TECHNICAL REPORT

ISD Meso-Scale Test bed Shared Data Network Demonstration Report

Date submitted:

December 22, 2012

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Submitted to:

U.S. Department of Energy
Office of Environmental Management
Under Grant # DE-EM0000598

FIU | Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY

Introduction

The U.S. Department of Energy has set a goal to reduce its footprint at various DOE sites, and has therefore identified many reactor buildings at Savannah River Site (SRS) for decommissioning. As an alternative to the traditional decontamination/disassembly/transport and disposal process, DOE is electing to utilize an in-situ Decommissioning (ISD) method as a way to safely trap contaminant and significantly reduce costs [1]. DOE has identified several reactor and process buildings that could be prime candidates for ISD. This process would permanently entomb a portion of a structure, or the entire structure, with its contaminants. These contaminants would be bound to the structure via a grout material that used to fill voids in the entombed structure. Several variations of the ISD process exists that depend on the structure to decommission and the risks associated with the process and final form. One such approach involves removal of all above-ground portions of the structure, and the filling of all below grade areas with cementitious materials (i.e. grout). This specific approach was successfully implemented at Idaho National Laboratory (INL) with the Loss of Fluid Test Facility, and will be implemented at SRNL as part of several reactor decommissioning strategies.

In order to monitor that such a entombed structure maintains the proper "health" to trap contaminants, a complex sensor network must be deployed that can survive the rigors of a grout filling operation. This network must continuously monitor the structure reliably for many years. Many of the sensors applicable to such a deployment have been developed, and exist at various technology readiness levels. Applicable technologies such as Electrical Resistance/Impedance Tomography (ERT) and Acoustic Emissions (AE) technology have been field-tested in large-scale environments, such as remediation sites [2] and aircrafts [3]. Other technologies, such as novel fiber-optic methods like FLR and FBG, are at varying stages of development; larger-scale testing of these technologies would assist in determining engineering challenges to address prior to full-scale deployment. The focus of Meso-Scale Test Bed (MSTB) at Florida International University (FIU) was to evaluate such promising sensor technology in an integrated operational scenario beyond the laboratory scale.

In order to evaluate a large suite of sensor systems, FIU personnel designed and purchased a pre-cast concrete open-top cube, which served as a mock-up of an in situ DOE decommissioned facility. The inside of the cube measures 10 ft x 10 ft x 8 ft. In order to ensure that the individual sensors would be immobilized during the grout pouring activities, a set of nine sensor racks were designed. The 270 sensors provided by INL, Mississippi State University (MSU), University of Houston (UH), and University of South Carolina (USC) were secured to these racks based on predetermined locations. Once sensor racks were installed inside the test cube, connected and debugged, approximately 32 yd^3 of special grout material was used to entomb the sensors. MSU provided and demonstrated four types of fiber loop ringdown (FLR) sensors for detection of water, temperature, cracks, and movement of fluids. INL provided and demonstrated time differenced 3D electrical resistivity tomography (ERT), advanced tensiometers for moisture content, and thermocouples for temperature measurements. UH provided smart aggregate (SA) sensors that detect crack severity and water presence. An additional UH sensor system demonstrated was a Fiber Bragg Grating (FBG) fiber optic system measuring strain, presence of water, and temperature. USC provided a system which measured acoustic emissions during cracking, as well as temperature and pH sensors. All systems were connected to a Sensor Remote Access System

(SRAS) data collection system provided by FIU. The purpose of SRAS was to collect and allow download of the raw sensor data files from all the sensor system, as well as allow upload of the processed data and any analysis reports and graphs. This SRAS provided data post-collection, i.e. after the data has been appended to a file and the file had been closed. This method was sufficient based on the initial time and cost of the MSTB plan. At the completion of the 6 month period of test bed monitoring, a recommendation for additional topics of research and several additional demonstration plans were put forth to SRNL [spell this out since first time mentioned] and DOE. One such topic was the integration of these systems under a shared data network that can be used to monitor the whole test bed in real time. Many of the sensor systems tested used proprietary software packages that required dedicated computers to acquire, log and analyze the data. FIU focused on bringing several of the sensor system data into one cube monitoring software package that can minimize computational resources for a final deployment, while allowing sensor PIs to access the data, and perform additional post-processing as needed. Also, a study on the utilization of electrical energy by some of the sensor systems, and the application of renewable sources of power, was an area of much interest. The sensors, as well as the ancillary equipment required of such sensor systems, such as renewable energy sources and ambient weather systems could be brought into a dedicated power and data network to provide an integrated, sustainable ISD monitoring system using existing hardware and software packages.

Background

One of the lessons learned from the MSTB demonstration was the lack of interoperability between the systems, and under consideration was how to address this to develop an integrated system that allowed for sensors systems to utilize their existing hardware platforms, but allow ISD engineers and operators monitor the integrated structure, as well as add sensor systems to get all up and running quickly. A review was done of sensor system design and manufacturer to determine what software platforms, and networking capabilities would allow the development of shared data network. Based on the results, a plan of how data integration could be accomplished was finalized and implemented. In particular, FIU wanted to focus on integration of data of sensor system(s), but also of ancillary equipment used by those systems for power, reference measurements, timing, etc.

In order to develop such an integrated data network, FIU needed the collaboration of several of the Sensor PIs that took part in the MSTB demonstration. Discussions were had with several sensor system PIs and some PIs were willing to provide system access to FIU in order to perform the integration. The PIs had anticipated participation in Phase III of the Meso-Scale Sensor Network initiative led by Savannah River National Laboratory, but based on delayed start of Phase III (anticipated starting January 2013), only Idaho National Laboratory accepted participation and provided necessary sensor system to conduct the FIU demonstration. INL allowed use of their Thermocouple & Active Tensionmeter (TC-AT) System, as well as the Electrical Resistance Tomography (ERT) system. FIU selected to demonstrate the shared variable engine using INL system(s) and the ancillary equipment that was part of the shared power and data network MSTB demonstration.

