Design and Implementation of Fuzzy Temperature Control System for WSN Applications

Roop Pahuja†, H.K Verma‡, and Moin Uddin¶

†Department of Instrumentation and Control Engineering, National Institute of Technology Jalandhar, 144011, India
‡Department of Electrical Engineering, Indian Institute of Technology Roorkee, 247667, India
¶Delhi Technological University Delhi, 110042, India

Summary
Motivated by present day research trends that focus on application specific deployment and information processing in WSN, this paper presents, in general the design and implementation of rule based, simple, robust closed loop temperature control system using Virtual Instrumentation (VI) technology. It can be used for plethora of ZigBee WSN distributed measurement and control applications in areas like environmental monitoring and control, controlled-environment precision agriculture, building automation and process control. Using node based or zone - node based addressing scheme and double-averaging measuring technique, a ZigBee WSN, configured for periodic data transfer over adhoc multi-hop mesh network, transmits the measured value of zonal temperature as a feedback signal to the dual input, three-term fuzzy temperature controller. The controller software is designed to provide optimized output to drive a heating and cooling actuator network. The self-developed software (application program) with GUI, running on host PC, integrates and controls the operation of the hardware components to provide continuous temperature monitoring and control along with execution of add-on intelligent features. Looking into the practical aspects of deploying actuator network to drive FCEs that require external a.c / d.c power source along with low-power wireless sensor nodes, a novel ZigBee - RS485 HWSAN (heterogeneous wireless sensor-actuator network) is proposed and used as system hardware for low-rate deterministic small to medium control networks. Housed in a small greenhouse (GH) chamber and controlled by system software, this network fuzzy temperature control system provides uniform and precise ambient temperature control within an offset of ±1% over a wide temperature range of -10 to 70°C at a fast rate with information refresh rate as high as 2s. It provides high measurement and control performance and has flexible and versatile design to support not only single zone/area base deployment but multi-zonal network deployment, where each zone is treated independently to meet same or different set point conditions. Moreover, the network has desirable level of security in terms of accurate, reliable and timely data transfer, fault tolerant configuration, alarm indication in case of node detection or network communication problem and low battery status indication to avoid battery-drained dead node situation

Keywords:
ZigBee - RS485 Heterogeneous wireless sensor actuator network, Fuzzy temperature controller, Greenhouse automation, Virtual Instrumentation, GUI

1. Introduction

WSN consists of spatially distributed embedded devices called sensor nodes, which form multi-hop adhoc mesh network, to cooperatively measure the phenomenon of interest within the application domain [1] and communicate it to a sink node server system that is interfaced to backend communication wired/ wireless system for end user access [2]. Before deployment each node is preprogrammed in embedded software to execute application specific sensor based data sampling and acquisition, simple computation and wireless multi-hop mesh communication to form a reliable, self-configurable and self healing network. A sink node collects raw data packet from each node and interface it via USB or Ethernet to host PC server system. A suitable program running on host PC deciphers the packet and converts it into useful data for analysis, information processing and display on network user interface.

