International Journal of Innovative Computing, Information and Control
Volume **10**, Number **2**, April **2014**
ICIC International ©2014 ISSN 1349-4198
pp. 631–658

COGNITIVE WIRELESS SENSOR ACTOR NETWORK: AN AGRICULTURAL PERSPECTIVE

Naseer Sabri[1], Syed Alwee Aljunid[1], Muhammed Sabri Salim[3]
Rezuwan Kamaruddin[2], R. Badlishah Ahmad[1]
and Mohd Fareeq Malek[1]

[1]School of Computer and Communication Engineering
[2]School of Bioprocess Engineering
[3]School of Mechatronics Engineering
University Malaysia Perlis
Perlis, Malaysia
nasseersabri@yahoo.com

Received December 2012; revised June 2013

Abstract. *Intelligent environments are exposing the next revolutionary steps of development technologies in automation of building, industrial, home, and transportation systems. The new generation of Wireless Sensor Actor Networks (WSANs) technologies of sensing the environment, computing and communicating advances at faster rates. It can be conceived that the world will eventually be covered by networks of autonomous smart sensor-actor nodes which yields revolutionary applications. Nowadays WSAN can be considered as passive networks of sensing the phenomena, while fusion of Artificial Intelligence (AI) concepts and algorithms into the network's nodes provide those nodes with the ability to mimics the human behavior in sensing and reacting which give the network the ability to be autonomous for a specific application. This paper presents the fusion of artificial intelligence represented by Fuzzy Inference System (FIS) with WSAN for greenhouse climate control. Smartness of current WSAN (SWSAN) is proposed based on FIS while the conventional control methods are not efficient in terms of energy, labor interference, productivity and flexibility. In this paper, Fuzzy Inference System (FIS) has been designed and fused within the coordinator node of WSAN, and hardware and software of network nodes and sensors have been presented. Indeed, this paper describes the new era of cognitive WSAN based on AI paradigm and shows a reprehensive set of new applications and identifies several possibilities of creating the smartness concepts of currently Wireless Sensor-Actor Network (WSAN). The primary concept of automation, wireless technologies and cognitive approach of WSAN within diverse application and particularly for agriculture application are presented and discussed.*
Keywords: Smart wireless sensor actor network, Artificial intelligence, Cognitive greenhouse climate control, Fuzzy logic control

1. **Introduction.** Smart wireless sensor actor network presents a crucial and exciting new era of technology of wireless monitoring and control systems. It targets to improve the current applications beside emerging new era of system technology in areas like precision agriculture, home medical care, smart cities and building, industrial management and automation, with numerous military applications [1-3]. WSANs, typically consist of a large number of limited computing, capacity sensing and communication ability of nodes that may fuse with various types of actors. The nodes of a WSAN may operate in noisy and harsh real world environment. High attention is given to real time applications, this interest is highly raised during the last 10 years to produce excellent low-level hardware

combined with efficient protocols to collect, routing, and perform sensor-actor tasks in reliable and effective power consumption environments [3,4].

Currently, most of greenhouses monitoring systems use cables for their data flow and communication [5]. Using of cables may result in many problems like cables barrier, aging and terminal loose, and thus resulting in complexity of construction and lower reliability of the system. Moreover, sensors are fixed at the original locations and this may yield difficulties in moving or adding new sensors; the maintenance and replacing also may result in some difficulties. Overall, the using of cables may raise the cost of human resources and can cause accidents [6,7]. Contrary, wireless communication of network nodes shows flexibility to add, replace, and relocation of nodes with less effort and cost. Nodes can be sealed and thus can be more compatible to work in harsh environment which leads to improve reliability of sensing and efficiency of the network [5,8]. Using of high efficient battery, the construction and the installation of wireless nodes can be simpler and results in reducing the human cost, and also network nodes can be replaced and maintained conveniently. Indeed, the flexibility to attach several different sensors to extend the applications of the network can be realized. Small, low cost, robust, reliable and sensitive sensors are needed to enable the realization of practical economical sensor network. Although a large number of measurements are of interest for WSAN applications, commercially available sensors exist for many of these measurements [9-11]. Generally, the wireless network functionality depends on the application it dedicated to, but typical requirements are shown as follows.

1. *Parameter specific values:* for a given location, the value of parameters must be precisely determined. For example, in an environment oriented WSN, one might need to know the temperature, pressure, amount of sunlight, and the relative-humidity at a number of locations. This yields that a given wireless network may be connected to different types of sensors, each with a different sampling rate and range of permitted values [12,13].

2. *Events detections:* detect the occurrence of events of interest and estimate the parameters of the events. For example, in a traffic-oriented WSN, one would like to detect a vehicle moving through an intersection and estimate the speed and direction of the vehicle [14-16].

3. *Classification:* identify an object that has been detected, for example, the type of a detected car [17].

4. *Tracking:* For example, in a military WSN, track an enemy tank as it moves through a geographic area covered by sensor network [18-20].

Intelligent Control System (ICS) is a branch of knowledge in which monitoring algorithms are created based on emulation of certain characteristics of smart biological systems. ICS has the ability to act appropriately in an uncertain environment, where a perfect action will optimize the probability of success [21-23]. Smart wireless sensor actor network can be defined as the integration of Intelligent techniques with wireless sensor actor network that does a process of sensing and acting the physical parameters under vision [24]. Latest developments in the technology of WSANs as well as the smaller in size of the sensor/actor nodes have facilitated precision agriculture to emerge. Precision agriculture focuses on providing the planters with harvest information, work management and growth information [25]. Agricultural productivity enhancement is in advance progressing through introducing sensor network technologies combined with actor network to monitor and control agriculture applications. The environment monitoring and control of greenhouses are crucial aspects for enhancement of the productivity and preventing diseases in the crops [25-27]. The rest of this paper is organized as follows. Section 2 discusses the related literature and presents the WSN technology, most recent applications and factors effects WSN design. Section 3 describes the well known intelligence control methods with agricultural viewpoint. Next, Section 4 describes the proposed smart WSAN based fuzzy controller architecture. The energy balance of a greenhouse climate is presented in Section 5. Section 6 shows the design of FIS of climate control and presents the cognitive agricultural WSAN embedding FIS platform, actor and circuitry is also presented and described. Results and discussion of simulation and test bed output are explained in Section 7. The conclusions are shown in Section 8, and references list ends this paper.

2. **Agricultural Automation Control Systems Based on SWSAN.** The WSN technology has been adopted in agricultural fields by many researchers and engineers [28-30]. Greenhouse monitoring/control based on a TINI embedded Web server unit which collects data and routes it from local sensor-actuator networks to a base station has been studied and done by Stipanicev and Marasovic [5]. Zhou et al. introduced an architecture and application of a ZigBee network combined with event-based control techniques [11]. The environment of a greenhouse using a WSN has been monitored and controlled by Ahonen et al. [31]. Kang et al. proposed an automatic greenhouse environment monitoring and control system [32]. The proliferation of WSAN which integrates wireless communication embedded computing, sensor and micro electro-mechanical system (MEMS) have gained increasing attention during recent years. The advances in these technology facilitate the development of WSAN, although those sensors-actor nodes have limited resources in terms of power, processing and computing, and small size that can adequate many particular applications. The main activities of those sensors are to sense the environment, measure and using of decision making unit for actuating processes. WSAN applies suitable actions which affects the environment under supervision [6,24,32,33].

Usually, the coordinator nodes and even the actor nodes are more complex devices than sensor nodes, and therefore the cost and the size of these nodes are relevant issues when

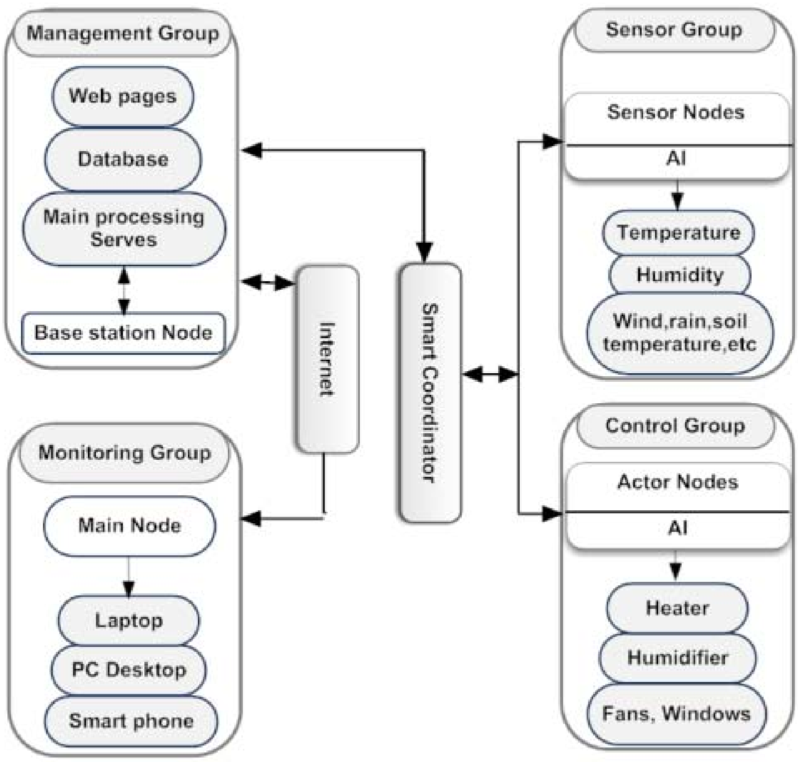


FIGURE 1. Architecture of smart wireless sensor-actor network

designing a WSAN and they are preferred to be as low as possible. Careful attention is needed for sensor selection because of its importance in measuring and controlling the environment which affects crop growth in practical greenhouse cultivation. It is important to select sensors which can withstand the high temperatures and humidity of a greenhouse environment and have higher sensitivity and reliability within a suitable range for crop cultivation [24,33-36].

Figure 1 depicts the fundamental elements of a proposed smart WSAN which integrates AI algorithms within networks nodes, SWSAN is more efficient and reliable than ordinary wireless sensor network, and it achieves better power saving, data aggregation and smart routing. The figure shows the four fundamental blocks of sensing, actuating, management and monitoring groups which cooperate with each other to perform a complete automation control system based SWSAN. AI module can be embedded within the coordinator, sensor and actuator nodes. It can manage the transmission power of the node, apply the optimal actuating process to a device and do a smart decision making unit for the data of the phenomena [23,24].

2.1. **WSN standards technology.** WSN standards can be categorized based on its features such as network data rate, size, transmission range and power consumption and thus lifetime. Different technologies of wireless communication were compared with each other.

The result of the comparison shows that the requirements of building SWSAN are met by Bluetooth and IEEE 802.15.4/Zigbee technologies. They have very important feature for the SWSAN such as small size which can be embedded efficiently, low power consumption which provides long life and different modes of operation power suitable for many applications and exposes good rule for prolonging network's life [24,37]. Table 1 shows a comparison of two important wireless networking standards, Bluetooth and Zigbee standards. It can be concluded that Zigbee has many advantages over Bluetooth

Table 1. Comparison of wireless networking standards

Technology	Bluetooth	Zigbee
Standard	IEEE 802.15.1	IEEE 802.15.4
Frequency (GHz)	2.4	2.4
Application	Cable Replacement	Monitoring – Control
Battery Life (days)	1-7	100-1000+
Network Size	8	65000
Data Rate (kbps)	1000	20-250
Transmission Range (meters)	1-10+	1-100+
Success Metric	Cost, Convenience	Reliability, Power, Cost
Latency (sec)	<10	0.03p
Spreading	FHSS[1]	DSSS[2]
RF Channels	79	16
Modulation Type	GFSK	O-QPSK
Data Type	Audio, graphic, file	Small packet of data
Power Consumption	$40mA$ Tx, Standby $0.2mA$	$30mA$ Tx, Standby $356\mu A$

[1]FHSS: Frequency hopped spread spectrum. [2]DSSS: Direct sequence spread spectrum.