Experimental Design

In order to connect to the INL's TC-AT system, information was collected on the acquisition and communication modules utilized for the system. ALL TC and AT signals are acquired by an array of Advantech ADAM-4000 remote I/O modules. These modules provide up to 8 channels for analog sensor acquisition. The modules utilize the RS-485 communication protocol, as well as Modbus/RTU serial for data transmission. The TC-AT system utilizes 11 modules for collection of the cube sensor data. All these modules are connected in a multi-drop configuration to an ADAM-4520 RS-232 to RS-485 converter. This allows for communication between the modules and a PC with a standard DB9/serial hardware port(Figure 1). The provided software and drivers from Advantech formats the query so that it is in a multidrop-compliant format that can be converted into a transmission pattern adhering to the RS-485 protocol. In order to interface with the unit without making any modifications, the focus was on utilizing existing communication drivers available via Labview® to format the data before transmitting to the ADAM-4520. Advantech provides a .NET utility to interface with their modules, but it requires installation of libraries that replace the capabilities already provided by Labview®. FIU developed an application that was able to format the data in such a manner to receive the correct information from the modules without the need for the provided Advantech drivers and software.

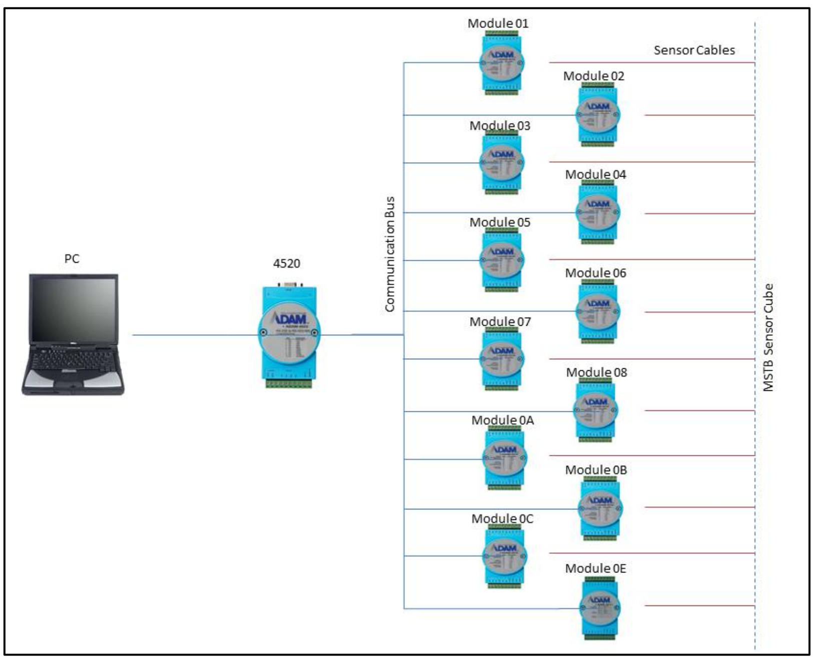


Figure 1. Diagram of INL's TC-AT System.

In order to monitor ambient conditions throughout the MSTB demonstration period, FIU installed and configured a weather station near the test cube (Figure 2). The station uses several capacitive and piezoelectric sensors to collect air temperature, relative humidity, barometric pressure, solar radiation, rain, and wind vector. The weather station (WeatherHawk 510) collects minute-by-minute data on these environmental parameters. FIU had an existing VI that was being used to continuously monitor weather conditions at the site by querying the station through a PC serial port. The weather station used a Modbus protocol for the communication and querying of site values; the developed VI utilized similar query conversion sub-VIs to translate the PC query into a Modbus-compliant format. The problem lied in the modification of this VI to allow for the data collected to be accessible as part of a shared data network.

Figure 2. Weather station installed on the office container.

Many of these sensor systems are combinations of various commercial components that have been integrated to complete the technical objective of the system, and have not been optimized for a possible full-scale deployment. This topic is focused on the current utilization of electrical energy by these systems, the type and quality of power required, and optimization strategies that can be used to minimize energy needs, especially when such ISD facilities that use this system transition into a long-term monitoring stage. One aspect of this effort was to power the sensors systems of renewable energy system, which would allow for a better determination of future energy sources, as well as power management strategies for the sensor systems. It was determined that a photovoltaic (PV) system could be set up at the site of the MSTB test bed as an alternative energy source for INL's Sensor systems, as well as the ancillary equipment required for communication (routers and switches) and ambient monitoring (i.e. weather station).

In order to accomplish the renewable energy system design, a study of power consumption rates for INL's sensor system was performed. Initially, INL provided a conservative estimate on expected power demands for their ERT and TC-AT Systems totaling 1020 W continuous. This would have required an energy source to provide over 24 kWh for daily operation. In order to obtain a more realistic estimate, a power analyzer was installed in line with all of INL's sensor system in order to log total power consumption for a period of three days. The analyzer logged an average daily energy consumption of 3.975 kWh. This was approximately 20% of the estimate provided by INL. It is important to note that this value resulted during the ERT in idle mode because of the lack of success to measure during current injection mode. IN order to compensate for this, the energy demand was padded with a 25% current injection margin based on the discussions with INL on total energy consumption rate and total injection time. In addition to this estimate, FIU included the weatherstation average daily consumption (0.6 KWh), the routers and switches daily consumption (1.08 kWh), and an additional laptop daily consumption (1.2 kWh) into an overall sensor system load. This estimate was used to size a PV system that could be located near the MSTB test bed, and provide AC and DC buses available for the loads.