This network not only measures the phenomenon of interest with desired level of accuracy and data integrity, but also provides better spatial and temporal resolution to meet stringent requirements of complex and distributed measurement and control applications that are multi-parametric, inaccessible, difficult, impractical and cost prohibitive to solve with wired networks [2][3]. Concentrating over the application domain of WSN, research review shows successful deployment of the network for data monitoring, event based detection, tracking, object classification, data collection for model building with less attention on control and automation [4][5]. Motivated by the concept of incorporating control in WSN, which is the need of some of the typical applications in the area of environmental monitoring and control, control environment agriculture [6], precision agriculture, building automation and process control [7], authors in this paper have projected a practical outlook of wireless sensor and control network and proposed the design and implementation of rule based simple, robust closed loop feedback fuzzy temperature control system using Virtual Instrumentation technology for such applications.
In today’s WSN application scenarios, depending upon the practical feasibility and need base, different control strategies such as wired/wireless, distributed/centralized, single/multi zone may be used to drive actuator nodes connected to FCEs. Combining control networks with sensor networks, henceforth broadly categories WSN as HWSAN (heterogeneous wireless sensor and actuator network) deploying wireless sensor network and wired actuator network and WSAN (wireless sensor and actuator network) deploying wireless sensor network and wireless actuator network with single zone/multi zone controlling capabilities. As compared to WSANs, HWSANs offer more rugged and reliable actuation networks, compatible to drive power hungry actuator nodes but involve wiring overhead and limitation to remote access of controller. Moreover many FCEs (such as heaters, fans, valves, coolers, pumps) used in control applications require ac/dc power for their operation that is provided by wired power systems, hence purely wireless control networks at present are not realized unless new generation nodes facilitate onboard power generation using nanotechnology. To meet such stringent control requirements it is suggested to have small to medium scale deterministic network deployment with area or zone based addressing scheme. In this case the entire network area to be monitored and controlled is partitioned into small number of manageable zones. ‘Zone’ here is introduced to refer to an entity identified by a ID number. that represents certain grid area within application domain of the network that has a few number of wireless sensor nodes placed in adhoc manner for effective measurement of the parameters and fixed number of actuator node's to initiate control action in response to the real time parametric information provided by sensor nodes. To address such a zone based sensor and control network a simpler and more efficient zone - based addressing scheme, a variant to node based addressing, is proposed as a method to uniquely address and identify the node in the network zone. It uses 16 bits zone-node ID addressing code with higher and lower byte specifying zone ID and node ID respectively. This is rather simpler and more power efficient location based addressing scheme as compared to GPS enabled location based addressing method but requires careful deployment of nodes designed for particular zones. For small areas where spatial variation in parameters is very small, single zone area based network deployment strategy is preferred, where entire network area is considered as a single entity with sufficient number of sensor nodes and actuator nodes paced in adhoc/uniform manner. It uses node based addressing scheme with 16 bit node ID to address and identify the nodes. Fig. 1 shows the schematics of general WSN based closed loop feedback control system. It collects the raw data packets, disseminate and preprocess the packets to retrieve meaningful sensor information to provide precise real time value of control variable as a negative feedback signal to the controller. Based on the error and is variants controller generates the output using conventional or AI analog/digital control techniques to drive the actuator systems. Control signals are coupled to actuator nodes using either wired networks or control signal packets are wirelessly transmitted to wireless actuator nodes which in turn drive FCEs with the aim to minimize error. In case of multi-zone wireless sensor and control networks, the controller is time shared between sensor network information from various zones to drive corresponding actuator nodes [8]. Based on the concept, following sections of the paper discusses in short (i) Design background using VI that explains the techniques used to define functionality of the components and system as a whole (ii) System architecture that provides in general the requirement of hardware components with system layout and implementation of system software (iii) Experimental work that involves field deployment of novel ZigBee-RS485 MWSAN system for ambient temperature control in a small GH chamber with test results, conclusions and future scope.

2. Design Background

Based on VI the overall system design concentrates in developing a single/multi-zone PC based sampled, point
by point temperature network packets acquisition, analysis and actuating system [9] in which a control loop iterates at each sample of temperature information from WSN from each zone to generate fuzzy controller o/p signals sequentially to drive heating and cooling actuator nodes all zones for uniform and precise temperature control within error band of ±1% FSR. The underlying data acquisition, analysis and control methods and techniques decide the design of hardware and software components to define the functionality of the system. The section below discusses the design methods of important components.

(i) Data acquisition and analysis: For deterministic multi-zone WSN, zone-node based addressing scheme is proposed as a method to deploy sensor nodes in zones and report the best measured zonal temperature with minimization of error in sensing as a feedback signal to the controller. This scheme allows network zones to be treated independently and simultaneously for uniform and precise control of ambient temperature over the network area. Preprogrammed in embedded software each node, samples temperature sensor, forms message packet containing digital information about temperature, zone ID and node ID with other header parameters and transmit the packets to the sink node server system [9]. The acquired message packets are deciphered and collaboratively preprocessed by the application program layer to indicate best zonal temperature value, best measured voltage value, voltage and temperature alarm functions as explained below.