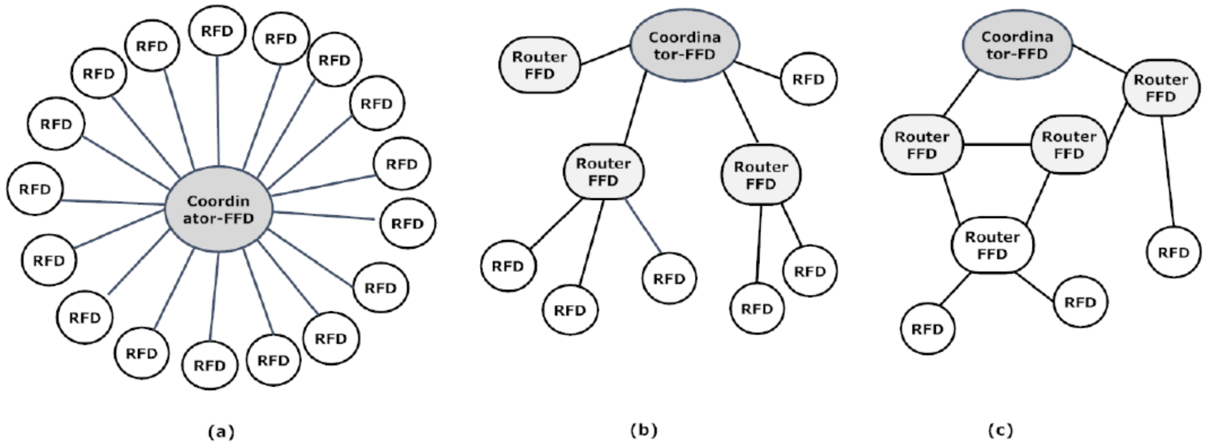


Figure 2. Network topologies supported by ZigBee (a) star (b) tree (c) mesh

that match SWSAN features and can be applied efficiently to agricultural monitoring and control applications [38-41].

2.2. **IEEE 802.15.4 and Zigbee standard.** The Zigbee specification is built on the IEEE standard 802.15.4. Zigbee was created for applications that require low cost and low power, but with the need for a large degree of flexibility. Potential applications of the IEEE 802.15.4/Zigbee standard include WSANs for home automation, smart badges, remote controls, interactive toys, etc. The standard uses the 2.4-2.4835GHz frequency band with sixteen channels and can achieve data rates of about 250kbps. The weak point of the network is the failure of the coordinator node and low data rate although there are many brilliant positive features of using Zigbee standard, as described in Table 1. Communication range is from 10-75m based on the field environment for the deployed network [40-42]. The IEEE 802.15.4 standard supports two addressing modes, 16 bit short and 64 bit IEEE addressing. The physical layer also has features for link quality indication, packet receive energy detection and clear channel assessment. A maximum packet size of 128 bytes is supported along with both contention based and contention free channel access. The MAC layer uses full handshaking for reliability and Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) for channel access.

ZigBee has three software layers on top of the PHY and MAC of the IEEE 802.15.4 layers, namely network, security and application. The network layer supports three types of topologies, star, mesh and cluster tree. Figure 2 shows an example of these topologies. The standard defines two types of devices: a Full Function Device (FFD) and a Reduced Function Device (RFD). An FFD is able to route data, while an RFD is not. The standard also defines that the network is coordinated by at least one FFD. A star topology promotes long battery lifetime since every RFD is connected directly to the coordinator. A mesh or peer-to-peer topology provides reliability and scalability since all nodes are FFDs and therefore can be interconnected. This introduces multiple routing paths. The cluster tree topology combines aspects of both the star and mesh topologies and tries to provide long battery lifetime as well as reliability and scalability. The security layer adds the ability to encrypt the MAC layer frames with 32 bit, 64 bit or 128 bit Advanced Encryption Standard (AES).

The application layer defines profiles that aim to enable interoperability. It also enables nodes to determine which other devices are within their vicinity and makes it possible to match devices based on their services. ZigBee standard is considered as a world wide open standard for wireless radio networks in the sensing, monitoring and control applications [43-47]. The standard was developed to meet the following important needs:

- Cheap, easy installation and low cost;
- Ultra-low power consumption, years of battery life;
- Works on 2.4GHz unlicensed radio bands;
- Flexibility of replacing, adding or moving nodes within the network range, and extendable networks;
- The basic channel access mode is "carrier sense, multiple access/collision avoidance" (CSMA/CA);
- Frequency agility for clear communication channels and coexistence problem avoids;
- Integrated intelligence, best path algorithm, for network set-up and message routing;
- Nodes can be installed cheaply and easily, without any power cabling, in harsh environment.

Zigbee networks are perfect solution for most applications specified by the following requirements, while the weakness points can be considered as its low data rate, single failure point and the lack of fully devices.

- Low data rates (less than 250kbps);
- Nodes working in a sleep or idle mode where there is no activity for long periods;
- Harsh environment installation, node locations where cables would be difficult or expensive to install;
- Flexibility for adding, removing or moving nodes while in service.

Typical application areas of Zigbee standard which it can provide a low-cost solution are commercial building and home automation, security, healthcare, vehicle monitoring and agriculture. Zigbee can be used for application that may require wide geographical coverage; it offers multi hop network topologies that allow the relaying of packets from node to others across the network.

Commercial building and home automation: Electronic control can be designed and implemented using SWSANs such as HVAC (heating, ventilation and air conditioning), lighting, curtains, doors, locks and home entertainment systems. Also deploying sensors for water, power, intruder, fire and smoke detectors exposes the home awareness system [8,49].

Industrial Plant: Process control, asset management, environmental management, energy management, industrial device control [50].

Healthcare: Currently Body WSN is a combination of sensors and diagnostic devices that can be networked by means of a wireless network for human body health monitoring. Applications include monitoring during healthcare programs such as fitness training, and patient monitoring [51].

Vehicle Monitoring: Many sensors and diagnostic devices are usually embedded within vehicles, and provide ideal applications for wireless networks. A pressure sensor in tires which cannot be connected by cables is a prime example of wireless communication [52-54].

Agriculture: Wireless networks can help farmers to monitor land and environmental conditions in order to optimize their crop yields. Such networks may require wide geographical coverage, but ZigBee addresses this issue by offering network topologies that allow the relaying of messages from node to node across the network [55-57].

Figure 3 illustrates the relationship between BER and SNR for IEEE 802.11b, IEEE P802.15.3 base rate, IEEE 802.15.1, and IEEE 802.15.4 which has excellent performance in low SNR environments. Figure 4 shows the superiority of 802.15.4 compared with Bluetooth standard where the battery life spans for 10 years when the check in interval almost every 20 sec. Naseer et al. illustrate by calculation that when the check in interval be 10 minutes will prolong the life wireless node based 210mAh [24].

2.3. **Factors influence WSAN design.** There are many factors that influence WSN performance, and equivalently WSAN, like costs, reliability, environment, and power consumption. The design of efficient WSAN must consider each of these factors in detail. Following are the factors that affect the overall performance of WSAN and how they impact the functioning of the protocol.

Reliability: One of the most important factors of any system is the reliability. In WSAN, reliability can be defined as the ability of the network to sustain its functionality regardless of the failure of nodes. WSAN is pervasive of sensor nodes and thus the failure of a single node should not affect the overall network performance. Sensor node can fail due to several reasons such as physical damage, environmental interference, decreased energy source. The reliability of a sensor node can be modeled using the poisson distribution. The probability of a node not having a failure within the interval $(0, t)$ is given by

$$R_k(t) = e^{-\lambda_k t} \tag{1}$$

where k is the failure rate of node k. t is the time period.

Scalability: The density of a WSN can be anything from a few nodes to a few hundred nodes per square meter and may be one WSAN. A WSN may consist of hundreds of nodes in a single network and thus the protocols have to be designed to be able to work with these large numbers of nodes and also utilize the high density of nodes. The density $\mu(R)$ can be defined as the number of nodes within the transmission range of a specific node.

$$\mu(R) = (N \times \pi \times R^2)/A \tag{2}$$

where N is the number of nodes in region A. R is the transmission range of the employed radio.

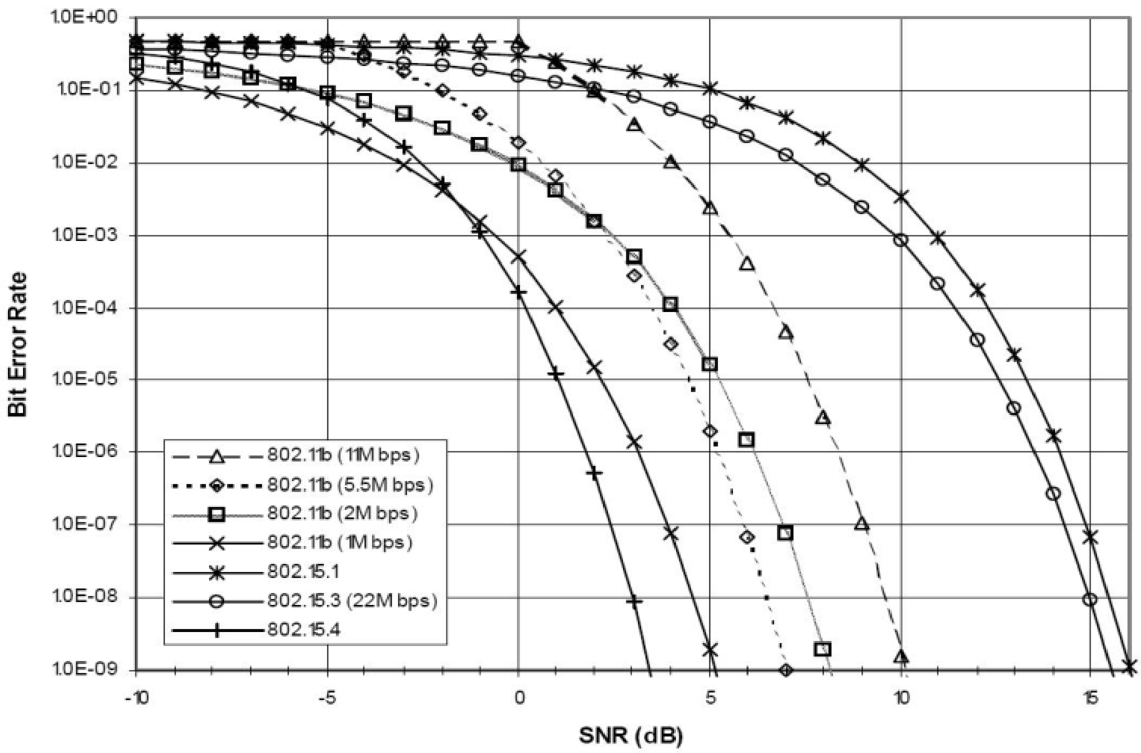


Figure 3. BER results for IEEE 802.11, IEEE 802.15.1, IEEE P802.15.3 and IEEE 802.15.4

Production Costs: Commercialization of WSAN is highly considering the cost of a sensor node. Since a wireless network can have more than a hundred nodes, the cost of a single node should not exceed a few dollars and for a network of thousands of nodes the price should be less than one dollar in order to be financially feasible.

Hardware Constraints: There are three basic components of WSAN nodes, a processing unit, sensing-actor unit and transceiver. Some sensor nodes also contain optional components such as a global positioning system (GPS), alternate energy source like solar cells, interfacing relays. The basic components of a sensor node are shown in Figure 10. The processing unit consists of a processor and memory. This unit is responsible for managing the tasks of the sensor unit. The sensing unit generally consists of a sensor and an analog to digital converter (ADC). The ADC converts the analog data from the sensor to digital data that can be processed by the processor. The transceiver connects the sensor node to the network. The transceiver usually uses radio frequency (RF) for communication between the nodes. Node may also has optional low power GPS or it could be a coordinated establishment algorithm that is implemented in the processing module to know its relative position to the base station. A mobilized unit can be used to enable a node to move if necessary. Relays can be used to activate devices connected to the sensor node. Recharging of battery cells can rely on using the solar cells so that the lifetime of the node can be increased.

Network Topology: Topology changes and maintenance can be viewed in three phases, namely deployment phase, post-deployment and re-deployment. The initial topology is set up during deployment in the field. Topology changes during the post-deployment phase are due to node failures and positional changes of nodes due to mobility. During the re-deployment phase, additional nodes can be deployed in the network.

Operating Environment: WSNs can operate in soft or harsh environment. It can be deployed in hospitable as well as extremely hostile environments. They can be deployed in a home, factory, on machinery, battle fields, ocean beds, disaster areas, toxic areas and so on. Precise details must be provided regarding construction, sensor tolerance levels, propagation problems and so on, according to the operating environment where the network is going to be deployed.