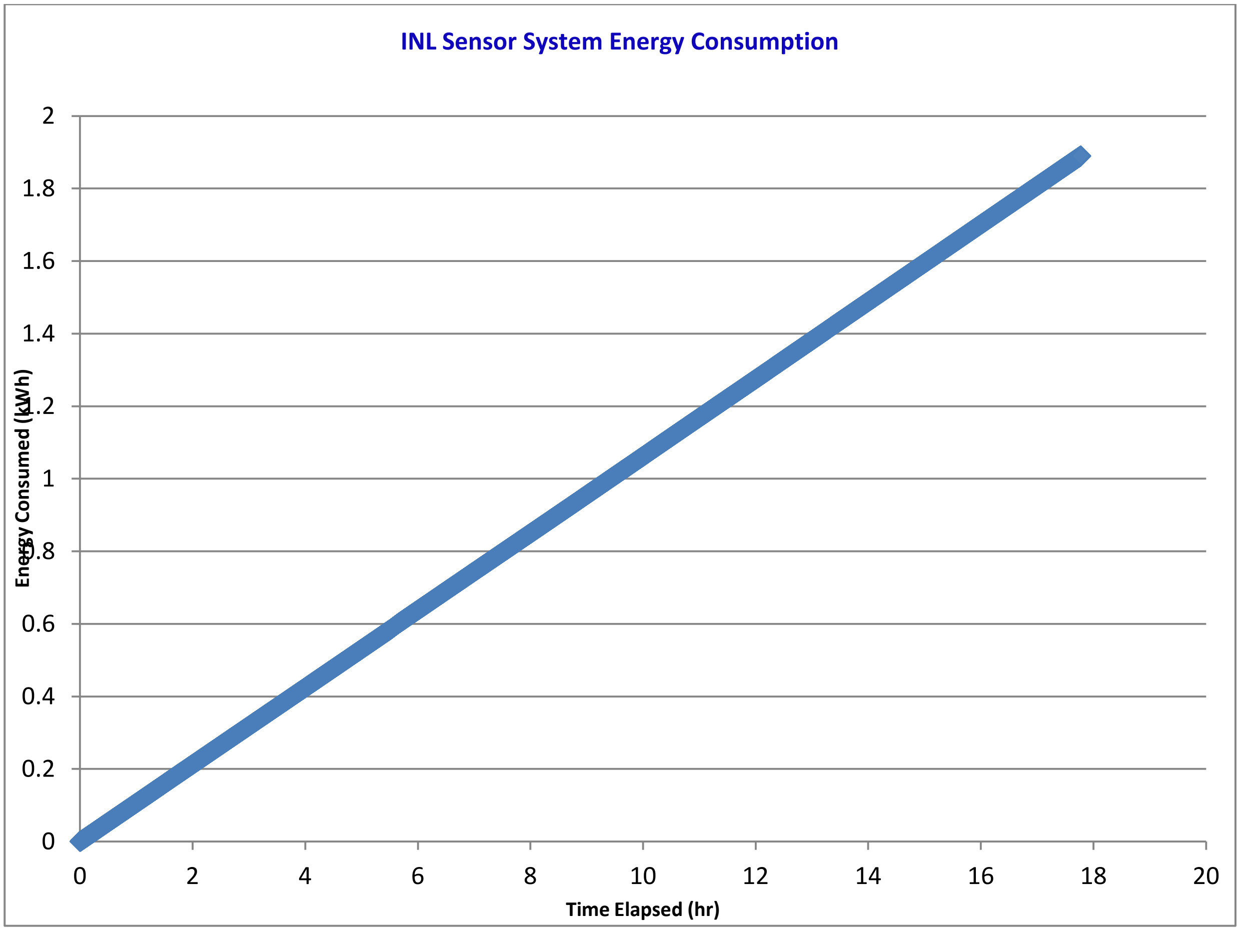


Figure 3. INL Systems energy consumption logged by Power analyzer.

Based on the measurements, a PV system was designed to operate as a stand-alone system (Figure 4). The system consisted of a 8-130 W Poly-crystalline photovoltaic modules wired in a 4-series, 2-parallel string. The array was mounted on top of a hinged A-frame assembly that allowed for tilt-angle adjustment depending on the seasonal solar path. The modules were wired to a charge controller with maximum power-point tracking (MPPT) capability, which allows for improved DC/DC conversion efficiency and battery charging. The battery bank used 4, 135 Ahr gel-based lead batteries for energy storage. The system used 2 sine wave inverters to perform the DC/AC conversion from the battery bank. In addition, the system was provided with a 12 VDC converter to directly power any available DC sources without losses from the inverters.

(a)

(b)

Figure 4. Photovoltaic System installed near the MSTB in order to power the sensor systems during energy analysis. Figure (a) shows the 1040 W PV array and mounting structure. Figure (b) shows the system enclosure with energy conversion, storage, control and remote monitoring modules.

The system also includes a remote power monitor module, which allows transmission of the energy parameters for the system in near real-time. In addition, this module allows local datalogging functionality unto an SD card. In terms of data transmission, this metering system utilized networking protocols in order to transmit the data from the module to a destination address identified on the module. This allows the data to be collected into a database at a central station, or in the case of the shared data network, into a real-time library (after parsing) for analysis and decision-making.

Initially, FIU intended to communicate with INL's ERT system, but due to a communication error with one of the system multiplexers, INL requested that FIU return the ERT System for repair. This forced FIU to continue the data network demonstration with the TC-AT system, weather station and the Power system. The ERT system was used as a test fixture for energy utilization, but could not be connected to the data network. The ERT will be repaired and sent back to FIU, where the integration into the data network will be performed.