For such a sampled WSN system, consider a network of area A units with n number of zones and m number of sensor nodes in each zone with the elements designated as: Zone = \( Z_i \) (i varies from 1 to n)

Sensor node in \( Z_i = SN_{ij} \) (j varies from 1 to m),

where each sensor node \( SN_{ij} \) measures node voltage and environmental temperature. The best sampled temperature value \( (SN_{ij}T)_{t} \) at the instant of sampling time \( t \), is the mean of the latest five samples of temperature collected and is given by equation (1).

\[
(SN_{ij}T)_{t} = \frac{\sum_{k=0}^{5} (SN_{ij}T)_{t-k}}{5} \tag{1}
\]

and the best recorded value of zonal temperature \( (T_{Zi})_{t} \) at the instant of sampling time \( t \), is the mean of the best sampled temperature values of the nodes in the zone and is given by equation (2).

\[
(T_{Zi})_{t} = \frac{\sum_{j=1}^{m} (SN_{ij}T)_{t-k}}{m} \tag{2}
\]

\((T_{Zi})_{t}\) calculated for each zone based on double averaging technique, is the current value of zonal temperature and feedback signal to the controller to initiate controller action for that zone.

For temperature alarm annunciation, each best recorded value of zonal temperature \( (T_{Zi})_{t} \) is compared with low temperature \( (T_{low})_{t} \) and high temperature \( (T_{high})_{t} \) alarm values to activate low \( (ATlow)_{i} \) or high \( (AThigh)_{i} \) temperature alarms respectively using comparative logical statements given by equation (3) and (4).

\[
\text{If } (T_{Zi})_{t} \leq (T_{low})_{Zi} \implies (AT_{low})_{zi} \uparrow \\
\text{else } (AT_{low})_{zi} \downarrow \tag{3}
\]

\[
\text{If } (T_{Zi})_{t} \geq (T_{high})_{Zi} \implies (AT_{high})_{zi} \uparrow \\
\text{else } (AT_{high})_{zi} \downarrow \tag{4}
\]

Similarly, battery voltage of each node is also measured to record the best sampled voltage value \( (SN_{ij}V)_{t} \) at the instant of sampling time \( t \), which is the mean of the latest five voltage samples collected given by (eq. 5). To keep track of low battery condition of nodes, the current value of the voltage is compared with low battery voltage value to activate low battery alarm \( (AB_{low})_{ij} \) using comparative logical statements given by equation (6).

\[
(SN_{ij}V)_{t} = \frac{\sum_{k=0}^{5} (SN_{ij}V)_{t-k}}{5} \tag{5}
\]

\[
\text{If } (SN_{ij}V)_{t} \leq (B_{low})_{ij} \implies (AB_{low})_{ij} \uparrow \\
\text{else } (AB_{low})_{ij} \downarrow \tag{6}
\]

In case of single zone/ area deployment, node based addressing scheme with double averaging measure technique is used and each node is preprogrammed with node ID. This being the limiting case of above system mathematical description remains the same by just eliminating \( Z_i \) and \( i \).

(ii) Feedback controller: It is the core element that reflects the working performance of the system. As a support to meet expert linguistic description of temperature control strategy, used in many complex WSN application which are difficult to be modeled mathematically, a rule based fuzzy control model is used to design robust temperature controller [10][11][12]. It is a dual IP three term fuzzy controller. Each controller IP variable, temperature error \( (TE= \text{set point} - \text{current temperature} - \text{change in temperature error} \text{CTE} = (TE)_{t} - (TE)_{t-1} \text{in the range } (-1,1) \), is fuzzified into seven linguistic terms: negative small (NS), negative medium (NM), negative large (NL), near zero (NZ), positive small (PS), positive medium (PM), positive large (PL) with triangular membership function and full term overlap and the controller O/P (FO) in the range (-1,1), is fuzzified into three linguistic terms: heater (H), OFF (OFF), cooler (C) with singleton membership functions. It has 49 control rules that capture the strategy for controlling temperature using heating and cooling system [8][13]. Depending upon the inputs, certain rules are fired and using Min – Min inference and Center of Maximum (CoM) defuzzification method most plausible crisp o/p is obtained.