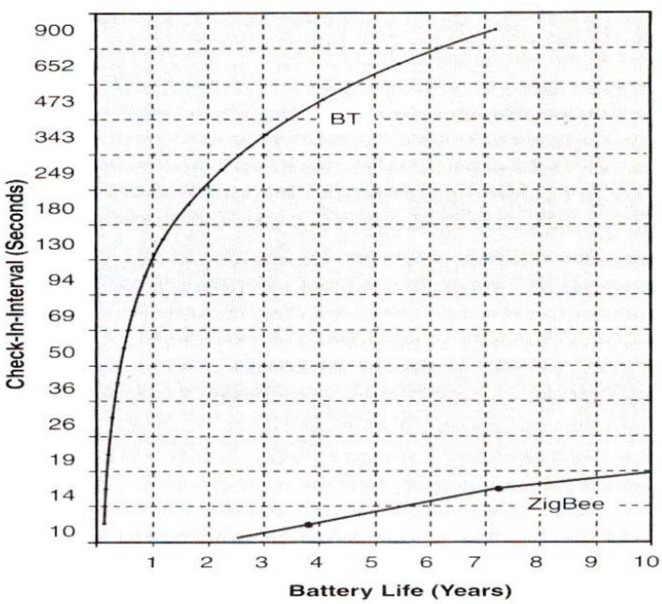


FIGURE 4. Battery longevity for Zigbee and Bluetooth standards

Transmission Media: RF or infrared wireless transmission is usually used with nodes of the WSN. Since these medias have low bandwidth, they may suffer from high rate errors and fading. The MAC layer of WSNs can be of either of the two types, TDMA or CSMA. Even though TDMA conserves more energy than CSMA-CA, it has higher setup requirements.

Energy Consumption: The power source of a sensor node is limited and hence its lifetime is a critical issue. In a WSAN, each node can originate or route data. When few nodes deplete their energy resources, topology changes occur which may require rerouting of data packets. A sensor node's task is to sense data, perform some processing and then transmit the data. Therefore, energy consumption in a node can be divided into three areas, communication, processing and sensing. A node traditionally expends most of its energy during communication. The transceiver unit consumes energy during both start-up and active states. As the size of the packets becomes smaller the energy consumed during transmission decreases. The power consumed during transmission can be calculated using below formula

$$P_c = N_T[P_T(T_{on} + T_{st}) + P_{out}(T_{on})] + N_R[P_R(R_{on} + R_{st})] \tag{3}$$

where N_T is the number of times the transmitter is turned on per unit time. P_T is the power consumed by the transmitter. T_{on} is the transmitter on time. T_{st} is the transmitter startup time. P_{out} is the output power of the transmitter. N_R is the number of times the receiver is turned on per unit time. P_R is the power consumed by the receiver. R_{on} is the receiver on time. R_{st} is the receiver startup time.

During the processing phase the energy consumed is small and can be reduced to a minimum level by customizing the processing task as much as possible. Therefore, keep the sensing task as simple as possible will affect highly the energy consuming and thus prolong node life. Sensing can be continuous or at discreet intervals of time and different types of sensors have different power consumption. Depending on the sensor or actuator being employed, the sensing task can be considered the second largest consumer of energy [23]. Liaw et al. divides sensor nodes into several groups whose total energies are the same into clustering form. Their proposed algorithms improve the lifetime of a WSN based developing of energy efficient protocols that can be applied for heterogeneous WSNs [58].

Data Aggregation: Data aggregation is an efficient method of reducing the number of redundant data in the system [59]. It can be defined as the process of combining data from different sources according to a certain function such as maxima, minima or average and thus less packet length is obtained. Signal processing methods such as data fusion can also be used to reduce the amount of redundant data. Routing algorithms such as LEACH and PEGASIS are based on data aggregation principles.

Fault Tolerance: Fault tolerance is the ability of a system to provide an acceptable level of functionality of the WSN in the presence of faults [60]. Sensor node mainly has two components, sensing and wireless transceiver modules, which are directly in contact with the environment that may change frequently and thus affect the nodes health. Hence, low reliability of performance of nodes might happen. Although the sensor hardware is good working, but the communication of the sensors nodes are affected by many other factors like the signal power, obstacles between nodes, weather conditions, interference and antenna angle. Fault tolerance of WSN's is mainly handled by the MAC and routing layers. Some of the capabilities available to these layers are adjusting transmitting power and signaling rates on existing links.

3. **Intelligence Control Methods An Agricultural Prospective.** Artificial Intelligence such as Fuzzy, Neural Network, Fuzzy-Neural and Genetic techniques is resulting

of applying soft computing techniques to control complex systems [61-63]. However, to achieve successfully the cognitive WSAN in reality, many challenges must be overcome both of hardware and software side, and find an adaptable platform that can be tuned for various applications. A new age of automation systems relates to embedment of smart algorithms within WSAN nodes where control decision will be made based on the collected sensor's data. These ICS such as FIS have the ability to find the optimal solution/decision and thus provide better environmental conditions based on crop requirements and increasing crop production and quality [33,35]. Many control strategies had been applied to GH in wired/wireless control technology; brief of most of them are presented below.

Switching control: This type of control is an enhancement of timing control strategy in which hardware timers are used based on preprogramming by the planter according to a specific task. Because no feedback information is from the plant field under control, extensive knowledge is needed for crops, weather conditions and a continuous monitoring by the planter to avoid/tune any unnecessary actuation due to sudden parameter change. Contrary, switching mode is based on ON-OFF control strategy as Figure 5 depicts, the sensed value will be compared with the set value and based on error value the decision unit with activate either max-limit or min-limit. A predetermined program will adjust the input variable to be within max-min limits based on error feedback value. This system maintains climate condition within two defined limits value, while this is easy and cheap to install and adjust, but it is not efficient due to interrelations of GH variables like the relation of temperature, humidity and carbon-dioxide, in which variation in one parameter affects other parameters values. The result of this strategy is continuous oscillation in these variables [64,65].

Proportional integral derivative controller (PID): PID control can be applied to improving the switching mode controllers. It responds to high and low levels of the control variables with a consideration of a set point. It is a linear controller and effectively can solve linear problems with less effort, time and cost. GH climate control based PID control exposes various inconveniences with respect to its implementation requirements. Figure

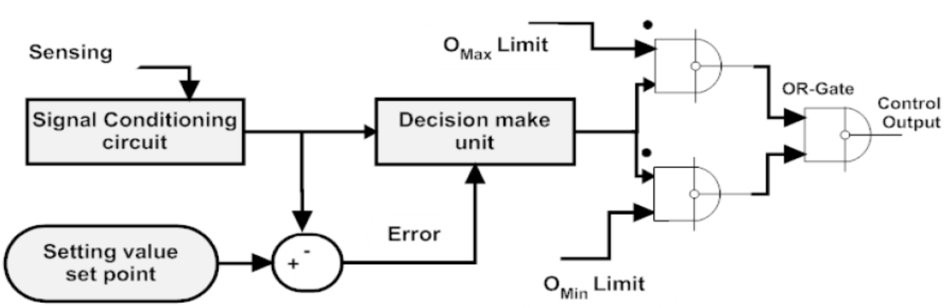


FIGURE 5. General switching controller (ON-OFF)

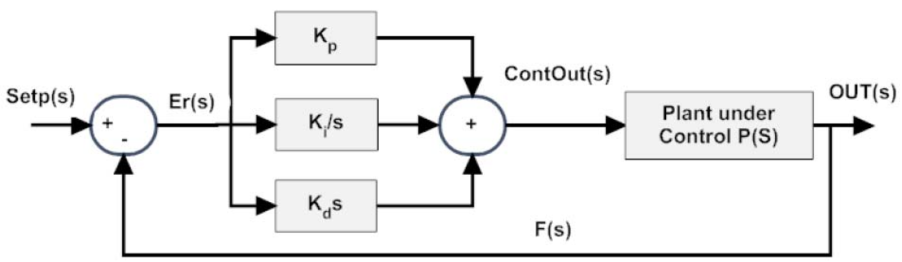


FIGURE 6. General PID controller of a plant

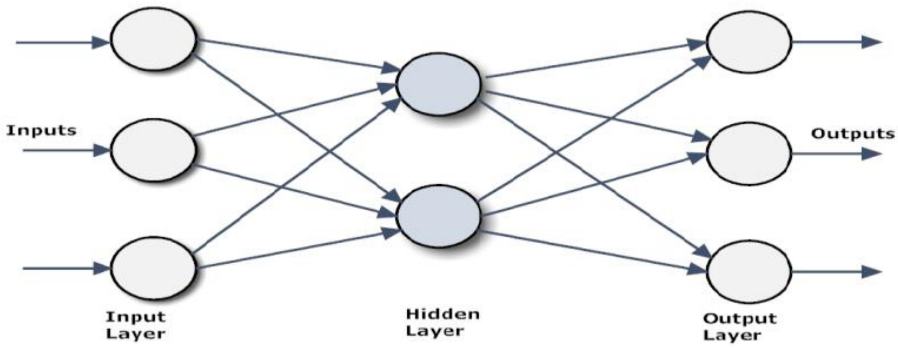


Figure 7. Perception of three layers: inputs, hidden and outputs

6 shows a general PID controller, where $r(s)$ is reference input (the set point input of the control variable), $h(s)$ is the feedback, $e(s)$ is the error value and $u(s)$ is the transfer function which describe the system behavior and consider s the interactions among all variables. Control plant (GH climate). The main applications of PID controller are related to the nutrition process of plants which provide a precise dose during irrigation phase [66-69].

Artificial neural network (ANN): ANN is based on mathematical modeling algorithm to simulate the human behavior. The ANN algorithm must be trained with a predefined set of data (supervised learning) to provide model that describe the behavior of the variables and produce suitable outputs which represent control actions or predictions about specific phenomena. Using of ANN as predictable controller for GH is limited by computational cost and large multi-dimensional sets of data that is necessary for algorithm training [70-72]. Figure 7 shows a general ANN. The circles represent processing neurons which use the interconnection as a channel for data flow between neurons. The neurons in input layer are considered as the input gates to the network which store the value of input and forward for above layers. Each processing neuron has limited amount of memory and ability to perform a calculation for its inputs to provide a dedicated output based on defined criteria.

Fuzzy controller (FC): Fuzzy logic is a method of modeling vagueness and uncertainties associated with human cognitive process, like thinking and reasoning based on membership functions. FC is a smart mathematical tool used to model non-linear systems and to develop complex controllers [73-75]. It has been applied successfully, both to large-scale systems (like sub way train system) and to small-scale systems (like human appliances). Also it is contributed to bioprocess and greenhouse climate control and irrigation/nutrition process [24,35,76]. There are four main features of FLC which expose better performance. First, FLC is an appropriate solution for uncertain or approximate reasoning, especially when mathematical model is difficult to drive. And second, when incomplete and uncertain information found, FLC allows decision making based on estimated values; third, FLC is customizable, FLC is easier to understand and tune its rule, and FLC uses human operator's strategy which is expressed in natural linguistic terms. Lastly, it is easy to learn how to design and operate FLC and apply it to concrete application [77,78]. FLC has features that make it perfect solution for WSN towards smartness network. FLC algorithms need small amount of memory, and thus execution time is less, also its mathematics is less complicated than other controlling approach. Hence, it is highly recommended for application based SWSAN [24].

Figure 8 illustrates the FLC, which has four main modules: The Rule-Base module, based on a set of predefined rules, holds the knowledge of how best to control the system.