Data Communication Protocols

In order to provide an integrated solution to the problem of communication with several sensor systems, a review of relevant hardware protocols related to communication was performed. In particular, at least one of three hardware protocols was shared in common by all the hardware systems: RS-232, RS-484 and Ethernet. Two of these protocols utilize DB-9/serial hardware port for connectivity, although the operating parameters of the protocol are very different. The RS-232 standard was defined as a serial binary single-ended data communication method between a terminal and a host processor or mainframe [2]. This protocol and the serial port, although practically removed from all modern-day computers, are still prevalent in sensor systems. The protocol defines the voltage levels and signal timing required for proper communication. RS-232 is designed of two client communication, and suffers from significant degradation in performance as a function of distance. The RS-485 standard was an extension of the capabilities of RS-232 standard, while utilizing the same serial hardware port connector. It is a differential data transmission protocol, designed with better noise immunity and longer range (up to 1 mile) [3]. The one particular advantage of the protocol is its support of standard multi-drop communications, allowing up to 256 devices to be connected to the same bus (assuming 1/8 unit load). This allows greater access to certain number of devices while minimizing connectivity issues and cabling. The differential signal mode allows for common-mode noise rejection capabilities, which improves noise immunity and signal degradation issues. Many of the newer acquisition systems being utilized in the MSTB contain the Ethernet protocol. The Ethernet Protocol (IEEE 802.3) defines communication among multiple devices along an individual differential bus. The distinguishing feature for this protocol is its flexibility in communication by passing all data-linking and network components to software. This has led to many advances in the use of the protocol for wide-area communication. In addition, the protocol has been defined with various physical configurations, including through power transmission through the physical connections (PoE). The standard software implementation of the protocol (TCP/IP) allows up to 4 billion distinct addresses (i.e. devices) to be connected to the network. It allows for different network topologies with various "hosts" that can control communication and accessibility between devices, as well as "clients" or "peers" that can be used for different specific network processes (e.g. security, data storage, processing, etc.) [4].

For the sensor systems to use in the integrated data network, most required RS-232 hardware protocol for communication, with specific software protocols above that layer for proper querying. The power system metering system utilized Ethernet protocol for communication. In order to demonstrate the shared data network, it required knowledge of the software protocols that handle communication with the systems.

Two of the systems to utilize in the network used the Modbus protocol for communication. INL's TC-AT system, as well as the weather station, required that the message be parsed in a Modbus-compliant message format. The Modbus protocol is an industry-standard application layer message and querying format that can be used to communicate with devices on either a serial (RS-232/RS-485) or Ethernet network [5]. Although the underlying hardware and data-link layers are different, the messaging framework remains the same. This protocol allows for messaging with individual or all network devices with a single message. It also allows development of a multi-node network where a single "master" manages all devices, even if the connection is configured in a peer-to-peer configuration like that in the TCP/IP protocol. The Modbus protocol has been applied to Industrial and Instrumentation environments for some time, and is very suited to a large-scale sensor deployment like those expected as part of the ISD.

In addition to Modbus, the Power system metering module utilized the UDP/TCP/IP software layer to communicate via Ethernet. These protocols define host-to-host communications. The IP protocol defines the network protocol on how packets should be parsed; the UDP and TCP protocols identify additional information to be added to the datagrams to verify data (UDP) and the connection (TCP). These protocols control communication by parsing a message into small "datagrams" with information on source address, destination address, the number of packets, message and a checksum to ensure the entire datagram was received. The IP protocol is an unreliable networking technology, which is why data has been added to the datagram under the TCP protocol to ensure reliable data transfer by adding additional mechanisms such as sequence numbers and 3-way handshakes [4]. The UDP protocol was defined for transferring data in a multi-cast, or broadcast mode, and as such lacks the reliability of TCP.

The current firmware on the power metering equipment only supports UDP/IP, but it is expected to add TCP capabilities in the near-future. With knowledge for the necessary interface layers for the hardware, research into the software avenues available for the data network were performed.

Software

Based on a review of the all the hardware manufacturers used by the sensor systems, the most promising software package to provide a complete integrated data network was National Instruments (NI) Labview® application environment. The key benefit in the utilization of Labview® stems from the extensive support of a multitude of instrumentation and control system manufacturers, which provide drivers and software APIs(as needed) to interface with their equipment. Labview® has much built-in functionality that allows for the development of large sensor network systems with processes spanning multiple nodes, while sharing data critical to all system processes. Labview® allows for the development of sensor system interfaces, but also can be used to deploy real-time scripting, parsing and analysis processes for data handling. This application lends itself to utilization as part of the ISD multi-node monitoring framework that has been initiated as part of the MSTB. Of particular use under the Labview® development environment is the shared variable engine (SVE) and the NI-Publish Subscribe Protocol (NI-PSP). The NI-PSP allows for the handling and control of real-time variables via networks. This protocol publishes the identified variable on a virtual server (called the SVE) that resides on the network node as an application. A PSP Universal Resource Locator (URL) is created for each variable, and can be used to access the variables current (and historical) data. The SVE also allows for secure access to all resources running on the server through access rights defined for each variable created. This limits use of the variable to specific processes or users.

Development

In order to successfully monitor throughout the ISD process, a sensor system must be capable of providing notification of the state of the grouted structure under times of possible issues; allow for variable sampling rates depending on occurrence of event of interest; report historical information related to individual sensors; and provide diagnostic information on sensor health/condition. Many of these items can be accomplished by integrating existing sensor systems on to a single data network, where information can be stored on individual nodes, and can be accessed, compiled and analyzed through a client station. In order to see how this would be possible with the existing sensor systems, FIU wanted to simulate an integrated data network that allowed for near real-time access to data from a client, and would allow for each node to manage its hardware interface, message parsing and data logging.