For use in real time situation with wireless sensor and actuator network, FC IPs are derived from process information. For the given high \( (TR_{high}) \) and low \( (TR_{low}) \) temperature range, temperature set point desired value
(TSP) and current value of zonal temperature (TZi) at that instant of time t are calculated using equations (7) and (8) receptively.

\[ (TEZi)_t = \frac{TSP - (TZi)_t}{TR_{high} - TR_{low}} \]  \hspace{1cm} (7)

\[ (CTEZi)_t = \frac{TSP - (TZi)_t}{2(TR_{high} - TR_{low})} \]  \hspace{1cm} (8)

Based on these real time I/Ps, FC produces O/P control signal (FOZi) at that instant of time to drive actuation system. This being the common design element is time shared between temperature inputs from different zones to sequential drive actuator nodes of zones. The controller design is optimized to suit wide temperature range (-10°C to 80°C) and provide high accuracy performance with error of ±1% FSR.

An interactive program as shown in fig.2 is developed and used to test and plot simulated multiple O/P-I/P characteristics of the controller as a basis to study/modify controller design and is also made a part of the main program for online access to the facility [13].

(iii) Actuation mechanism: The O/P of FC is an analog value in the range (-1,1), that is mapped to three terms (positive, negative and near zero) to drive the heating or cooling actuating nodes. Simple ON/OFF control logic [8] based on equation. 9 produces digital o/p control signals for cooler (CZi) and heater (HZi) of zone Zi at the instant of time t in response to (FOZi) at.

If (FOZi) < -0.003 => (CZi)↑ otherwise (CZi)↓

If (FOZi) > 0.004 => (HZi)↑ otherwise (HZi)↓

If -0.003 < (FOZi) < 0.004 => (CZi) and (HZi)↓

The fuzzified digital control o/p signals in real sense are coupled to digital output or relay ports of wired or wireless actuator network nodes of different zones to switch ON/OFF power supply to heating and cooling elements for temperature control. This fuzzy ON/OFF controller not only provides the simple expert model of control actions but also reduces offset and provide better control performance as compared to ON/OFF controller.

3. System Architecture

Temperature Control System for WSN is Virtual Instrumentation system that uses general purpose computing platform (PC), WSN data acquisition and actuator network hardware, graphical programming language and driver software [10][14] to develop software controlled PC based data acquisition and control network system where software (based upon design techniques) integrates all the hardware components and defines its functionality and features. The section below explains the hardware requirements and software development for system integration.
node (gateway node) for connecting network to the external
host PC or server system. Sensor node is a battery operated
embedded device and has a microcontroller interfaced to
IEEE 802.15.4 transceiver and sensor board with smart
environmental temperature and other sensors. Preprogrammed
in embedded WSN software (such as TinyOS, SOS, Mantis),
each node is a FFD (full functional device) and has basis
capability to sense, process and rout data packets to sink
node using multi-hop mesh routing. It supports multiple traffic
types including periodic data using beacon mode and
determinate low latency data with GTS to generate and
transmit data packets in a MAC frame format using
underlying CSMA-CA technique. Data packets as collected
by the sink node are interfaced to PC control system using
USB and Ethernet connectivity. A suitable high level
application program running on PC collects, deciphers and
processes the network data packets for information display
and visualization on GUI [1] [19] [20].