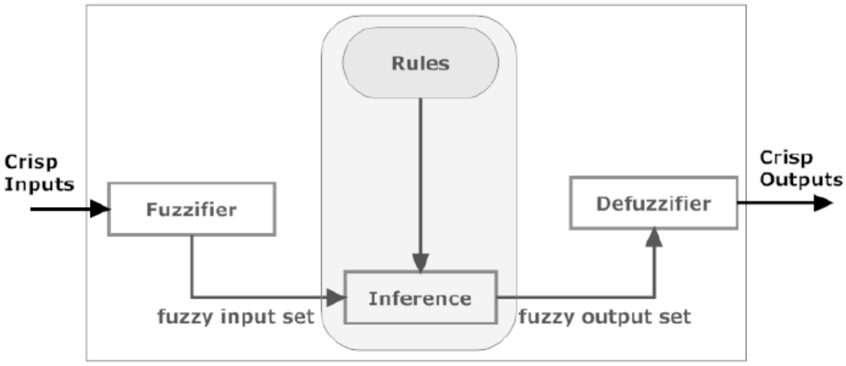


Figure 8. Fuzzy logic controller

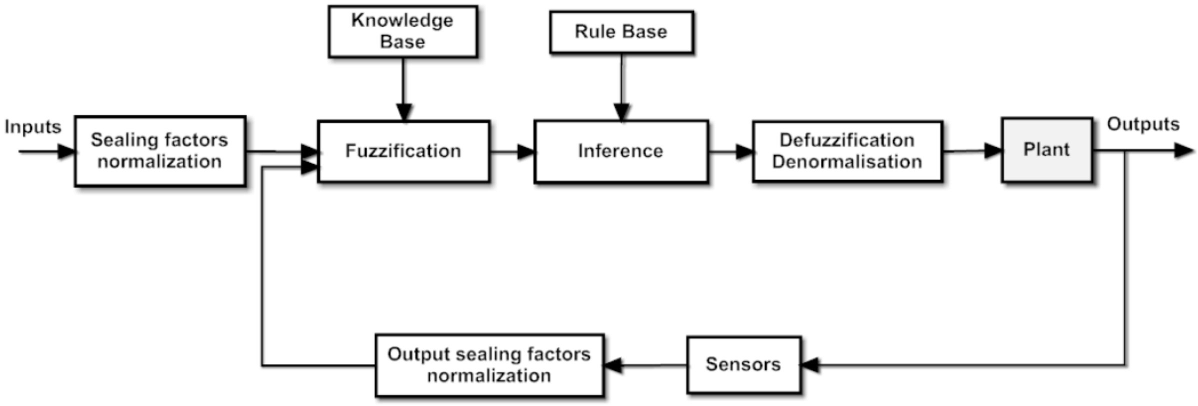


Figure 9. Typical fuzzy logic controller in a system

Algorithm 1. Fuzzy logic controller Algorithm	
1. Initialization process:	Define the linguistic variables and terms Construct the membership functions Construct the rule base
2. Fuzzification process: functions	Convert crisp input data to fuzzy values using the membership
3. Inference process :	Evaluate the rules in the rule base Combine the results of each rule
4. Defuzzification process:	Convert the output data to non-fuzzy values

The Fuzzification Interface module, simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base. The Inference Mechanism module, defines which control rules are relevant at the current time and then concludes what the input to the plant should be at the moment. Finally, the Defuzzification Interface module, converts the conclusions reached by the inference mechanism into the inputs to the plant. Figure 9 depicts a closed loop controlling system based on FLC in a system; inputs refer to the system setting point while the feedback inputs is the controlled variable information sensed by sensors inside the plant under vision [79,80].

Algorithm 1 explains the process of fuzzy logic. During fuzzification process, a crisp set of input data is gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. Then an inference is made based on a set of rules. The resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzication step.

Fuzzy logic controller and ANN emerged by concepts of the computational power of human. FLC provides methods for inference based on cognitive uncertainty. It attempts to mimic human brain that is systems think like people. On the other hand, ANNs provide means for pattern recognition and classification. They attempt to be like the biological sensory system. Both FLC and ANN are developed independently, but they can complement each other in numerous applications.

4. **Smart WSAN Based on Fuzzy Controller.** For greenhouses, the quality and the productivity of plant are the most important parameters that have to be optimized. Those factors are highly affected by temperature, humidity, light and the level of carbon-dioxide. The continuous smart monitoring system of climate parameters will lead to well understanding of how the plants being affected by these factors and how to optimize the setting of these climate parameters to maximal crop production and quality [24,80,81].

Recently, WSAN based greenhouses provides a useful part of the automation system architecture. Monitoring and collecting of data based on wireless communication offer fast, cheap and easy installation and re-architect the network's nodes for new location within the limit of communication area of the coordinator node. Moving or hanging of nodes is easy to implement due to the small node size and light weight; they can be easily moved or hanged up to plant's branches or ceiling in situation when GH flora is high and dense or to achieve a line of sight communication with the coordinator node [38,82,83]. The maintenance of nodes is almost cheap and easy, and the only overdue cost is when nodes run out of battery charge thus they need either to be replaced or recharged. Adopting of intelligent algorithm for power saving within physical layer or the network layer of the node can indeed enhance the overall lifespan of the nodes for several years and thus provide effective low cost and higher reliability system.

FLC can be merged into WSAN in various forms; it can be implemented by embedded hardware form such as adequate FPGA chip [84]. Other form of merging is fusion fuzzy logic controller with WSAN to program its control algorithms with node's micro-controller and use part of its resources. Naseer at el., 2012, used star topology for their climate control WSAN based on fuzzy approach as a controller for daytime and nighttime

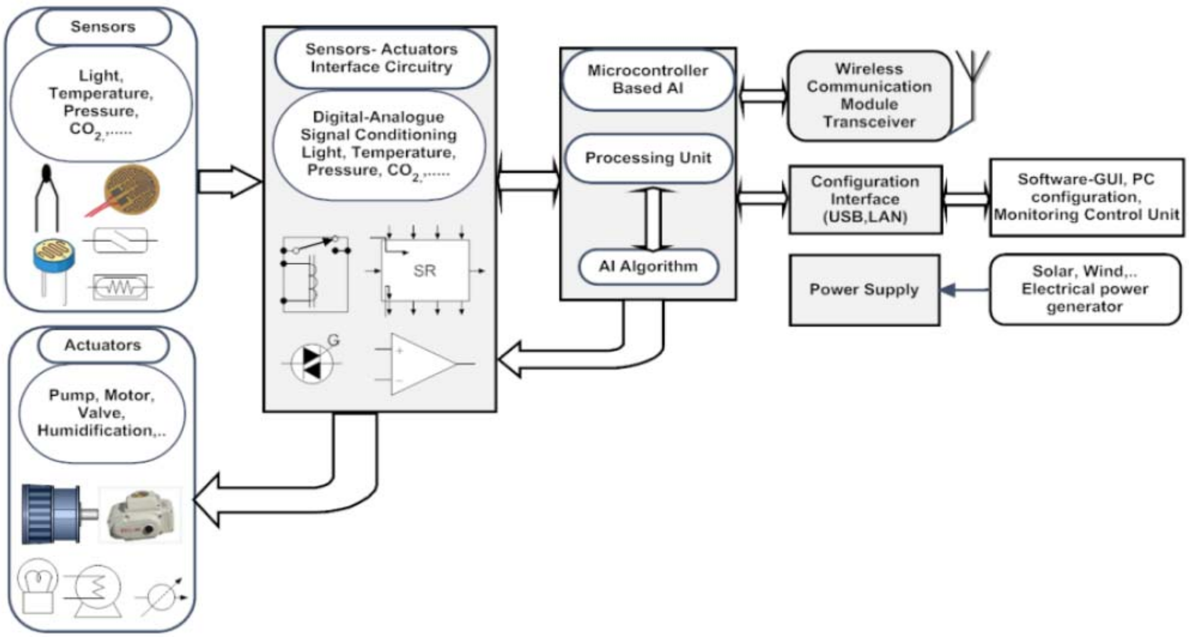


FIGURE 10. Smart sensor-actor node

temperature and humidity [24]. Their works shows successful result and reliable smooth variation of these climate parameters which simulate it natural variation in nature that yields better environment to the crop. Nodes spatial distribution was to optimal converging and to minimize number of nodes/sensor needed. The smart algorithm of collecting data and filtering before overhead it through the network shows high positive impact on packets length and hence error, reliability and nodes life time which spans for more than 10 years [24,85,86]. Also, FLC can be embedded with nodes for best routing of information of multi hop network; it can be used with multimode power node to offer best power saving and hence prolong the sensor-actor nodes life. While the system can consider as first step towards SWSAN, it opens the door for a complete system based fuzzy logic of new era of WSAN for various applications, especially with the currently massive fast advances of technologies, software and researches of WSAN.

The proposed smart sensor nodes may have four main sub modules, as Figure 10 shows. The AI module is embedded with the processing unit and can also participate for both sensor/actor node decision making unit. These modules are shown as follows.

Power module: Power supply and management is crucial parameter for the network node. An appropriate energy infrastructure is necessary to prolong node operation for years depending on the application sampling rate and strategy of the operation [77,78].

Computational logic and storage: It is represented by the microprocessor of 8, 16 or 64-bit. It used to handle onboard data processing and manipulation, transient and short term storage, encryption, modulation, digital transmission and receiving.

Sensor module: The sensor transducer(s) is the interface of the hardware of the network node and the environment. Sensors can be of digital or analogue.

Communication module: Wireless network has the ability to communicate using point to point, multipoint to point, and may multi hop communication strategy. At least one of these communication strategies must be adopted by this module. Distance ranges from a few of meters to a few of kilometers; lower layer of the network tends to be of the IEEE 802.11/15 class. Throughput that ranges from 10-256Kbps in most application is required.

AI module: This module could have hardware or software forms. According to the AI technique, the optimal solution will be chosen and provided to the network. For near future, all nodes of wireless sensor network will be combined with this module and tend towards autonomous nodes of a wireless sensor-actor network.

5. **Greenhouse Climate Energy Balance Modeling.**

The energy balance modeling of a greenhouse is used to predict the inside climate based on a given state of the system, outdoor weather and control purposes. The only one homogenous component of a greenhouse is the blocked air, where the interior is considered to be a perfectly stirred tank consisting essentially of air. This model is shown to be highly nonlinear. Greenhouse dynamic Equations (4) and (5) govern sensible and latent heat, as well as water balances on the interior volume and can be derived by considering the differential equations [87,88]; the temperature and humidity prediction equation are:

$$\begin{aligned}\rho C_p V \partial T/\partial t = (q_{heater}(t) + S_i(t) - \lambda q_{fog}(t)) - \rho C_p V_R(t)(T_{in}(t) - T_{out}(t)) \\ - AU(T_{in}(t) - T_{out}(t))\end{aligned} \tag{4}$$

$$\begin{aligned}\rho V \partial w_{in}(t)/\partial t = -\beta_T w_{in}(t) + q_{fog}(t) + \alpha S_i(t)/\lambda - V_R(t)(w_{in}(t) - w_{out}(t)) \\ - AU(T_{in}(t) - T_{out}(t))\end{aligned} \tag{5}$$

where T_{in} is the interior air temperature (°C), T_{out} the outdoor temperature (°C), AU the heat transfer coefficient (W K^{-1}), ρ the air density (1.2 kg m^{-3}), C_p the specific heat of air (1006 J kg^{-1} K^{-1}), q_{heater} the heat provided by the greenhouse heater (W), S_i the intercepted solar radiant energy (W), q_{fog} the water capacity of the fog system (g H2O s^{-1}), λ the latent heat of vaporization (2257 J g^{-1}), V_R the ventilation rate (m3 [air] s^{-1}), w_{in} and w_{out} the interior and exterior humidity ratios (water vapor mass ratio, g H2O kg^{-1} of dry air), respectively.

In this climate model, two variables have to be controlled namely indoor air temperature and humidity ratio through processes of heating, cooling, humidifying, and/or dehumidifying. Also, in warm climates and when the relative humidity of the outside air is very low, only ventilation can be used to dehumidify the greenhouse air by exchange moist air with drier outside air. Raising humidity levels requires some sort of evaporative device such as misters, fog units, or roof sprinklers, all of which cool and add water vapor to the air. Evaporative cooling devices require good ventilation rates. Fresh air must be continually got through and warm humidified air exhausted. When humidifying occurs under sunny conditions, ventilation is necessary since the greenhouse would soon become a steam bath without offering fresh dry air to evaporate more water, and to cool, humidify and displace hot greenhouse air. In warm climates, ventilation is required most of the day to lower the temperature, and a conflict exists between the need to ventilate and the desire to moisturizing. Common practice usually views ventilation and moisturizing as mutually exclusive.

6. **Cognitive Agricultural WSAN Embedding FIS.** Since greenhouse has blocked environment in which climatic and fertilization parameters can be visioned and controlled precisely, provide an optimal growth of crops [22]. Many engineering and agriculture efforts have been cooperated to reduce the complexity and produce high efficient methods to keep the optimal desired sets of temperature and humidity. Reduce complexity of controlling problem of GH due to coexistence of many parameters that affect the climate and crops. Two parameters (temperature and relative humidity (RH)) have been studied as they are the most sensitive to each other and to crop production. The using of FIS within WSAN shows robust cooperation to build autonomous SWSAN. Temperature and humidity of GH climate can be controlled by ways of adapting heater, humidifier and fan systems. Those parameters are very important and related directly to the growth of plants which is highly affected by temperature and humidity variation. The sunny weather causes to increase the indoor temperature and crop damage [23], contrary at night time a lot of heat emission lost, and hence temperature values may drop under their desired values. As a result the temperature and consequently the humidity change frequently during day/night time which affects the crops health yielding to have a suitable controlling process to achieve optimal crop growth [89].

For perfect variation of those parameters, two threshold values must be declared so that optimal climate parameters inside the greenhouse must simulate the natural variation of those parameters in nature. The two threshold values proposed produce a tolerance space that temperature and humidity can swipe up and down relative to the average value of max-min threshold values.

The design of FIS for temperature and humidity must adopt the optimal variation of those two parameters during the day and night time within the predefined setting values. Many parameters affect temperature and humidity and cause the deviation of their values from the setting range values. For example, diurnal temperatures of crops like tomato and cucumber have range of 24-30°C while night temperature is 8-15°C [22].

