AC 2007-1525: A RELIABLE WIRELESS LINK COUPLED WITH COMPUTER BASED VIRTUAL INSTRUMENTATION FOR CONTROL APPLICATIONS

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Abstract

Wireless telephone systems have been available for quite sometime. However, wireless devices that can send and receive analog and digital data from industrial control process in a noisy industrial environment have only been introduced recently. Such devices can be used as a wireless digital and analog conduit. This technology is basically a commercialized version of the spread spectrum license free frequency hopping communication techniques used by the defense industry. Since the system is license free and is a maintenance free wireless conduit (communication channel), it eliminates costly and time consuming cable installation for new and retrofitting of existing project. This wireless conduit is an interference free link between remote devices and control rooms. Thus it is ideal for a noisy industrial environment.

Direct computer control applications using virtual instrumentation techniques are often restricted to applications such as space and military. A primary reason for this was historically their high cost. Today with availability of ever increasing computer processing power, low cost and high density memory coupled with reliability of low cost computer hardware components, and enhancement in personal computer based software packages, it has become more cost effective and feasible to monitor and control industrial processes from a computer terminal that includes animated computer graphics.

The purpose of this paper is to demonstrate the partially developed laboratory facility and course material that are being integrated into process control courses. This laboratory facility will also be used to do research and development in the area of direct computer control over a wireless conduit. This laboratory facility will develop new models, standards, and framework for direct computer control over wireless conduit, promote the technology to the industry, produce graduates that will be capable of implementing the technology for the industry, and in turn stimulate the economic growth.

Immediate benefits to the industry include decreased time and cost of upgrading and retrofitting existing processes. Since these wireless technologies can be mixed with traditional industrial instrumentation for a plant, it can be retrofitted in phases. A comparable example is networking of computers at home and office using wireless routers. Just a few years back networking of computers needed either Cat-5 or coaxial cables from computers to a router. Today, same task of computer network at home and at office can be painlessly achieved without running cables and using wireless routers. Many universities provide secure wireless access point to their local area network for students and faculty. Also there are unsecured wireless access points available at major airports and malls. All these are possible because of easy availability of the wireless technology. This project has the same idea but used for instrumentation and control of industrial processes. However, for industrial control purposes, technologies required to be secure and immune to industrial noises. The process combines the power of computer processing, local area network (LAN) and convenience of wireless conduit in one control system.
I. INTRODUCTION

In recent years telecommunications and computer industries have seen sweeping improvement and numerous new and innovative technologies. Many of these have been commercialized and introduced for control and data acquisition for industrial processes. Currently reliable and economical wireless links for industrial control and data acquisitions are readily available and can be implemented in the process control. This paper presents the suitable wireless links, relevant software for computer animation, control of remotely located rotating machinery over LAN and the required hardware for a complete computer animated wireless control of remote rotating machinery. The effectiveness of the procedure and the capabilities of the hardware and software will be demonstrated by examples. The subject of this paper deals with monitoring, controlling, testing, and acquiring data continuously from a remotely located rotating machine using dependable wireless conduit and over LAN. The authors plan to demonstrate the interfacing of a three phase induction motor to a direct computer control system located at a distance from the motor, its power driver, load, and monitoring traducers. The monitoring and controlling of remote rotating machines via a reliable link without sacrificing the data integrity and the ability to analyze the acquired data will be discussed. We are proposing to show how this wireless conduit coupled with LAN is a two-way monitoring, controlling and data acquisition solutions for rotating machinery in heavy interference environment where other radios fail to perform.