In order to accomplish this, several Labview®-based programs were developed, and deployed on individual "nodes" (simulated using laptops connected to sensor systems) to demonstrate the functionality of the approach. The Labview® programs, also called virtual instruments (vi), were developed in order to communicate with the appropriate system, parse the system response into the appropriate format, perform any needed scaling or data correction, load the data into the appropriate shared variable, and deploy the variable. In order to test the functionality, the sensor system scanning time was also set as a shared variable in order to allow modification during operations. Three specific major VIs were developed for the demonstration: a TC-AT monitor VI, a Power system metering VI and a weather station messaging VI.

The TC-AT monitor VI consisted of a serial interface portion (known as a visa workflow), a module query portion, module data-parsing portion and a shared variable load portion (Figure 5). The serial interface portion sets up communication via the node serial port, transfers the appropriate query string(s) to the serial send buffer, checks the receiver buffer for data and, if data is available, transfers the contents into a string for parsing. The serial portion also controls serial port closing upon program shutdown, or computer restart.

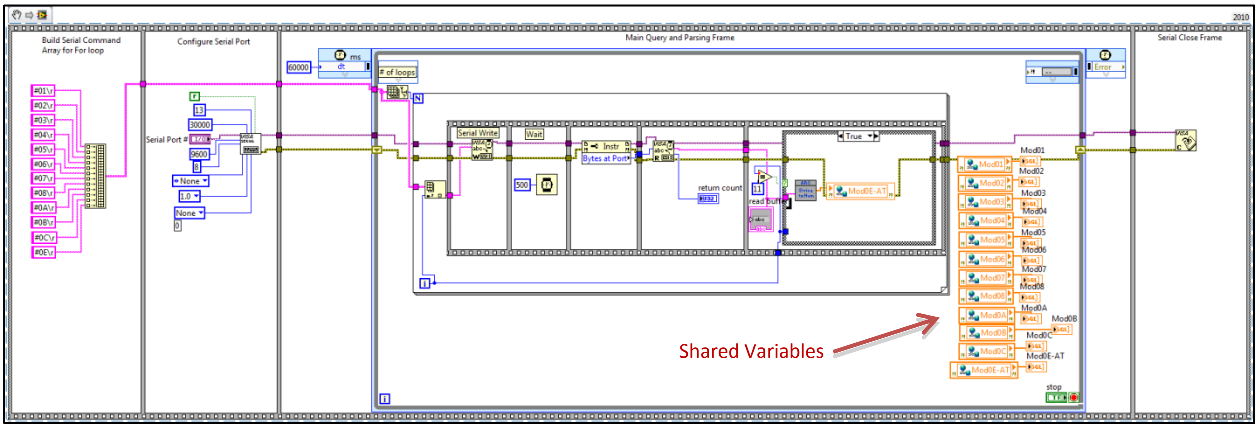


Figure 5. TC-AT VI. The main query and parsing loop utilizes an integrated for loop and case diagrams to query and store the data. The shared variables used are read at the end of message cycle to display the results on the GUI for testing purposes.

The module query portion handles the configuration of the necessary query required to obtain a response from the individual module on the system. These commands were based on the defined address given to each module during setup; this address can also be changed if needed. The commands request that the individual modules transfer all active channel values in response to the query. The module data-parsing portion handles the reconfiguration of each module's response string into a numeric array that contains all the active channel values on that module. This is accomplished through the use of a search and replace subVI provided by Labview® that allows for identification of the delimiter character, and the transfer of characters between those delimiters into a string array. Once the string array has been constructed, each element can be converted into a valid numeric type. This completed numeric array is then passed to the shared variable load portion, which places each array into the appropriate shared variable. Each shared variable is named after the module from where it originates, although this can be changed to the sensor panel from where the measurement resides. Once all these values have been populated, the monitor VI countdown the scan timer until the reset allows the sequence to re-run. Of the 12 modules utilized in the TC-AT system, one is specific to the AT sensors. This module returns 3 AT measurements, and those are parsed and loaded into a shared array variable for real-time access. The timing of this VI is set to run in 1-minute intervals, but can be adjusted as needed by writing a new millisecond value to the 'TimeStep' shared variable. This VI was deployed on a laptop PC as a standalone application as part of the demonstration, although it could have been run on a low-power controller.

The power metering VI (Figure 6) consisted of a UDP receiver portion, message parsing portion, and a shared variable load portion. The UDP portion of the VI captured the broadcast message sent by the power metering module. This module was configured to send the message to one specific destination IP address, which was the test laptop used to run the VI. The UDP receiver portion would listen on a specific port pre-assigned for the message. Once the received data had been received in its entirety, and verified via the checksum characters, the data was transferred to the message parsing sub-VIs. This set of VIs took the data and split it into three particular strings, corresponding to the charge controller and two inverters on the PV system. The three strings were then scanned for the appropriate measurements and status codes provided by each component. The strings provided information on power received, power consumed, battery system status, component(s) status and diagnostic information. Each component string had to be split into individual character elements, and a delimiter removed in order to access the decimal or integer part of measurements. The values for each measurement required that these parts be combined into a float value. Once all the measurements and codes were finalized, they were loaded either into a string array or numeric array identified by the power system component were the values originated.