6.1. **Greenhouse fuzzy membership function.** The test bed of SWSAN is composed of five nodes based JN5148 platform, each equipped with three sensors of temperature,

TABLE 2. Temperature and humidity fuzzy logic rules

		TEMPERATURE			
		LT	NT	HT	VHT
HUMIDITY	LH	Hu_Med He_Max Fan_OFF	Hu_Max He_OFF Fan_OFF	Hu_Med He_OFF Fan_Med	Hu_OFF He_OFF Fan_Max
	NH	Hu_OFF He_Med Fan_OFF	OFF	Hu_OFF He_OFF Fan_Med	Hu_OFF He_OFF Fan_Med
	HH	Hu_OFF He_Max Fan_OFF	Hu_OFF He_OFF Fan_Med	Hu_OFF He_OFF Fan_Med	Hu_OFF He_OFF Fan_Max

LH: Low Humidity, NH: Neutral Humidity, HH: High Humidity, Hu: Humidity, LT: Low Temperature, NT: Neutral Temperature, HT: High Temperature, VHT: Very High Temperature, He: Heater, Max: Maximum, Med: Medium

humidity and light. These nodes are deployed inside a greenhouse of 12m×6m dimensions. Each node performs a predefined task before delivering data to the coordinator. FIS work based sensor data inputs sent by the sensor nodes.

The primary in designing the FIS is to choose the inputs sensors and the output actuators. Two main sensors used with FIS are the temperature and humidity sensors and three actuators types. The inputs to the FIS are categorized into four sets, set one of inputs consist of the temperature and humidity average values (T_setD, H_setD) with a deviation value (T_devD, H_devD) for both higher and lower than the average values, while inputs of set two are the same as those of set one except it is for night setting $(T\_setN, H\_setN, T\_devN, H\_dev\ N)$. The current reading of temperature and humidity (T_c, H_c) forms the set three of inputs to the FIS. The sensing of day or night time has been determined by using LDR sensor. The crisp input and crisp output are defined as

Crisp input $T\_day : T\_c - T\_setD$; $H\_setD : T\_c - H\_setD$

Crisp input $T\_night : T\_c - T\_setN$; $H\_night : H\_c - H\_setN$

Crisp output: Heater, Fan and Humidifier, delivered power expressed by PWM.

Based on the definition of input and output crisps, membership functions of fuzzy logic will be determined. The crisp input of the temperature (T) is divided into four regions while crisp input of humidity (H) into three regions. The crisp output consists of three regions and is to be used mutually to assign crisp output values for heater and humidifier devices, the third crisp output will be used with the ventilation system.

The error value has been defined as OK if it is within $(\pm T\_dev, \pm H\_dev)$ for temperature and humidity respectively.

The membership functions limits can be varied easily to adapt for working for new crop parameters of temperature and humidity within the GH requirements. Obviously, by choosing other range for each membership function will assist in providing optimal solution for the specified crop based on working experience knowledge and plant requirements. Adjusting these values was controllable and easy, resulting in tuning the outputs to be more adequate with the requirements of the crop. Table 2 shows the fuzzy logic rules of the system.

6.2. **Greenhouse smart WSAN.** The system of SWSAN based GH has been built with a star topology network where sensor and actor nodes are equipped with temperature, humidity and light sensors. Star network is common, easy to implement and maintain. It

```
main () {
initialization ();        /* declare and initialize variables and constant*/
Crisp_Input (int *T, int *H); /* Crisp input calculation */
I_Memebership (int *Tmem, int *Hmem); /* Find the membership of crisp inputs */
O_Memebership (float Omemt, float Omemh, float Omemf); /Find membership of crisp out*/
Crisp_Output (float OFIS[]); /* calculate Crisp out value*/
Pass_tx (OFIS); /* Send out */
    }
```

Figure 11. FIS implementation based greenhouse problem

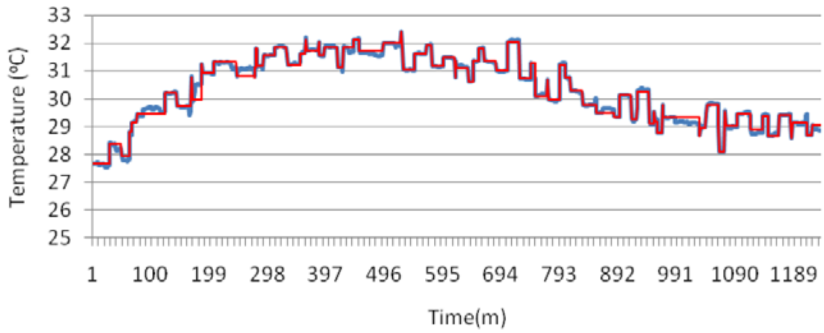
is used widely for control applications that is eager to prolife its operation while depending on limited power supply.

The coordinator node of the GH will be fused with FIS to form the cognitive part of the network. The whole network now has the ability to sense and react in a way that mimic the human behavior. This approach can be implemented easily in all WSAN based on what FIS features. The programming language of the FIS and other algorithms is C language. This language is adequate for programming the network nodes, efficient, flexible and widely used by developers. Figure 11 shows the main function of FIS embedded program which is ended by defuzzification process. Because the output to any practical system cannot be given using the linguistic variables like “moderately high”, “medium”, “very positive”, it has to be given only in crisp quantities. These crisp quantities are therefore obtained from the fuzzy quantities using the defuzzification method discussed above. As a result, the membership values are assigned easily.

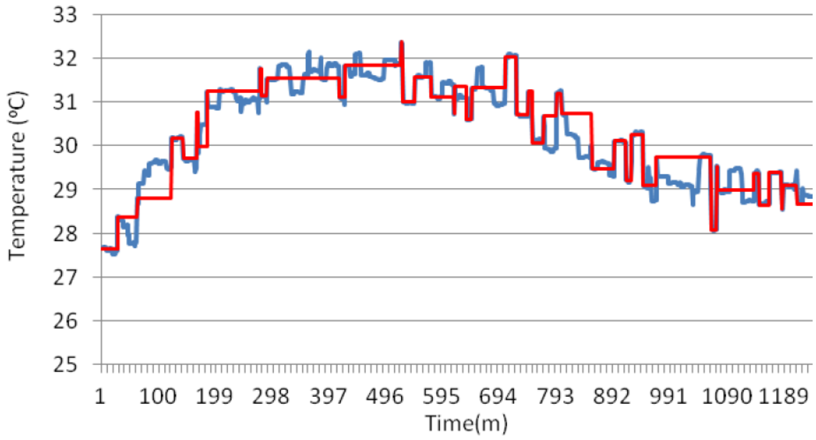
The application developed is capable of executing within a fraction of second. The fuzzification and the defuzzification process are performed using flat mathematic commands. The user can obtain the output in any required form. This makes the FIS within WSAN a successful approach to achieve the cognitive of the new era of WSAN.

The sensor nodes perform data aggregation and apply average-threshold algorithm before sending the data. The samples data will be processed using average-threshold algorithm over two minutes period to get more realistic reading. A threshold technique has been used to reduce the number of bytes of the payload section within the packet. A threshold of the difference between the current average reading and the previous average reading is chosen to be 0.5 for temperature and 1% for humidity. The packet will contain a short code of No_Change when sending it to coordinator node; this will reduce the total power consumption by reducing the time of transmission due to short packets length.

The effects of the threshold limit can be observed in Figure 12, where the transmission of the inside temperature signal is shown. As it can be noticed, the transmission data is smaller for 0.5 threshold but proving bigger signal destruction. This limit has a direct influence on the quantity and quality of transmitted data. The event based control concepts through using the threshold algorithm shows a saving of (85-90%) of transmission data when using 0.5 and 10 as thresholds of temperature and light respectively. Table 3 shows the experimental results of applying different thresholds of temperature, humidity and solar radiation during 24 hours with 2 minutes check-in period.



(a)



(b)

FIGURE 12. Effect of threshold level on number of packet transmission. (a) Threshold is 0.25 and (b) threshold is 0.5.

TABLE 3. Data transmission results

Variable	Time-based Samples [1]	*Threshold* Th_T=0.5, Th_S=10	Saving (%)	*Threshold* Th_T=0.25, Th_S=5	Saving (%)
Temperature-In	18000	1638	90.09	3142	82.54
Humidity-In	18000	1776	90.01	3286	81.74
Solar Radiation	18000	2194	87.81	4267	76.29
Temperature-Out	18000	2612	85.48	4094	77.25

[1] 2 minute check-in period

Average-threshold algorithm is used to get precise reading over period of time and only worth data queued for sending. The power consumption will be less, preserve for longer life time of operation. The transmission scheduled every 10 minutes for each node in time slot criteria. The function of the sensor nodes is periodically to implement three main tasks; data collection and threshold, processing of data and then reporting to coordinator node of the network.

The coordinator node manages the network initialization and control mechanism. It is embedded within the following tasks:

- Initiate the network and maintain its operation;
- Periodically stimulate the sensor nodes for health check and data query;
- Accumulate and evaluate the samples read from sensor nodes with its own sensors reading and fed to the fuzzy inference system (FIS), which is embedded within coordinator node for diurnal and nocturnal controlling of temperature and humidity;

- Activate the actuator nodes.

Figure 13 depicted the main steps of CWSAN-GH architecture flowchart.

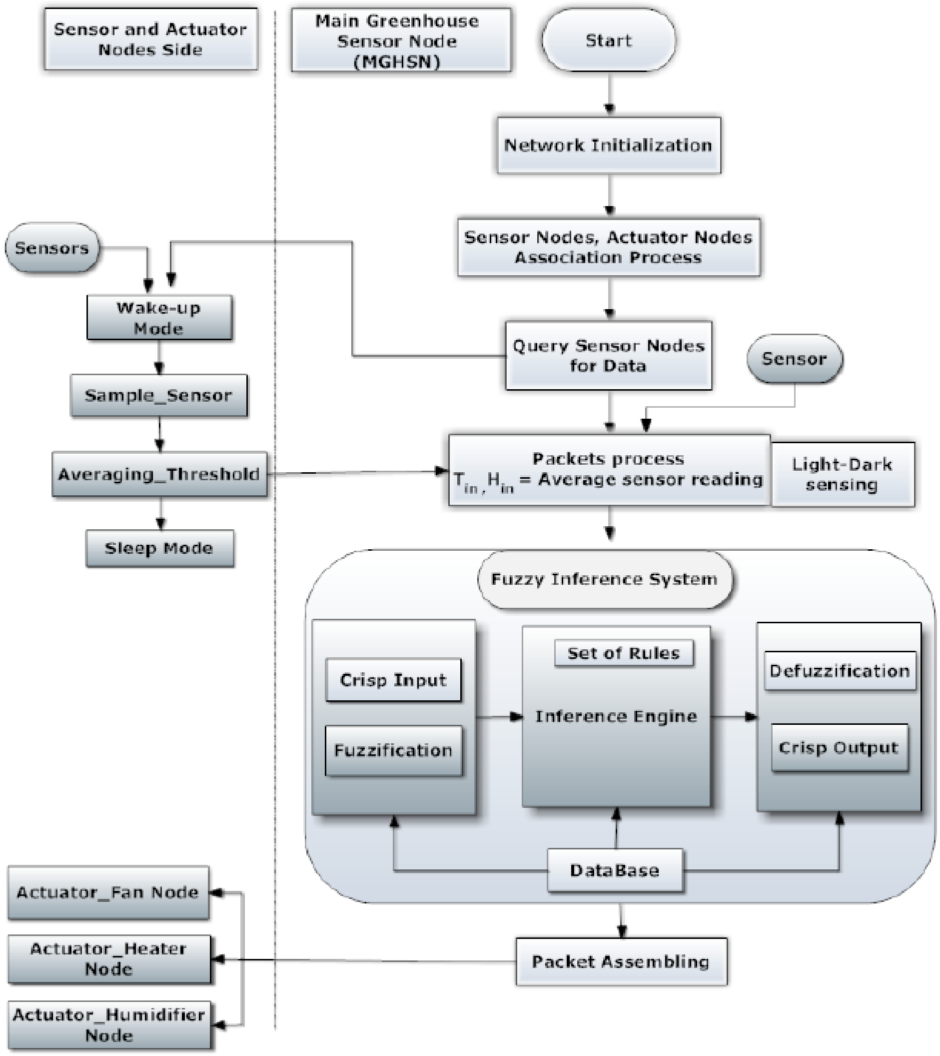


Figure 13. Cognitive wireless sensor-actor network main algorithm structure

6.3. **Smart WSAN technology.** ZigBee technology is low cost; power consumption is low and low data rate of maximum 250 Kbps. It is dedicated for automation and remote control and monitoring application.