The animated control model for controlling, testing, data acquisition from a three phase induction motor and associated control algorithm are created using LabVIEW™ software and graphical development tools introduced by National Instruments™ (NI). Hardware interface to PC has been made through Signal Conditioning eXtensions for Instrumentation (SCXI) produced by National Instruments. Wireless link for the remote interface of the computer, rotating machine and associated controls is made by HS-900 Hoplink Codeless Wire™ transceiver systems produced by Omnex Control System Inc. HS-900 Hoplink Codeless Wire™ transceiver systems is a license free 902-928 MHz band coupled with Omnex’s proven Frequency Hopping Spread Spectrum technology. This wireless conduit is capable of transmitting and receiving analog and digital signal reliably over distance of about 1 to 2 miles using special antennas. Figure 1 shows the block diagram of the integrated wireless motor control system coupled with LAN.
The proposed model, monitors, controls, and produces data history in desired formats. The model is also capable of executing SPC that provides presence of extraneous influences and predicts deterioration of certain parts of the rotating machine over given period of time. We are using animated computer graphics to represent the motor control system and interface it with the real-world system. Using the model a test engineering or an operator can monitor and control power, and speed of the motor in real-time. The goal of this research is to develop an integrated model for an industrial process that could monitor, control, and analyze an industrial process in real-time over a wireless conduit coupled with LAN. In this paper, however, we like to show you how a high speed device such a three phase induction motor can be controlled using feedback PID loop and data could be collected and viewed in real time and later analyzed for diagnostic purposes. In addition to remotely located dedicated computer station, the rotating machinery setup could be accessed for control and data acquisition from an LAN computer also located remotely in a different location. The remote LAN computer stations do not require NI Software Tools. NI software tools are only available in dedicated laboratory computer station, where it is being executed from any of the other LAN computers.
II. MEASUREMENT AND CONTROL HARDWARE AND SOFTWARE

In most motor control systems, there are generally three steps: measurement, decision, and action to solve the variation or problem. In the measurement phase, the variables that are measured can be in the form of various analog and digital signals. For example, analog variables include speed (rpm, rps, and m/s), torque (N-m, ft-lb), input power (W, kW), output load (W, kW, and HP), temperature (°C, °F), controlled variable (frequency, f) of the induction motor, etc. The digital signals are ON/OFF, events, YES/NO, motor start (START SW), motor stop (STOP SW) signals, etc. These analog and digital variables are converted into standard currents and voltage signals. Generally, these standard analog signals are 4 – 20 mA DC current, 1 – 5 VDC or 0 to 10 VDC voltage, and digital signals are 0 and 5 VDC, 0 and 10 VDC, and 0 and 115 VAC and so on. Commercially available transducers are used to make these conversions. However, external power supply DC and AC are used for these conversions. Linearization is also part of the conversion. After the variables are converted, they are transmitted using OMNEX DS-900 transceiver to the location where the computer is located. The other side of the OMNEX transceiver system is interfaced with National Instruments (NI) Signal Conditioning eXtensions for Instrumentation (SCXI) system. The SCXI system then communicates with LabVIEW virtual animation software tools. PID algorithm in LabVIEW controls, acquires, and stores transmitted data from the motor as comma-separated variables in a file. Controlled output from the LabVIEW PID algorithms is further processed by SCXI hardware and transmitted by OMNEX transceiver to the motor side of the transceiver in the form of 4-20 mA signals. The 4-20 mA signal drives the variable frequency driver that in turn drives the three-phase induction motor. The motor side of the ON-OFF control is directly interfaced with the OMNEX transceiver system. Computer-side motor ON-OFF control is interfaced with LabVIEW through SCXI hardware. In addition, in a few cases we needed to use solid state relays (SSR) for interfacing with SCXI systems.

For this research and implementation, we are using SCU universal transmitter/isolator produced by Dwyer® Instruments and standard three terminals RTD sensors for the motor temperature measurement. Hall Effect sensor coupled with magnetic wheel and Chase 1000 signal conditioner for speed measurement. A 30WRP500 series three-phase WATT/VAR transducers is used for real and reactive power measurement. A clamp on type Hall Effect sensor for is used for the current measurement. On the power control side, we used Allen-Bradley 160 SSC™ Variable Speed Driver to control motor speed. Induction motor is coupled with a DC generator and the DC generator is connected to resistive load bank for accurate measure of motor load. Output load can be measured by a DC power transducer system. Power side of the ON and OFF switching of the motor is connected directly to the wireless transceiver. All these analog and digital control is connected to a dedicated remote computer feedback control system via wireless transceiver system. Motor can be turned ON/OFF, and speed set point is transmitted over the wireless link. Speed of the motor is continuously controlled by a PID feedback algorithm located in the dedicated remote computer.