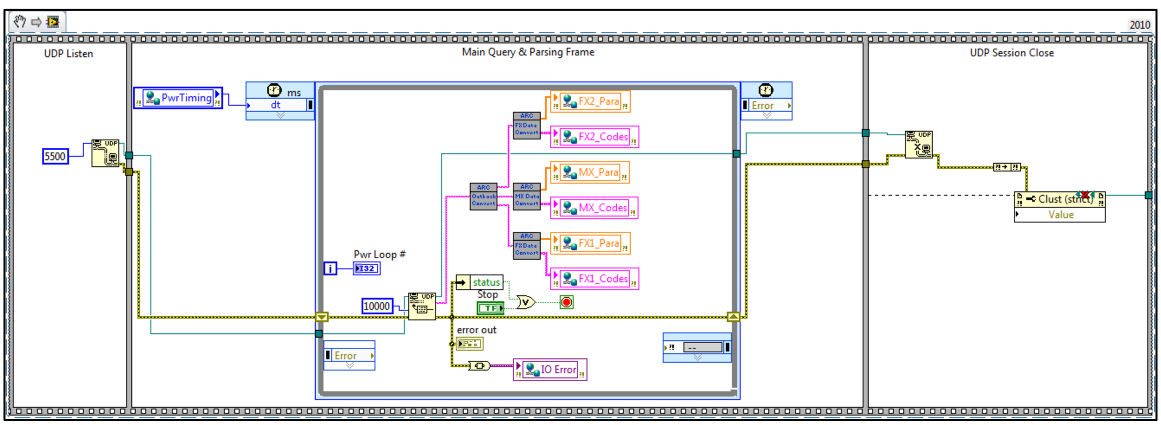
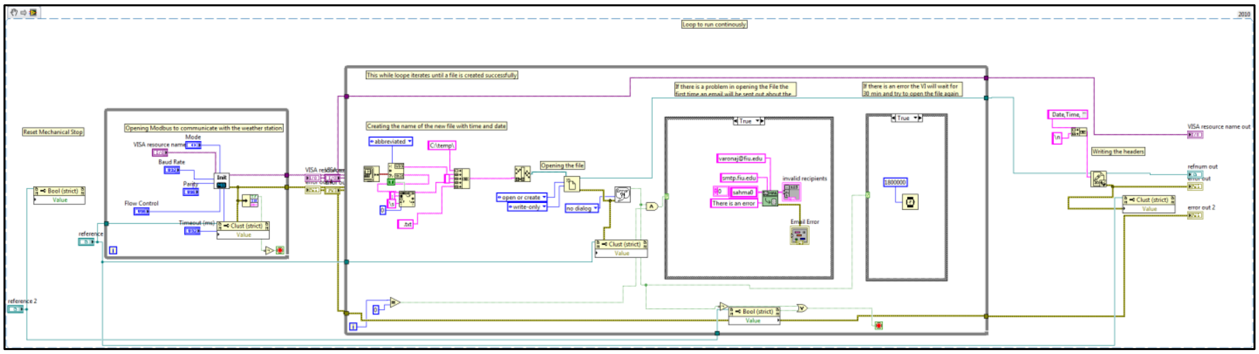
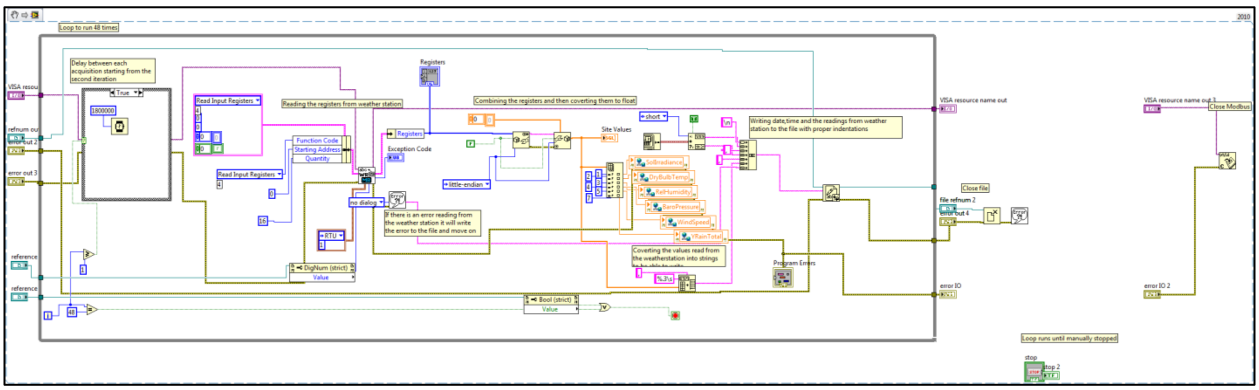


Figure 6. Power Meter VI. The

The weather station VI (Figure 7) provided the querying, message parsing and shared variable loading required for monitoring ambient conditions at the MSTB. Originally, this VI was designed to load the data into a text file for use by the sensor PIs during the MSTB grout curing process. This VI was also designed to query and store data every 60 minutes. In order to assess the integrated data network viability, this VI was rewritten to provide data every 60 seconds into the required shared variables. The VI utilized Modbus protocol subVI to format the query for weather station processing. Also, the Modbus subVIs provided a method to set and get weather station operating conditions such as battery status, and to reset rain measurements. The message parsing for this VI took the 8-bit integer response from the Modbus query and concatenated specific array elements to create a 32-bit float value for specific measurements. The elements were then loaded into individual shared variables corresponding to the ambient parameter being measured.



(a)



(b)

Figure 7. Weather station VI. (a) shows Modbus configuration and error handling portions. (b) shows Modbus query, message parsing and shared variable loading.

All the developed VIs were loaded into individual laptops or PCs and deployed as stand-alone applications. Once deployed, the data was pulled from the shared variables using a client VI running at a remote location from the MSTB, and on a different subnet from the MSTB systems. The client VI was a simple timed loop accessing all variables and updating, as new values were available.