The platform consists of a coordinator, sensors and sensor/actuator nodes. Those are used as a test bed of this research. A sensor network equipped with ZigBee can be used to achieve high level of networking performance. All sensor boards sent their data to the main node to be processed by FIS and a proper actuation command follows the network back to the actuation nodes. The dynamic behaviors of the network through sensing-activation procedure provide accurate, fast response to mitigate any disturbance of changing the parameters values inside the greenhouse.

The hardware platform was built using new single chip 32 bit wireless microcontroller. Economical and compact wireless sensor nodes have been developed using JENNIC wireless node. It consumes 18mA at receiving status while 15mA at transmission status with +3dBm. The 32 bit wireless microcontroller has 128 KB ROM, 128KB RAM and new enhanced coding technique provides it with adequate features for developers to integrate

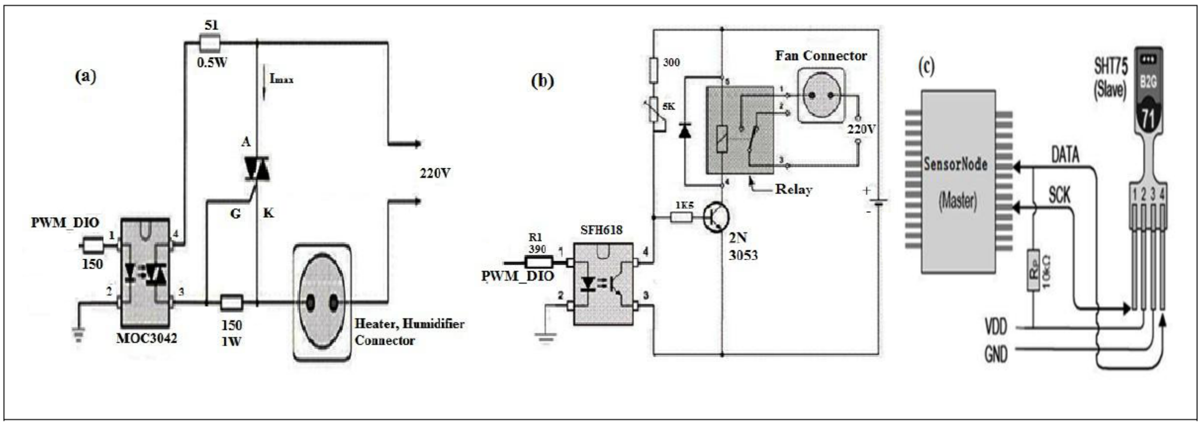


FIGURE 14. Actuator node interface circuit, (a) Heater and Humidifier interface circuit, (b) Fan interface circuit. SHT75 sensor with I2C connection to the wireless microcontroller (JN5148)

their embedded application and the ZigBee PRO stack into a single efficient and low power consumption integrated chip.

6.4. **Sensor and actor nodes.** Figure 14 shows two types of actuators used. They are used to activate the Heating and Humidifying system. This actuator trigged by ON_HEATER packet is received by Heat Active_actor Node. This packet contains the ON action and the ON_Duty cycle time. The actor node uses the PWM technique applying it to the attached device. Same procedure will apply to humidifier and fan with packet ON_HUMIDIFIER and ON_FAN respectively. These actors are used to adjust the climate inside the GH by means of heating, humidifying or ventilation. The heating and humidifying systems are connected to the node as described by the actuator node circuitry in Figure 14(a), and Fan system interface circuitry is shown in Figure 14(b). The FIS and actuator node will encode the required amount of power as a variable square pulse duration using PWM technique. PWM is a powerful technique for controlling analog circuits with the digital outputs of a processor. Using on chip PWM controller (like Jennic wireless microcontroller) makes implementation easy and power consumption can be radically reduced. The coordinator will pool the nodes for data every 10 minutes.

The SHT75 sensor shown in Figure 14 is a temperature and humidity sensor. It has low power consumption, tolerance against wetness climate and fast response time. This sensor is considered as a perfect solution for GH environment (www.sensirion.com). Table 2 shows the specification of SHT75 sensor. It needs only one pull-up resistor to be connected between VDD line and Data line, with two communication line DATA and SCK lines that connect to the sensor node microcontroller JN5148 SIF_D and SIF_CLK. The mode of operation flips from sleep mode to active mode on measuring status; hence, sleeping mode is a crucial parameter for low power consumption concepts.

7. **Results and Discussion.** The sensor nodes are deployed in greenhouse with the existence of the line of sight LOS between the sensor nodes and the MGHSN, the quality of link was high and the error was very less than 2%. Indeed the sensor nodes apply average-threshold algorithm which enhances the overall system showing. The network performance was highly reliable and achieved stable performance during one week of operation. Xia et al. found that the packet loss rate remains less than 10% when the transmission power is set to 0dBm in different nodes. The packet loss varies nearly from 0% to 100% of the area between 9m and 13m [90]. Thus, the overall performing of

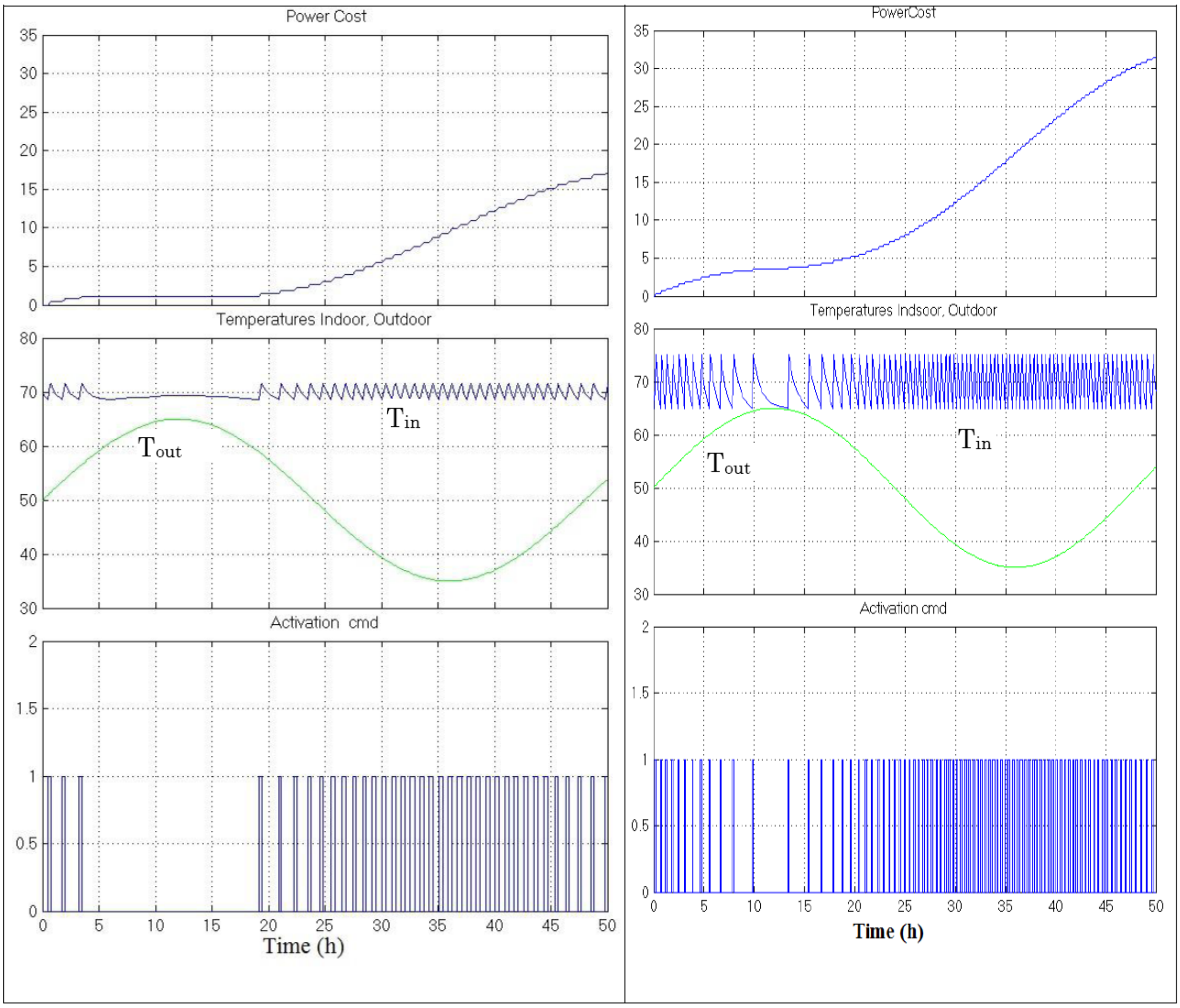
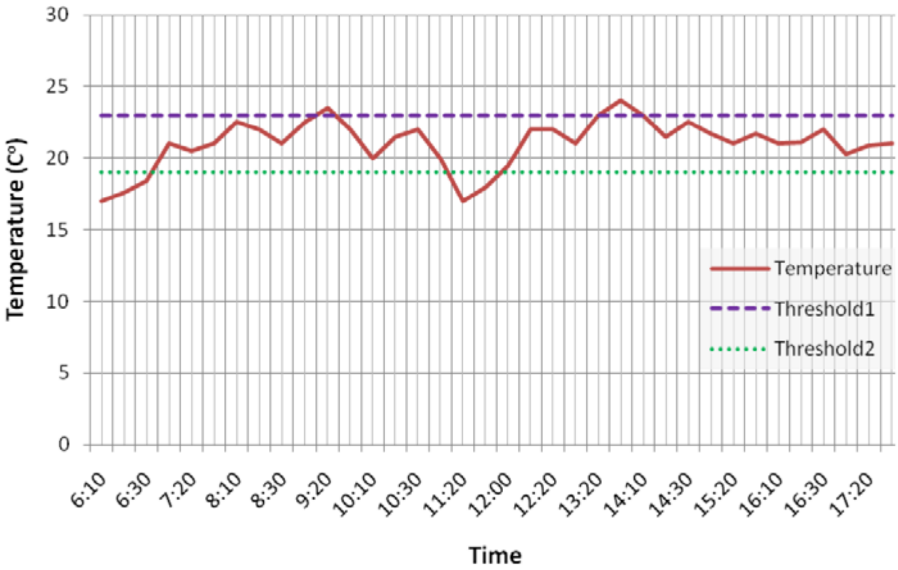


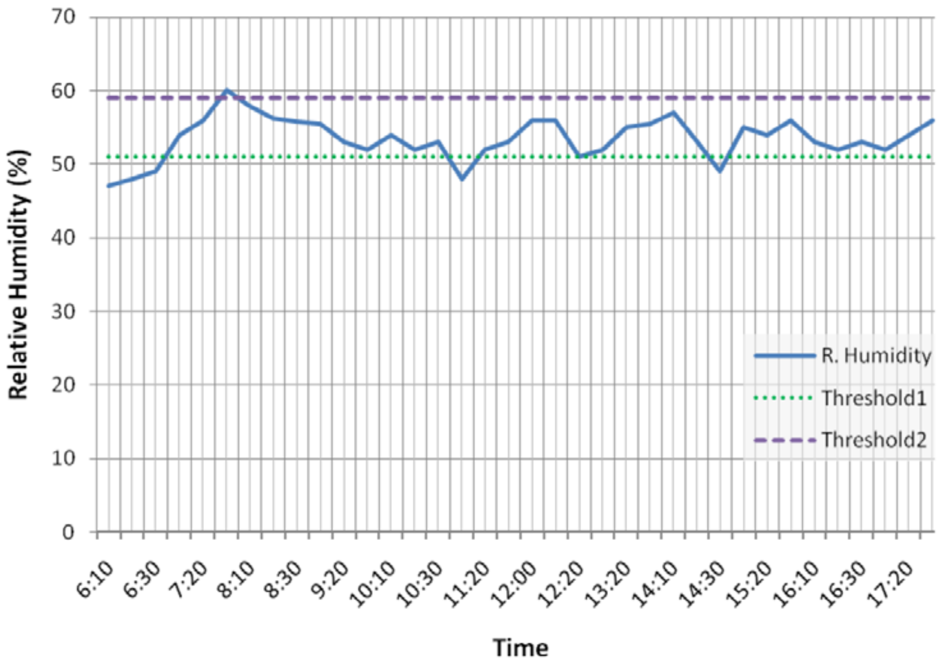
FIGURE 15. Fuzzy based greenhouse simulation model (left), traditional controller based greenhouse model (right)

nodes within SWSAN-GH is above of 95% of packets transmission rate. Using of fuzzy simulation tool such as MATLAB will ease the tuning of the fuzzy rules and member function sets based on set-test strategy with the cooperation of agricultural knowledge specialist. This strategy helps to find the optimal control setting before applied to real time hardware programming where each possible linguistic value of inputs is assigned to a consequential action. Figure 15 (right) shows the simulation results, for extreme temperature margin, for a conventional controller where the number of activating the assistance devices and thus energy consumption will be directly related to the width of the hysteresis/dead-band value which also affects the reliability of controller. Contrary, the use of FIS for controlling provides smoother output and saver energy consumption as can be seen in Figure 15 (left).