Data collected from the motor control system are actual speed, input power, and motor temperature. All are transmitted over the wireless conduit. Data are stored in a comma-separated variable in a file located in the dedicated computer station where NI software is located. Action of decision making from the remote computer depends on the measured value of the speed at any given instant. Other LAN computers that are in remote desktop mode can control the remote
machinery setup as the dedicated computer communicating with the machinery setup through wireless transceiver. The control privilege of other LAN computer can be controlled; however, they are all kept same for the time being.

**System Description**

Figure 4 shows the motor control setup.

*Speed Monitoring:*
(a) Hall Effect Sensor NPN type Open collector,
(b) 60 pole pair Magnetic Ring
(c) Chase 1000 series signal conditioner, outputs 4-20 mA and 0 to ±10 VDC.

*Speed Controlling:*
(d) Allen-Bradley 160 SSC, three-phase variable frequency driver, rated at \( \frac{1}{2} \) HP.

*Temperature Monitoring:*
(e) Three-terminal type RTD temperature sensor
(f) SCU universal transmitter/isolator produced by Dwyer®
(g) Temperature overload is integrated part of the variable frequency driver.

*Torque*

(h) Currently we have DC generator and variable load bank.

*AC/DC Current Measurement*

(i) Clamp on type Hall Effect current sensor

Speed is monitored by the Hall Effect sensor coupled with Chase 1000 signal conditioner (4-20 mA) transmitted over the wireless conduit.

**III. FUNCTIONAL DESCRIPTION**

*Speed Control Loop*

Speed of the three phase induction motor is kept relatively constant with the changing mechanical loads by a PID feedback control loop. The control loop continuously monitors the speed of the motor using a Hall Effect sensor and transmits it over the wireless conduit to the dedicated computer side of the wireless link. The speed signal is then processed by the SCXI hardware system. LabVIEW’s virtual instrument is then further processes the variable through PID (Proportional Integral and Derivative) algorithm and generates a controller output. The controller output variable is then transmitted over the wireless link to the motor side of the transceiver. The controller output variable (4-20 mA) signal is then fed in to the Allen-Bradley 160 SSC Variable Frequency Driver that in turn controls the motor speed.

The motor is mechanically loaded by a DC generator mechanically couple with the motor. The DC generator is loaded by a set of resistor bank. Since the resistors in the resistor bank are connected in parallel, switching in a resistor increases the load. In this way the motor is loaded at various load values, such as 25%, 50%, 75%, 100% and 110% of the full load. At each of these fixed load conditions motor speed set point is changed up and down and the actual speed of the motor is monitored in time scale by the computer remotely located. At each of these fixed load settings differential amount of set point change upward and downward also varied and tracking time of the actual speed are monitored and recorded.
**Motor Temperature Measurement and Control Loop**

Motor temperature is monitored by a three terminal RTD sensor and conditioned by SCU universal transmitter/isolator produced by Dwyer®. The signal is then transmitted by OMNEX transceiver system to the computer side of the OMNEX transceiver. After processing by SCXI system, LabVIEW system saves them in comma separated variable in to a file. The information is used later for analysis and diagnostic purposes. The temperature data is also used to shutdown the motor from the remote computer system. In addition to this, motor side also has an emergency start and stop switch.

**Control Algorithm**

Any types of control algorithm such as ON-OFF, P, PI, PD or PID can be performed on process variable (speed) loop from the LabVIEW virtual instrument software tools. Tuning the control loop is toughest of all tasks. In addition to finding the actual values for proportional band or gain (K_p), integral constant (K_i) and derivative constant (K_d), we used controller output rate limiting algorithms and reduced sampling rate to stabilize the control loop.