Results

The completed shared variable library during demonstration is shown in Figure 8. The shared variables are shown by their format using a library reader developed by National Instruments. The shared variable library, once deployed on all the nodes, could be access by either a client VI or via a webpage running on a server with the capability to access the SVE.

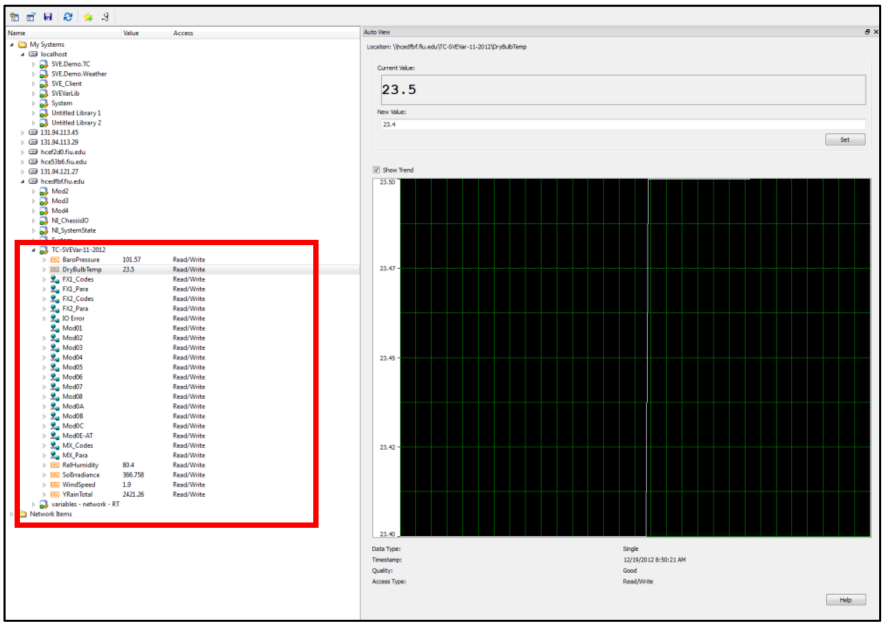


Figure 8. Shared variable viewer showing all the MSTB data network variables updating in real-time.

In addition to being able to view the variables being deployed by all the systems, the data was collected in a client application running on a remote machine. This VI (Figure 9) was designed to act as a client for all sensor data. The VI was organized in a layout consistent with the cube configuration, where 9 sensor panels support all the sensors on the MSTB cube.

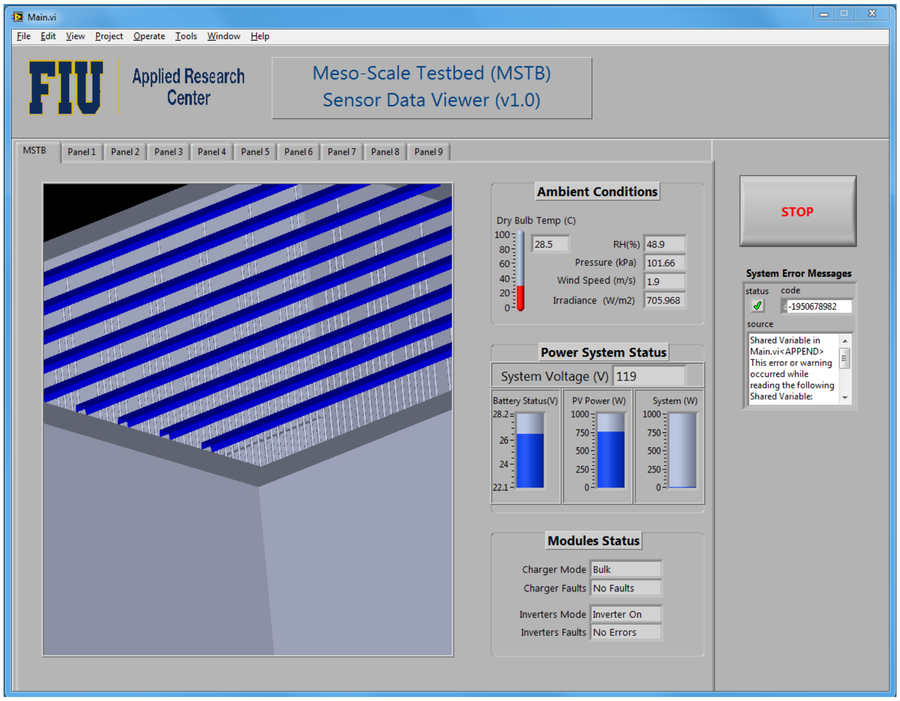
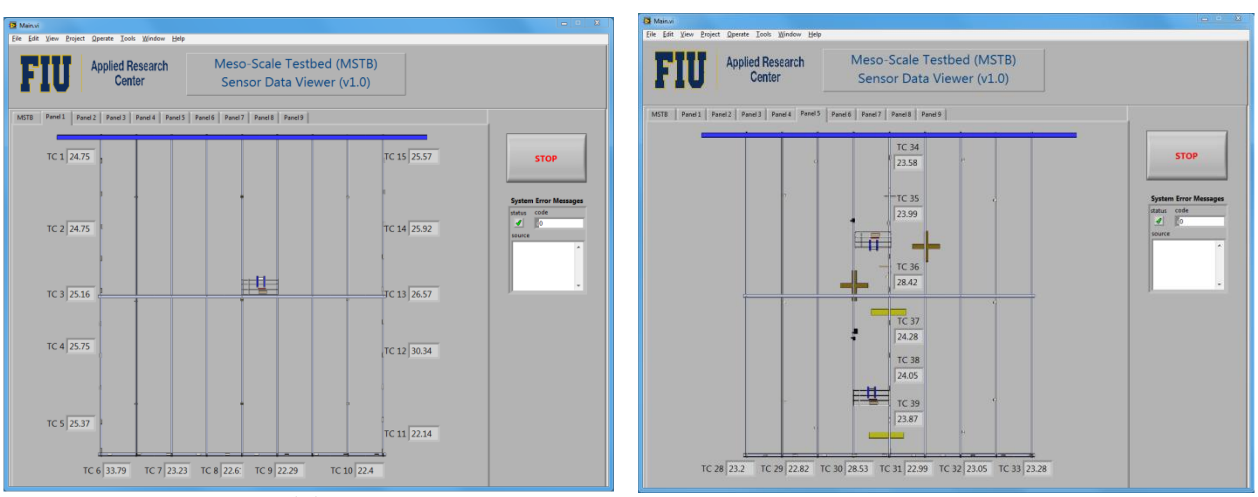