The energy supplied and hence the cost is about 50% less with FIS than with conventional controller, and also it is clear that the number of activation command for assistance device is less than that with conventional controller. The continuous high fluctuation of conventional controller is higher than controller based FIS for the same environment, and the high fluctuation around the desired temperature value leads to instability of the system and shorter operation life for activation circuitry and devices.



(a)



(b)

FIGURE 16. Average reading of temperature (a) and humidity (b) of sensor nodes

All sensor nodes reading were almost similar with little bit difference with wall side sensor nodes reading during sunny days. Figure 16 shows the average reading of temperature of the sensors attached to the coordinator node and the four sensor nodes of temperature and humidity. The cooling system is represented by the ventilation process while using the heater to warm up the climate inside the greenhouse. The 10 minutes period is enough for homogeneity of temperature within the greenhouse area during ventilation while for heating it is seen during the second period of sampling data where the climate temperature reaches stable fluctuation within the predefined limits. The allowance of temperature limits provides the optimal weather for growth of plants. The overall system performance shows high confidential result for both temperature and humidity controlling process. The fluctuations of those parameters are smooth over the average value, while in some cases of sudden heavy rain their values affected and shown as using a positive or negative spike in the graph. The FIS tracks those changes and within next period of time it guides the temperature and humidity values to be within their limits.

The Fuzzy Inference System adjusted the heat and the humidity based on the new samples reading once every 10 minutes. Erratic environment changes such as sudden heavy rain during days of test affected the result, while normal graduated change shows smooth controlling bias.

The CWSAN-GH applied event based concept of controlling using average-threshold algorithm which reduces the total number of packet transmission by 60% with very high performance of the system. Depending on event based strategy conducted by Pawlowski et al. [89] will lead to eliminating the ability of self warning system, since it will be ambiguous to recognize dead nodes. SWSAN encoded 1 byte payload message to show no change in current reading with previous reading and also encode the health of the node itself. Moreover the total number of actuating during one sample day does not exceed 5 times with the support of the two limits threshold algorithms of temperature and humidity values. PWM provides a very efficient way of power consumption, reliable and accurate controlling scheme. PWM has been provided by the output values of FIS.

The using of artificial intelligent represented by Fuzzy Inference System and integration it with the WSAN based provides the first step of complete autonomous controlling system using actor wireless sensor network for GH applications field.

8. **Conclusions.** The AI Techniques (Fuzzy, Neural and Genetic) are being applied increasingly to diverse applications such as military, industry, agriculture and medical applications. They are leading to optimal solutions over conventional control methods. Using of artificial intelligence represented by fuzzy inference system and the integration with a wireless node controller to form a new cognitive wireless sensor actor network can sense and react in optimal performance without interference of planters, exposes the successful steps of autonomous controlling wireless network (SWSAN) for agriculture, such as greenhouses, and many other various applications. SWSAN can be defined as a network of sensor and actor nodes which cooperatively sense the environment and, if need, control it with the smartness of artificial intelligence. This enables a smart real time action process that aims to automate the network tasks. Nowadays, WSNs blend almost all life's applications. Based on benefits gained from the small size, low cost distributed sensing network can be deployed anywhere and even with harsh environments. It defines the way of smart event sensing, analyzing and reacting. This research paper focuses on intelligent WSAN with application to agriculture filed. The concepts and design issues show the possibility to fuse the current WSANs nodes with AI algorithms and embed the new hierarchical system within specific application. Applications include, but are not limited to, industrial machine monitoring and control, agriculture monitoring greenhouse environment control, field combat monitoring and target tracking and surveillance systems. Because of the new trends which arise with WSANs, new efficient algorithms, protocols of communication and design are needed to be more focused on actor tasks side, optimizing the response time, and providing instant solution. SWSAN with such dedicated hardware, software and application may be the next challenge researchers for and developers.

In SWSAN based on FIS, the activation of assistance devices and consumption of energy is less than other traditional controllers; for example, 40-50% energy profit can be achieved and longer life for assistances device since less number of activation and hence less maintenance labors fees. While using of normal controller like the ON-OFF controller, the real time value will track the desired predefined value with hard continuous oscillations around the desire value and this leads to instable system.

The results show a controllable CWSAN based on FIS for climate control of a greenhouse with acceptable error (3-4%) and the system shown to be in steady performance. The acceptable error is to attend to service as sudden natural variation that affects the inside temperature like sudden heavy rain, high speed wind and cloudy sky. Overall the crops need this small variation around the desired temperature value which is considered the perfect environment for the crops.

FIS designed and embedded within JENNIC wireless sensor network test bed can be tuned for other important greenhouse parameters such as irrigation, gas controlling and nutrition systems. Multiple clones of the FIS can be modified to apply those systems using time scheduling strategy for different uninterrupted tasks. This can be achieved easily with fuzzy concept since its takes less memory and its mathematical model is easy to implement with node's hardware.

The combination of AI with actor WSN proves high efficiently, cost effective method, beside flexibility of tuning the whole system for other agricultural tasks. The result of the work shows it is highly recommended to build new generation of intelligent wireless sensor actor network and to embed a programmable FIS within WSAN nodes.

REFERENCES

[1] W. Dargie and C. Poellabauer, *Fundamentals of Wireless Sensor Networks: Theory and Practice*, 1st Edition, John Wiley and Sons Ltd., 2010.

[2] F. Xia, Y.-C. Tian, Y. Li and Y. Sung, Wireless sensor/actuator network design for mobile control applications, *Sensors*, vol.7, pp.2157-2173, 2007.

[3] A. Rezgui and M. Eltoweissy, Service-oriented sensor-actuator networks: Promises, challenges, and the road ahead, *Computer Communications*, vol.30, pp.2627-2648, 2007.

[4] E. Cayirci, T. Coplu and O. Emiroglu, Power aware many to many routing in wireless sensor and actuator networks, *Proc. of the 2nd European Workshop on Wireless Sensor Networks*, vol.2, pp.236-245, 2005.

[5] D. Stipanicev and J. Marasovic, Networked embedded greenhouse monitoring and control, *IEEE International Conference on Control Applications*, Turkey, pp.1350-1355, 2003.

[6] J. Yick, B. Mukherjee and D. Ghosal, Wireless sensor network survey, *Computer Networks*, vol.52, pp.2292-2330, 2008.

[7] L. B. Tik, C. T. Khuan and S. Palaniappan, Monitoring of an aeroponic greenhouse with sensor network, *IJCSNS*, vol.9, pp.240-246, 2009.

[8] V. B. Kirubanand and S. Palaniammal, Study of performance analysis in wired and wireless network, *Am. J. Applied Sci.*, vol.8, pp.826-832, 2011.

[9] W. Liang, J. Xu and Y. Liu, Towards energy saving and load balancing data aggregation for wireless sensor networks, *Inform. Technol. J.*, vol.10, pp.409-415, 2011.

[10] L. Ruiz-Garcia, P. Barreiro and J. I. Robla, Performance of ZigBee-based wireless sensor nodes for real-time monitoring of fruit logistics, *J. Food Eng.*, vol.87, pp.405-415, 2008.

[11] Y. Zhou, X. Yang, X. Guo, M. Zhou and L. Wang, A design of greenhouse monitoring and control system based on ZigBee wireless sensor network, *Proc. of the International Conference on Wireless Communications, Networking and Mobile Computing*, Shanghai, China, pp.2563-2567, 2007.

[12] C. Wang, C. J. Zhao, X. J. Qiao, X. Zhang and Y. H. Zhang, The design of wireless sensor networks node for measuring the greenhouse's environment parameters, *Comput. Computing. Technol. Agric.*, vol.259, pp.1037-1046, 2008.

[13] E. H. Callaway, *Wireless Sensor Networks: Architectures and Protocols*, Auerbach Pub., NY, 2004.

[14] B. Son, Y. Her and J. Kim, A design and implementation of forest-fires surveillance system based on wireless sensor networks for South Korea mountains, *Int. J. Comput. Science and Network Security*, vol.6, pp.124-130, 2006.

[15] L. Y. Yu, N. Wang and X. Q. Meng, Real-time forest fire detection with wireless sensor networks, *Proc. of International Conference on Wireless Communications, Networking and Mobile Computing*, Wuhan, China, vol.1-2, pp.1214-1217, 2005.

[16] T. A. Santoni, J. F. Santucci, E. De Gentili and B. Costa, Using wireless sensor network for wildfire detection, a discrete event approach of environmental monitoring tool, *Proc. of ISEIMA*, pp.115-120, 2006.
[17] E. S. Nadimi, H. T. Sogaard and T. Bak, ZigBee-based wireless sensor networks for classifying the behaviour of a herd of animals using classification trees, *Biosyst. Eng.*, vol.100, pp.167-176, 2008.
[18] O. Ozdemir, R. Niu and P. K. Varshney, Tracking in wireless sensor networks using particle filtering: Physical layer considerations, *IEEE Trans. on Signal Processing*, vol.57, no.5, pp.1987-1999, 2009.
[19] Y. Zhou, J. Li and D. Wang, Collaborative target tracking in wireless sensor networks using quantized innovations and sigma-point Kalman filtering, *Proc. of the IEEE Intl. Symp. Industrial Electronics*, Seoul, Korea, 2009.
[20] S.-T. Cheng, G.-J. Horng and C.-L. Chou, Adaptive vehicle to vehicle heterogeneous transmission in cooperative cognitive network Vanets, *International Journal of Innovative Computing, Information and Control*, vol.8, no.2, pp.1263-1274, 2012.
[21] L. A. Zadeh, The role of fuzzy logic and soft computing in the conception and design of intelligent systems, *Proc. of the 8th Austrian Artificial Intelligence Conference on Fuzzy Logic in Artificial Intelligence*, 1993.
[22] D. Park, C. Park, S. Cho and J. Park, Wireless sensor network-based greenhouse environment monitoring and automatic control system for dew condensation prevention, *Sensors*, vol.11, pp.3640-3651, 2011.
[23] N. Wang, N. Zhang and M. Wang, Wireless sensors in agriculture and food industry – Recent development and future perspective, *Comput. Electron. Agric.*, vol.50, pp.1-14, 2006.
[24] S. Naseer, S. A. Aljunid, R. B. Ahmad, M. F. Malek, Y. Abid, R. Kamaruddin and M. S. Salim, Smart prolong fuzzy wireless sensor-actor network for agricultural application, *Journal of Information Science and Engineering*, vol.28, no.2, 2012.
[25] D. H. Park, B. J. Kang, K. Y. Cho, C. S. Shin, S. E. Cho, J. W. Park and W. M. Yang, A study on greenhouse automatic control system based on wireless sensor network, *Wireless Pers. Comm.*, vol.56, pp.117-130, 2009.
[26] E. Rico-Garcia, I. L. Lopez-Cruz, G. Herrera-Ruiz, G. M. Soto-Zarazua and R. Castaneda-Miranda, Effect of temperature on greenhouse natural ventilation under hot conditions: Computational fluid dynamics simulations, *J. Applied Sci.*, vol.8, pp.4543-4551, 2008.
[27] N. Bennis, J. Duplaix, G. Enéa, M. Haloua and H. Youlal, Greenhouse climate modeling and robust control, *Computer Electron Agr.*, vol.61, no.2, pp.96-107, 2008.
[28] S. A. O'Shaughnessy and S. R. Evett, Integration of wireless sensor networks into moving irrigation systems for automatic irrigation scheduling, *ASABE Annual International Meeting*, Providence, RI, USA, 2008.
[29] Z. Zhang, Investigation of wireless sensor networks for precision agriculture, *ASAE/CSAE Annual International Meeting*, Ottawa, ON, Canada, 2004.
[30] Y. Kim, R. G. Evans and W. M. Iversen, Remote sensing and control of an irrigation system using a distributed wireless sensor network, *IEEE Trans. on Instrum. Meas.*, vol.57, pp.1379-1387, 2008.
[31] T. Ahonen, R. Virrankoski and M. Elmusrati, Greenhouse monitoring with wireless sensor network, *Proc. of the IEEE/ASME International Conference on Mechtronic and Embedded Systems and Applications*, Beijing, China, pp.403-408, 2008.
[32] B. J. Kang, D. H. Park, K. R. Cho, C. S. Shin, S. E. Cho and J. W. Park, A study on the greenhouse auto control system based on wireless sensor network, *Proc. of the International Conference on Security Technology*, Sanya, China, pp.41-44, 2008.
[33] N. Sabri, S. A. Aljunid, M. F. Malek, A. M. Badlishah, M. S. Salim and R. Kamaruddin, Towards smart wireless sensor actor networks: Design factors and applications, *IEEE Symposium on Industrial Electronics and Applications*, pp.704-708, 2011.
[34] C. K. Lee, I. G. Jung, J. H. Sung, B. Y. Lee, S. O. Chung and W. K. Park, The current status analysis of precision agriculture research in USA and Japan, *Journal Korean Soc. Int. Agr.*, vol.17, pp.133-140, 2005.
[35] F. Hahn, Fuzzy control decreases tomato cracking in greenhouses, *Comput. Electron. Agric.*, vol.77, no.1, pp.21-27, 2011.
[36] M. Manciso and F. Bustaffa, A wireless sensor network for monitoring environmental variables in a tomato greenhouse, *Proc. of the IEEE International Workshop on Factory Communication Systems*, Italy, pp.107-110, 2006.