**Wireless Conduit**

Reliable wireless conduit for analog and digital data communication is a Frequency-Hopping (FH) link. This wireless link is much more reliable because it adds an additional set of barrier from intrusion. Unlike single channel radio, the FH data is continually hopping across a wide range of frequencies in a pseudo random sequence. To listen to the data, the intruder must know the hopping sequence and follow along as the bits and pieces of the message. Omnex HopLink system uses 252 different pseudo random hopping sequences.

**Hardware Link**

Hardware link between Omnex DS-900 and the computer is National Instruments’ SCXI system and NI PCI-6035 bus. Speed, temperature, torque, controller output and current all these signals are converted in to equivalent amount of 4-20mA or 0-10V signal for communication through DS-900 or enter in to computer through PCI-6035 bus. Often conversion from 4-20mA to 0-10V and vice versa is necessary for the communication.

**LabVIEW Software Tools**

Implementing the feedback control using LabVIEW software is the most time consuming and complicated part of the entire task. Bidirectional communication of data is made with LabVIEW tools through analog input and output channels. PID algorithm used here has tuning parameter available on the front panel. Real time process-data are collected by LabVIEW tools are written in a Microsoft™ Excel file in a time sequence order. Real time clock available within LabVIEW tool is used for the time sequence order. In addition data are continuously shown in real time on the computer screen like a strip chart display. Data bundling, concatenate strings, ‘For Loop’, ‘While Loop’ ‘Sequencer’ etc. were necessary for the feedback logic implementation. User control panel (Front Panel) on the computer has Start and Stop switch, emergency Stop switch, Set Point input knob, tuning parameter (K_p, K_i, K_d) numeric control, strip chart type display in real time of Set Point, Process Variable (speed) and Controller Output.
Speed Set Point change and other types of control on the remote hardware can be established from any of the network terminal. Remote network terminals do not need to have the LabVIEW software tools. Computer that has the NI software tools must have 1.5 to 2GHz processor speed.

IV. DISCUSSION OF RESULTS

![Graph](image)

Figure 2: Various Set Point Differential at Fixed Load Condition (100% of the Rated Load)

We are in the process of performing many more experiments on the system. Current data in Figure 2 suggests that at 100% rated motor (full load =1/3 hp) load it take about 1.5 second for the motor speed to attain the set point value. Figure 3 data suggests that at 20% of the rated load it takes about 0.80 second for the actual motor speed to attain the set point value. At increased load condition it takes longer time for the actual speed of the motor to follow the set point value. Also larger differential value of set point versus smaller differential has almost similar kinds of effect on the actual speed tracking. We also experience that since the control algorithms are implemented in the computer where LabVIEW software tools are running, the computer needs to be at least a 1.5 to 2GHz processor. Also the computer resource in this computer needs to be managed carefully.
Figure 3: Various Set Point Differential at Fixed Load Condition (20% of the Rated Load)

V. CONCLUSION

We have successfully completed hardware interface of the wireless system to the direct computer motor testing and control system. We are currently in the process of doing many more experiments on the system. Ever increasing demand of wireless and direct computer control system led us to feel confident that such system could be used for long term and shot term control, testing, and data acquisition from rotating machinery systems. Additional controllability (even limited) over LAN adds an enormous flexibility to data acquisition controlling of remote machinery. Authors plans to continue further research with the system. Also since the system is computer controlled and performed from a remote location long term data acquisition, testing, implementation of complex control algorithms, data security, predictive maintenance, safety and security of workforce could be less expensive. Retrofitting of existing system without the time consuming and expensive part of laying cables shall be much less expensive and painless.
Figure 4: Complete Motor Control, Test Setup and Wireless, Computer, and LAN Interfaces
REFERENCES