Because of ZigBee (IEEE 802.15.4) standard there has
been an ever-expanding market potential for short-range,
low data rate wireless sensor network applications,
according to ON World, and sheer volume of the low data
rate wireless devices are predicted to be three times the size
of Wi-Fi (802.11) in the next five years. With Crossbow
Technology (now Mimsic) being pioneer to commercially
manufacture WSN platforms and systems, designed by UC
Berkeley in the research projects funded by DARPA, [1]
the market is now flooded with sensor nodes from different
vendors. Top on the list are: Mica2DoT, Micaz, Iris, Telos
B, Wasp mote, Sensnode, T-mote sky, XYZ node,
Neomote, Shimmer [21]

(ii) Control Systems: As discussed in section 1, in today’s
WSN application scenarios, two types of control strategies
are deployed viz wireless actuating network and wired
actuating network.

Wireless actuating network is a similar kind of standard
ZigBee WSN where the nodes have actuating capabilities
digital or analog O/P) to drive FCEs [1]. These nodes are
generally static, small in number as compared to sensor
nodes and form multihop network with other nodes. In
response to the wirelessly transmitted control message
packet as generated by network coordinator system, the
actuator node drives the digital or analog output lines or
relays terminals to control the operation of FCEs. However
actuator nodes drain more power as compared to sensor
node because of high duty cycle and moreover require
external a.c or d.c power source to drive FCEs. Because of
power constraint purely wireless solution for actuator
nodes is still not realized practically. Recently launched
ZigBee home automation systems and products for
heterogeneous home area networks (HANs), control
devices such as wireless ON\ OFF light switches and
dimmers are available for such dedicated applications.[22]

Wired actuating network is a PC based network that uses
one of the established industrial serial networking standard
such as RS-485 to drive analog and digital output control
modules. Easy to install, the network has simple point-to-
point, multi-drop topology where all the field control
modules are connected to the network communication
module just over the differential twisted pair of data lines,
thus minimizing noise interference and wiring cost [23].
Based upon master-slave, half duplex and command-
response communication protocol, the field modules
initiate the control action in response to the control
command issued by PC to drive FCEs. DC and AC power
lines running across the network supply power to actuator
nodes and FCEs. Because of its high data transmission
speeds (35 Mbits/s up to 10 m and 100 Kbits/s at 1200 m),
relatively large distance span (up to 4000 feet or just over
1200 meters), easily scalable network from 32 to 255 nodes
with repeaters, low installation cost, availability of
multifunctional input\ output modules from different
vendors, easily programmable command set, this network
is recommended as an ideal solution for many applications
such as building automation, environment control in closed
chambers or agriculture greenhouses [24].

Rugged in construction, these nodes easily integrate
FCEs that require external power to operate and form
highly reliable functional actuator network, compatible to
work with 2.4GHz wireless network without interference
problems.
3.2 Software.

Software is the heart of the system that not only integrates the system components and control operations but define functionality and features using underlying techniques and methods. System software has two parts, one is Sensor node program and other is Controller Display program. Node program is Tiny Operative System (TOS) based application program, embedded in the nodes before deployment that define its functionality [19]. TOS Application component is developed by wiring together low level TOS driver components and other high level components through interfaces and implementing functionality using commands and event functions provided by interfaces in nesC programming language and TOS [25][26]. When the network is established and nodes are powered ON, TOS program in each node is executed to sample temperature and voltage A/D ports at the predefined rate, encapsulate raw sensor readings in the standard TOS message format with node and zone ID and transmit the packets to sink node using multihop mesh network protocol. Sink node preprogrammed with standard base program collects the network packets and interface them to host PC USB port.

Controller Display program is high level application software running on host PC (computer, controller and display unit) based upon sampled point by point packet collection, analysis and control paradigm. It supports two operational modes to interface with single zone and multi-zone WSN, collects and deciphers sensor network packets information [26], does all data processing for temperature monitoring, calculates real time fuzzy controller inputs to drive predefined fuzzy controller to obtain O/P, initiate digital controller to control ON/OFF controller to drive FCEs, interface the control signals to RS485 actuator network or wirelessly transmit control packet to ZigBee actuator nodes to power ON/OFF heater and cooler for temperature control.