Figure 9. MSTB Client VI in operation.

Each sensor panel was assigned a tab that allowed a view of the current, real-time measurement of the participating sensors (Figure 10). In each tab, a layout of the sensors in each panel was dynamically added to allow for the value to be placed next to the respective sensor. This provided a visual indication of the sensor placement, and allows for a quick comparison of data from the sensor in the same vicinity to determine any operational or technical issues. This VI was set to limit update rate of each sensor to 60 seconds in order to not tax the network with faster updates. Figure 10a shows the 15 thermocouples located on Panel #1 measuring from 22.29 to 30.34 degree Celsius. Figure 10b shows the 12 thermocouples located on Panel #5 measuring from 22.99 to 28.43 degree Celsius.



(a) (b)

Figure 10. Sensor panel tabs showing the values for INL's TC and AT systems. Figure (a) shows Panel #1. Figure (b) shows Panel #5

In addition, the visualization of the historical data in real-time was developed for the VI. This functionality is currently being improved, as the shared variable buffer cannot provide the lossless capabilities required for this functionality.

Issues and Lessons Learned

The major issues with interoperability of the sensor systems for this demonstration had to do with technical issues related to the INL's ERT System. Due to problems with the system, FIU was unable to include the data into the shared network. It is expected that the system can be repaired in the short-term, and completion of the VIs used to communicate, parsing and load data can be performed. Another issue with the demonstration was the increase in power demand as a result of the number of computers necessary to test the concept (Figure 11). Initially, all the computers were on the PV system, but were utilizing more energy that the system had been sized for. This was causing low power conditions during the early morning hours. This was initially addressed by transferring several computers to utility power during the demonstration.

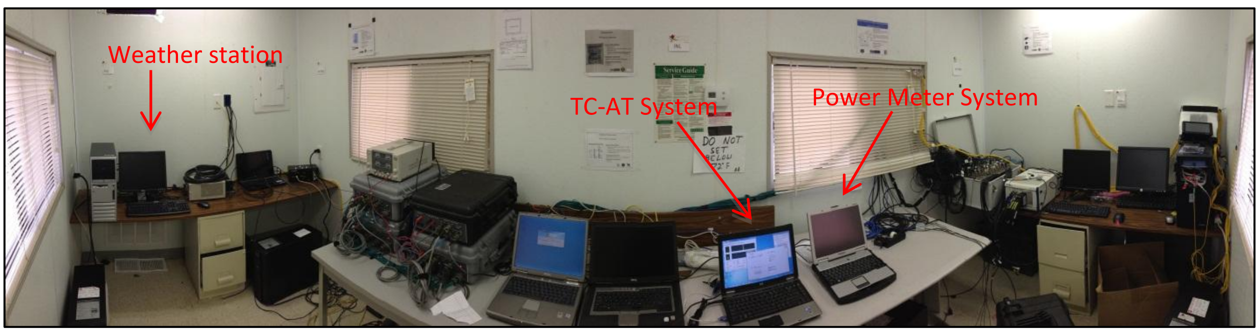


Figure 11. MSTB data network demonstration components inside the MSTB container. Laptops for communication to individual systems are labeled.

Conclusions

Based on the success in demonstrating the feasibility of creating a shared data network with several systems that are part of the MSTB, FIU intends to expand the network to include INL's ERT and MSU's FRL systems, but this will be delayed until additional funding is available to support the effort from those collaborators. The shared data network utilizing the existing commercial tools provides a guide for developing larger and more complex systems for the development of full scale data network. This network can also support addition of new sensor systems, or ancillary hardware and tools, without disruption of the current monitoring activities. This approach provides the necessary adaptability necessary to monitor the ISD structure, as well as surrounding areas, for a long term.

As part of the expansion plans, FIU began the evaluation of a controller that could be used in lieu of the existing hardware-interfacing PCs/laptops in order to communicate with the systems on the shared data network. This controller provided RS-232, RS-485 and Ethernet connectivity, while in a low power package that utilized less than 30W under full load. The VIs that had been developed were reformatted to run on this controller, and were deployed for additional testing (Figure 12). The current hardware platform is now performing the communication with the devices, while entering an idle mode when the processes are no longer needed. Also, the module query portions of several VI are going to be expanded in order to perform auto-configuration of the hardware, and status query in an advance version of the portion.

Figure 12. MSTB Container with all simulated nodes replaced by a low power controller that can communicate with all systems.

As part of this effort, the power metering module proved very useful in the development of an integrated data network. This data allows a client to see energy utilization in real-time for the system. The integration of all these ISD monitoring components on a data network will allow for implementation of a power management strategy that can managed by individual sensor systems. These systems can poll the appropriate shared variables for energy consumption use, battery voltage or PV power input, and determines the optimal operating mode and sampling rate based on the value of these measurements. This allows for a true node-based network approach, were each element has sufficient system knowledge to determine an appropriate operating state.

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