[37] Q. Shan, Y. Liu, G. Prosser and D. Brown, Wireless intelligent sensor networks for refrigerated vehicle, *Proc. of the IEEE 6th Symposium on Emerging Technologies Mobile and Wireless Communication*, China, pp.525-528, 2004.

[38] N. Sabri, S. A. Aljunid, R. B. Ahmad, M. F. Malek, A. Yahya, R. Kamaruddin and M. S. Salim, Performance evaluation of wireless sensor network channel in agricultural application, *American Journal of Applied Sciences*, vol.9, no.1, pp.141-151, 2012.

[39] N. Baker, ZigBee and bluetooth – Strengths and weaknesses for industrial applications, *Comput. Control. Eng.*, vol.16, pp.20-25, 2005.

[40] IEEE, *Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)*, The Institute of Electrical and Electronics Engineers Inc., New York, NY, USA, 2003.

[41] Bluetooth, *The Official Bluetooth Website*, www.bluetooth.com, 2009.

[42] *ZigBee Standards Overview*, http://www.freescale.com/webapp/sps/site/overview.jsp?nodeId=01J4 Fs25657725, 2012.

[43] F. Ding, E. Tong, A. Song, J. Li and G. Song, Development of a portable ZigBee-based nuclear radiation monitoring and detection system, *Applied Mechanics and Materials*, vol.130-134, pp.2639-2642, 2012.

[44] Y. W. Zhu, X. X. Zhong and J. F. Shi, The design of wireless sensor network system based on Zigbee technology for greenhouses, *J. Phys.*, vol.48, pp.1195-1199, 2006.

[45] W. Chang, T. Sung, H. Huang, W. Hsu, C. Kuo, J. Chang, Y. Hou, Y. Lan, W. Kuo, Y. Lin and Y. Yang, A smart medication system using wireless sensor network technologies, *Sensors and Actuators, A Physical*, vol.172, no.1, pp.315-321, 2011.

[46] M. J. Chae, H. S. Yoo, J. Y. Kim and M. Y. Cho, Development of a wireless sensor network system for suspension bridge health monitoring, *Automation in Construction*, vol.21, no.1, pp.237-252, 2012.

[47] X. Wang, Z. Wang, L. Xu and D. Chen, Wireless communications radiation monitoring system based on ZigBee and GPRS, *Advanced Materials Research*, vol.403-408, pp.1956-1959, 2012.

[48] G. Werner-Allen, K. Lorincz, M. Welsh, O. Marcillo, J. Johnson, M. Ruiz and J. Lees, Deploying a wireless sensor network on an active volcano, *IEEE Internet Computing*, vol.10, pp.18-25, 2006.

[49] S.-F. Li, Wireless sensor actuator network for light monitoring and control application, *Proc. of the 3rd IEEE Consumer Communications and Networking Conf.*, vol.2, pp.974-978, 2006.

[50] H.-J. Koerber, H. Wattar and G. Scholl, Modular wireless real-time sensor/actuator network for factory automation applications, *IEEE Trans. on Industrial Informatics*, vol.3, no.2, pp.111-119, 2007.

[51] C. Otto, A. Milenkovic, C. Sanders and E. Jovanov, System architecture of a wireless body area sensor network for ubiquitous health monitoring, *Journal of Mobile Multimedia*, vol.1, no.4, pp.307-326, 2006.

[52] B. Zho, J. Cao, X. Zeng and H. Wu, Adaptive traffic light control in wireless sensor network-based intelligent transportation system, *IEEE the 72nd Vehicular Technology Conference*, 2010.

[53] S. Y. Cheung and V. P. Ergen, Traffic surveillance with wireless magnetic sensors, *Proc. of the 12th ITS World Congress*, San Francisco, CA, USA, 2005.

[54] X. Yang, C. Lu and W. Pan, A ZigBee-based highway vehicles prevent collision warning system research, *The 4th International Symposium on Computational Intelligence and Design*, vol.1, pp.270-273, 2011.

[55] G. Vellidis, M. Tucker, C. Perry, C. Wen and C. Bednarz, A real-time wireless smart sensor array for scheduling irrigation, *Comput. Electron. Agric.*, vol.61, no.1, pp.44-50, 2008.

[56] M. C. Chiu, An automatic thermal control for a greenhouse using network remote control system, *J. Applied Sci.*, vol.10, pp.1944-1950, 2010.

[57] V. Harvanova and T. Krajcovic, Implementing ZigBee network in forest regions – Considerations, modeling and evaluations, *International Conference on Applied Electronics*, pp.149-152, 2011.

[58] J.-J. Liaw, L.-H. Chang and H.-C. Chu, Improving lifetime in heterogeneous wireless sensor network with the energy-efficient group protocol, *International Journal of Innovative Computing, Information and Control*, vol.8, no.9, pp.6037-6047, 2012.

[59] D. Y. Kim, J. H. Yoon, M. Jeon and V. Shin, Distributed information fusion with intermittent observations for large-scale sensor networks, *International Journal of Innovative Computing, Information and Control*, vol.7, no.11, pp.6437-6451, 2011.

[60] H.-C. Hsieh, J.-S. Leu and W.-K. Shih, Reaching consensus underlying an autonomous local wireless sensor network, *International Journal of Innovative Computing, Information and Control*, vol.6, no.4, pp.1905-1914, 2010.

[61] T. J. Ross, *Fuzzy Logic with Engineering Application*, McGraw-Hill, NY, USA, 1995.
[62] R. F. Garcia, Improving heat exchanger supervision using neural networks and rule based techniques, *Expert Systems with Applications*, vol.39, no.3, pp.3012-3021, 2012.
[63] F.-T. Lin and T.-R. Tsai, A two-stage genetic algorithm for solving the transportation problem with fuzzy demands and fuzzy supplies, *International Journal of Innovative Computing, Information and Control*, vol.5, no.12(B), pp.4775-4785, 2009.
[64] M. Madan, N. Gupta and K. Sinha, Intelligent control systems, *Theory and Applications*, 1996.
[65] K. J. Astrom and T. J. MacAvoy, Intelligent control: An overview and evaluation, in *Handbook on Intelligent Control*, D. White and D. Sofge (eds.), Van Nostrand Reinhold, NY, 1992.
[66] F. Bounaama and B. Draoui, Greenhouse environmental control using optimized MIMOID technique, *Sensors & Transducers Journal*, vol.133, no.10, pp.44-52, 2011.
[67] H.-B. Shin and J.-G. Park, Dynamic model of thermoelectric cooler and temperature control based on adaptive fuzzy-PID, *Applied Mechanics and Materials*, vol.130-134, pp.1919-1924, 2012.
[68] K. J. Arzen, A simple event-based PID controller, *Proc. of the 14th IFAC World Congress*, 1999.
[69] I. Mizumoto, H. Tanaka and Z. Iwai, Adaptive PID control for nonlinear systems with a parallel feedforward compensator, *International Journal of Innovative Computing, Information and Control*, vol.6, no.7, pp.2901-2916, 2010.
[70] P. M. Ferreira, E. A. Faria and A. E. Ruano, Neural network models in greenhouse air temperature prediction, *Neuro Computing*, vol.43, pp.51-75, 2002.
[71] J. A. Barrios, M. Torres-Alvarado and A. Cavazos, Neural, fuzzy and grey-box modeling for entry temperature prediction in a hot strip mill, *Expert Systems with Applications*, vol.39, no.3, pp.3374-3384, 2012.
[72] Y. Zuo, Y. Wang, X. Liu, S. X. Yang, L. Huang, X. Wu and Z. Wang, Neural network robust control for a nonholonomic mobile robot including actuator dynamics, *International Journal of Innovative Computing, Information and Control*, vol.6, no.8, pp.3437-3449, 2010.
[73] J. I. Horiuchi, Fuzzy modelling and control of biological processes, *J. Biosci. Bioeng.*, vol.94, pp.574-578, 2002.
[74] Z. Kovacic and A. Bogdan, Fuzzy controllers design theory and applications, *CRC Taylor and Francis Group*, vol.397, Boca Raton, FL, 2006.
[75] F. Li, C. Jin and Y. Shi, Fuzzy programming theory based on synthesizing effect and its application, *International Journal of Innovative Computing, Information and Control*, vol.6, no.8, pp.3563-3572, 2010.
[76] F. Lafont and J.-F. Balmat, Optimized fuzzy control of a greenhouse, *Fuzzy Sets and Systems*, vol.128, no.1, pp.47-59, 2002.
[77] R. R. Yager and L. A. Zadeh, *An Introduction to Fuzzy Logic Applications in Intelligent Systems*, 1st Edition, Springer, New York, 1992.
[78] H. J. Zimmermann, *Fuzzy Set Theory and Its Applications*, 2nd Edition, Kluwer Academic Publishers, Boston, MA, 1991.
[79] T.-S. Shih, J.-S. Su and J.-S. Yao, Fuzzy linear programming based on interval-valued fuzzy sets, *International Journal of Innovative Computing, Information and Control*, vol.5, no.8, pp.2081-2090, 2009.
[80] L. Pan, W. Wang and Q. Wu, Application of adaptive fuzzy logic system to model for greenhouse climate, *Proc. of the 3d World Congress on Intelligent Control and Automation*, Hefei, China, 2000.
[81] M. N. Ödük and N. Allahverdi, A study on developing greenhouse automation by fuzzy control method, *Word Academy of Science Engineering and Technology*, vol.7, pp.599-603, 2009.
[82] R. F. Tate, M. A. Hebel and D. G. Watson, WSN link budget analysis for precision agriculture, *ASABE Annual International Meeting*, Providence, RI, USA, 2008.
[83] P. Andrade-Sanchez, F. J. Pierce and T. V. Elliot, Performance assessment of wireless sensor networks in agricultural settings, *ASABE Annual International Meeting Minneapolis*, MN, USA, 2007.
[84] R. Castaneda-Miranda, E. J. R. Ventura-Ramos, R. R. Peniche-Vera and G. Herrera-Ruiz, Fuzzy greenhouse climate control system based on a field programmable gate array, *Biosyst. Eng.*, vol.94, pp.165-177, 2006.
[85] J. Singh and D. Pesch, Towards energy efficient adaptive error control in indoor WSN: A fuzzy logic based approach, *The 8th IEEE International Conference on Mobile Ad-Hoc and Sensor Systems*, Valencia, 2011.
[86] M. Collotta, G. Pau, V. M. Salerno and G. Scata, A fuzzy based algorithm to manage power consumption in industrial wireless sensor networks, *The 9th IEEE International Conference on Industrial Informatics*, 2011.

[87] L. D. Albright, R. S. Gates, K. G. Arvanities and A. E. Drysdal, Environmental control for plants on earth and in space, *IEEE Control System Magazine*, pp.28-47, 2001.

[88] G. D. Pasgianos, K. G. Arvanitis, P. Polycarpou and N. Sigrimis, A nonlinear feedback technique for greenhouse environmental control, *Computers and Electronics in Agriculture*, vol.40, pp.153-177, 2003.

[89] A. Pawlowski, J. L. Guzman, F. Rodriguez, M. Berenguel, J. Sanchez and S. Dormido, Simulation of greenhouse climate monitoring and control with wireless sensor network and event-based control, *Sensors*, vol.9, pp.232-252, 2009.

[90] F. Xia, Y. C. Tian, Y. J. Li and Y. X. Sun, Wireless sensor/actuator network design for mobile control applications, *Sensors*, vol.7, pp.2157-2173, 2007.