Fig.4 shows functional flowchart of the application software based on design techniques explained in section II and implemented using graphical system design Virtual Instrumentation programming platform, NI LabVIEW 8.5[9] [27][28]. It has a multi-panel, modular and hierarchical design with top VIs (virtual instrument) calling low level VIs (used as subVIs) with concurrency and synchronization among execution of various operations. Main front panel provides user options to select Crossbow WSN hardware and feed deployment information indicating number of zones (single zone, multi-zone) and calls Temperature Control panel for single zone, multi-zone to execute all functions and provide information. It has a well designed, interactive graphical front panel for user interaction (as shown in fig.6) linked to the block diagram program code, logically implemented with functional module subVIs. Depending on the user fed inputs from the front panel, program code is executed to display results on it. It supports multiple functionality of being a network temperature monitor, fuzzy controller, plotter, recorder and logger with many add-on features summarized below:

- Provides on line connectivity to Crossbow mixed node wireless network and Advantech RS-485 heating and cooling actuator network.

![Functional flowchart of the Controller Display VI program](image)

- Shows graphically the zonal view of the network with each node indicating best sampled temperature and voltage value.
- In response to real time zonal temperature values, calculates and normalizes the fuzzy controller input and provide controller o/p to actuate heating and cooling system on RS-485 actuator network.
• Represents zonal temperature values and continuously plots its variation with time along with set point thus indicative of controller performance.
• Provides alarm annunciation visually to indicate high\low temperature alarm condition and low voltage alarm condition by changing node color.
• Indicates heater and cooler ON/OFF status of each zone visually.
• Simultaneously log zonal temperature and set point values with time and date stamp.
• Provides options to view historical trends of data for off line statistical analysis.
• Indicates network status to warn user of network connection \ node detection problem.
• Allows user to feed and dynamically change temperature range, alarm values and set point in accordance with real process information. Provide options for individual set point for all zones.
• Allows access to Test panel to study and plot fuzzy controller characteristics.

4. Experimental Work

4.1 Field Layout

With an aim to demonstrate, the working performance of the designed fuzzy temperature control system for WSN applications, a novel ZigBee-RS 485 HWSAN is deployed for ambient temperature control of single zone prototype Greenhouse (GH) chamber. Greenhouse is one of the CAE (Controlled Environmental Agriculture) techniques that caters to the growth of plants|fruits|vegetables|flowers in a closed structure with the control of multiple interactive soil and ambient parameters that affect the plant growing process. The aim is not only to improve the plant quality and yield for better returns but to facilitate off-season vegetation, vegetations in harsh climatic conditions with conservation of energy|water resources. In the on-going process to successfully automate production systems for optimal growth of plant species in different greenhouse structures, various engineering techniques and methods have been used and systems developed, from time to time, latest being WSN.

Reasons to use proposed ZigBee-RS485 HWSAN for temperature control in a complex GH and related applications are many folds. WSN provides a unique and easy method to facilitate distributive, multi-point temperature sensing with better spatial and temporals resolution, eliminating wiring cost and installation hassles. Over the past few years, it has been considered as a unique and acceptable data acquisition tool for collecting and accessing multivariables in GH environment that would also, in future facilitate remote control and management of GH's.[29][30]. Use of node based (single zone), zone-node based (multi-zone) addressing with double averaging is ideal to accurately and co-operatively report the best measured zonal temperature for instant distributive control action to cover up spatial and temporal temperature variations in GH network area. Actuator nodes being small in number, fixed in location and suitable to drive a.c\d.c power controlled FCEs, reliable wired RS-485 actuator network is used that is easily scalable, simple to install, multi-drop network and uses programmable command-response based communication. Moreover use of fuzzy controller, captures expert linguistic description of temperature control rules, devise for complex GH applications, to intelligently control ON/OFF operation of heater and cooler to obtain high performance controller response with low offset.

