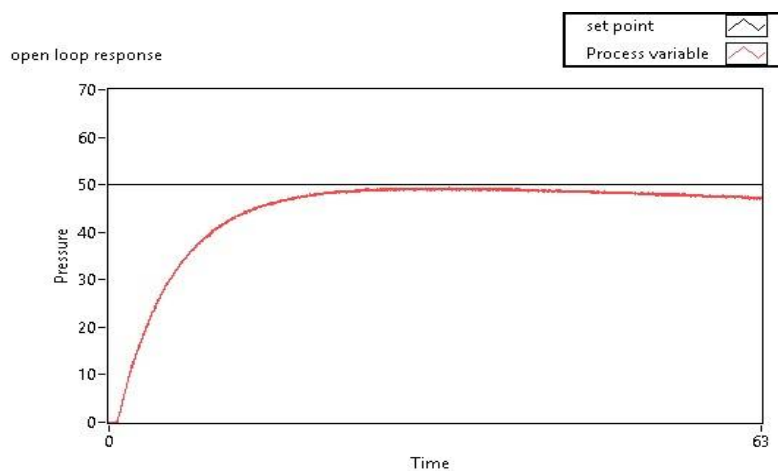

Fig. 8 Open loop response curve

For closed loop response, the set point of 50 Kg/cm^2 is given in terms of pressure. The process variable acquired is feedback to give error signal. The proportional and integral gain calculated from open loop response is entered in PI block. The block generates a signal which is converted to 0 to 255 signal using a gain of 51 for the corresponding control valve action to maintain pressure at the set point. Closed loop response curve is shown in Fig. 9.
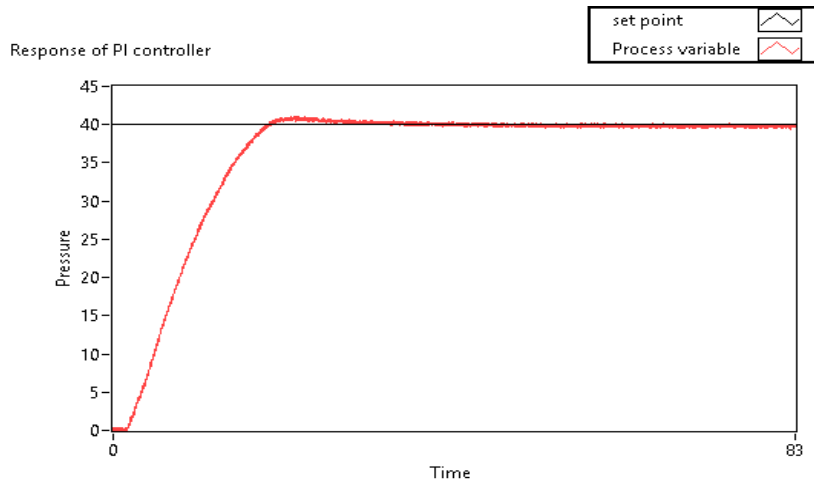
Fig. 9 Closed loop response curve

A remote front panel of the open loop and closed loop model is created using web publishing tool in LabVIEW. Under tools menu web publishing tool is selected. Figure 5.4 shows the web publishing tool dialog box. Particular VI is selected which is to be monitored and controlled. In viewing mode, embedded option is selected so that the clients can monitor as well as control. The front panel can be previewed in browser. Proceeding to the next step, the wizard will create a server name like "http://SMART-PC:8000/closed%20loop%20response.html".

This name is saved in LabVIEW server folders so that the panel can be viewed remotely by just entering this address in the browser. The remote front panel is shown in Fig.10.
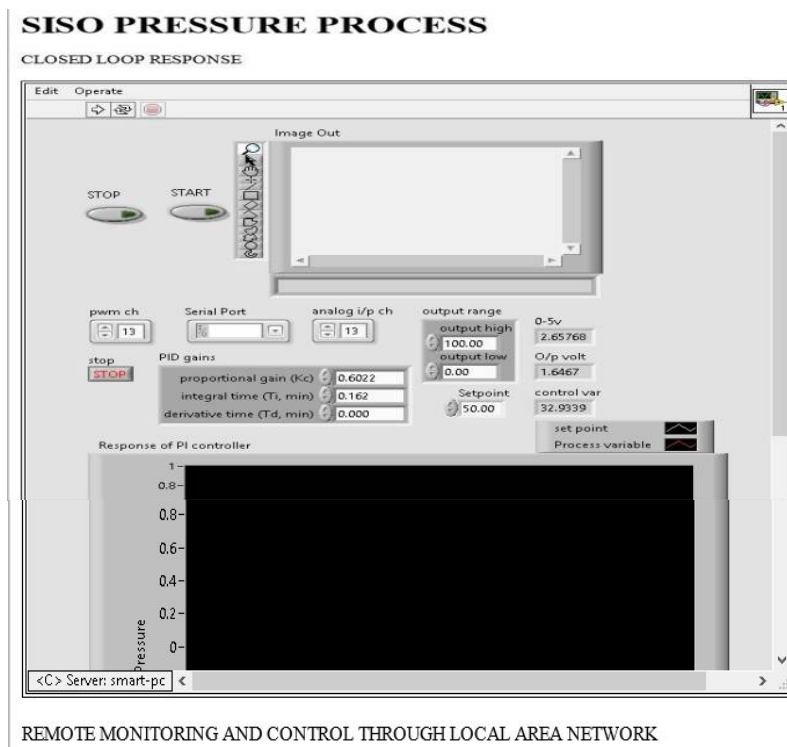

Fig. 10 Remote front panel

VI.CONCLUSION AND FUTURE SCOPE

A. Conclusion

The DAQ device which is implemented can be used for any process application. It is cost effective. It can be interfaced with LabVIEW by using LINX toolkit. It can be used in many process industry applications which involves 4 to 20 mA signal for measuring process variables. The remote monitoring technology enables user to monitor and control the process station from remote locations through local area network.

B. Future Scope

Wi-Fi technology can be implemented with the Arduino such that the data from DAQ hardware to PC can be transmitted wirelessly. DAQ connectivity between two or more stations can be handled by toggling the relays using Smart Phone applications. This allows to switch the DAQ connectivity to the any process station. Controller settings can also be calculated using Smart Phone application by logging process variable data with respect to time.

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