Fig. 5 shows the block diagram schematics of PC based ZigBee-RS485 HWSAN to monitor and control ambient temperature of small Greenhouse chamber. Host PC is interfaced to Crossbow Zigbee WSN gateway node (USB gateway board with Iris mote preprogrammed with TOS Base application) and Advantech RS-485 network controller, to form a wireless and wired link to wireless sensor nodes and actuator node respectively, housed in a small greenhouse chamber (15 ft × 15 ft). 5 number of Crossbow wireless sensor nodes (battery operated Iris motes with MDA300 sensor board with on - board temperature sensor) are installed at the height of 2 ft in zigzag manner to cover the greenhouse area. Before deployment each node preprogrammed with TOS application program and node id (for area deployment), senses battery voltage and temperature periodically at the preset sampling time of 2s, encapsulate their digital equivalent values in data payload fields with node ID and other header information to form message packet and transmit each packet using multi-hop mesh networking to the gateway node. Packets thus transmitted by nodes are collected by gateway node and interfaced to USB port of PC for application layer to collect and process. Sensor nodes with gateway node thus form Zigbee multi-hop mesh network for periodic data traffic where each node is a FF Zigbee device with sensing and routing capabilities.[19] [32]

For control purposes GH also has 1 no. of RS 485 network based Advantech 4000 series digital output module as an actuator node that is fixed at an appropriate place. Port 0 and 1 of the actuator node are connected to relay operated heater and cooling fan to control ON/OFF operation in response to fuzzy temperature based digital control signals issued by PC. [31]

Application program with GUI (described in section III), running on host PC integrates and controls the operation of multi-platform hardware components for automatic temperature acquisition, analysis and control with execution of intelligent features.
4.1 Results

When the hardware system as shown in fig.5 is deployed and power ON, Main panel of application program is configured to select WSN hardware (Iris motes and MDA300 sensor boards) and feed deployment information specifying number of zones. Upon execution it opens Temperature Control panel for single zone (as shown in fig.6), that is configured with node deployment and temperature information related to set point, range and alarm settings and ‘START’ button is clicked to establish network connectivity and display results on GUI as indicated in fig 6. In continuous running mode, network packets are sampled and collected periodically with time interval of 2s signifying reported time instant, to update and refresh information on panel. As shown on GUI, at the current reported time network view indicator is graphically showing network area (single zone) with five number of detected sensor nodes, each operating within normal temperature range and battery voltage (Green color), and indicating node id and best sampled value of local environmental temperature. Temperature graph depicts variation in zonal temperature over time to track set point of 30°C. With present zonal temperature of 29.8°C and set point of 30°C fuzzy ON/OFF controller drives heater ON and cooler OFF, with status as indicated. Network current status as shown is OK, all the nodes deployed are detected with no network connectivity or node detection problem. Simultaneously each value of zonal temperature and set point with date and time stamp are logged in spreadsheet data files. Fig.7 plots the historical trends of 8 hours recorded data showing how temperature tracks the changes in the set point thus providing precise control of temperature with offset of ±1% FSR.

Evaluating the working of the system for obtaining desirable control action and validating the accuracy of temperature measurement by comparing the results against standard software, [33] it is assured that the system has high measurement and control performance. It also provides satisfactory network performance with desire level of security. Based on standard ZigBee wireless protocol with true multi-hop mesh networking capabilities, sensor nodes provide reliable and timely data delivery on self healing, self configuring fault tolerant network. RS - 485 wired actuation network offers rugged and reliable control system, with minimum wiring installation cost compatible to work in close proximity with WSN without signal interference problems. Moreover, system software allows the user to continuously monitor battery and network status and take corrective measures in case of alarm situations thus enhancing physical security level of WSN.
5. Conclusion

ZigBee-RS485 MWSAN, based on node1 zone-node based addressing, double averaging and fuzzy temperature control techniques, is a well featured, high performance, versatile, programmable temperature monitoring and control system for WSN applications. In fact the proposed system is general purpose, simple, real time, practical solution for LR small to medium scale deterministic WSAN applications in the field of precision agriculture, control environment agriculture, building automation etc. that require temperature control over the network area or zones, where each zone is treated independently to meet same or different set point conditions.

Implemented using Virtual Instrumentation technology, system software, integrates multi-platform data acquisition WSN and actuator network, control its operation and provide all functionality for temperature monitoring and control with execution of multiple intelligent features and display of network data and information on intuitive GUI. Tested under various conditions, it offers continuous temperature control with maximum offset of ±1% FSR in a wide temperature range of -10°C to 80°C at a fast rate. It has the capability to capture and display the network information with refresh rate as high as 2s and optimally drive the final control elements with low duty cycle. It not only provides reliable data transfer over self healing, multi-hop network but also offers scalable and flexible system configuration.

Future scope involves implementation of intelligent multivariable control system for WSAN applications with integrated software having additional test facility to evaluate the field performance of the network.

References

H.K. Verma graduated in Electrical Engineering in 1967 from University of Jodhpur and obtained Master of Engg. and Ph.D. degrees in 1969 and 1977, respectively, from the erstwhile University of Roorkee (now Indian Institute of Technology Roorkee). He has been on the faculty of Department of Electrical Engg., University of Roorkee/Indian Institute of Technology Roorkee since Sep. 1969. For two years during 1980 to 1982, Dr. Verma worked as R&D Manager of a public limited company. Prof. Verma was Head of Electrical Engineering Department from Sept. 1991 to Sept. 1994, Dean of Sponsored Research and Industrial Consultancy of the Institute for the period of May 2000 to June 2003 and Dean of Faculty from Aug. 2003 to Aug. 2004. Presently, Dr. H.K. Verma is the Deputy Director of the Indian Institute of Technology Roorkee, Professor of Electrical Engineering and the senior-most professor in the Institute. Prof. Verma has published about 200 research papers, and guided 14 Ph.D. theses and 114 M.E./M.Tech. dissertations. His current research interests include smart sensors and sensor networks, digital relays and power system protection, biomedical instrumentation and teledermatology, intelligent and energy-efficient buildings, and embedded systems. Prof. Verma has done extensive work in the field and for the society related to Small-Hydro Power Development, e-Governance and e-Learning.

Moin Uddin received B.Tech/B.E and M.Tech/ M.E degrees from Aligarh Muslim University in 1972 and 1978 respectively and obtained Ph.D degree in 1993 from University of Roorkee. After working as Associate Lecturer (from 1975), Lecturer (from1979), Associate Professor (from 1984) at REC/Srinagar, he joined Jamia Millia Islamia in 1990 as Reader and became Professor in the Department of Electrical Engineering, National Institute of Technology Jalandhar (NITJ), she has been an Associate Professor at NITJ since 2009. Her research interest includes sensors, sensor networks, PC based data acquisition systems, virtual instrumentation, graphical intelligent system design and implementation for measurement and control applications. Presently she is pursuing her Ph.D from NITJ in the area of WSN and its application in the field of environmental monitoring, precision agriculture and controlled environmental agriculture.

Roop Pahuja received B.Tech. and M.Tech degrees, from Thapar Institute of Technology, Patiala and Indian Institute of Technology, Roorkee in 1994 and 2003 respectively. After working as a Lecturer (from 1995), Senior Lecturer (from 2001), Lecturer in Selection Grade (from 2006) in the Dept. of Instrumentation and Control Engineering, National Institute of Technology Jalandhar (NITJ), she has been an Associate Professors at NITJ since 2009. Her research interest includes sensors, sensor networks, PC based data acquisition systems, virtual instrumentation, graphical intelligent system design and implementation for measurement and control applications. Presently she is pursuing her Ph.D from NITJ in the area of WSN and its application in the field of environmental monitoring, precision agriculture and controlled environmental agriculture.

[22] ZigBee Alliance, ZigBee Vision for the Home, November 2006.