Wireless Sensor Actor Network Based on Fuzzy Inference System for Greenhouse Climate Control

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Abstract: The pervasive merit of wireless sensor networks has led to a swelling interest in rendering them to be smart and autonomous which have the potential to enable a large class of applications in multiple fields. A novel cognitive wireless sensor-actor network based Greenhouse climate control (CWSAN-GH) is presented in this research. Fusion of artificial intelligence with nowadays Wireless Sensor Actor Networks (WSAN) is a promising era of smart WSAN. Primarily two most important greenhouse climate parameters are considered which are the temperature and humidity during diurnal and nocturnal time. Actuator and sensor nodes has been managed by CWSAN-GH Coordinator node (MGHSN) which mimics the brain of the planter to provide reliable, power conserving, autonomous control system of a greenhouse. The conventional control methods are not efficient in terms of energy, labor interference, productivity and flexibility. In this study, the adoption of Artificial Intelligent (AI) approach to controlling tasks within Wireless Sensor-Actor Network (WSAN) is presented. Fuzzy inference system has been designed and fused within the coordinator node of WSAN, hardware and software of network nodes and sensors has been presented. Initial field test for the CWSAN based greenhouse are also presented. The combination of AI with actor WSN proves high efficiently, cost effective method, beside flexibility of tuning the whole system for other agricultural tasks.

Key words: Wireless sensor actor network, artificial intelligent, fuzzy inference system, greenhouse climate control

INTRODUCTION

Actor wireless sensor networks that combine sensors and actuator nodes currently are considered as one of the most significant technology in the information era (Xia et al., 2007; Razgui and Eltoweissy, 2007). WSAN has great advantages in terms of cost, flexibility, autonomy and robustness as it compared to wire sensor network. Its application extended to cover both civilian and military aspects like environment control, home automation, disaster early prediction and battlefield monitoring (Tik et al., 2009). Greenhouses are used to enhance the environment condition for crops; hence, the climate control of a greenhouse (GH) requires deploying of a large amount of wire that connects sensors and actuators. System complexity and cost value will be higher beside the difficulty of adding sensors/actuators nodes of various positions within greenhouse (Narasimhan et al., 2007). Using automatic control will highly assist of reducing energy conservation, scalability, enhance productivity process and reduce human intervention (Zadeh, 1993; Komor and Challa, 2003; Wang et al., 2006).

Greenhouse climate control based on a remote control system shows highly efficient improvement of crop production. Also it helps in lowering the cost of laborers through using a remote base station for monitoring and controlling the processes of the greenhouse (Chiu, 2010). The advances of automation technologies help to replace traditional agriculture by protected cultivation in greenhouses (Soto-Zarazua et al., 2011). Emerging AI techniques like neural network and fuzzy logic within GH control applications provides favorable conditions for crops growing and health (Salazar et al., 2010; Risco-Garcia et al., 2008).

This study has presented an Artificial Intelligent (AI) approach fused with nowadays WSAN to control precisely the GH climate of temperature and humidity autonomously. The main focus is to show the efficiency of adopting of Fuzzy Inference system (FIS) with WSAN to build intelligent WSAN coordinator that keeps the GH parameters at the desired set values. The following issues has been addressed:

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Tel: +60 1 9252 9327, +60 1 6310 5440
• AWSAN based on Fuzzy inference system for GH control design and implementation
• Optimal power consumption within actuating nodes connected to a heater, humidifier and fan devices based on FIS control
• Sensor node spatial distribution, data aggregation and summarization

GREENHOUSE CLIMATE CONTROL

Since GH has blocked environment in which climatic and fertilization parameters can be vision and controlled precisely, providing an optimal growth of crop (Rodriguez et al., 2008; Park and Park, 2011). Many engineering and agriculture efforts has been cooperated to reduce the complexity and produce high efficient methods to keep the optimal desired sets of temperature and humidity. To reduce complexity of controlling problem of GH due to coexist of many parameters that affect the climate and crops, two parameters (temperature and Relative Humidity (RH)) has been studied as they are the most sensitive to each other and to crop production. The using of Fuzzy inference engine within WSAN shows robust cooperation to build autonomous CWSAN-GH. Later this research can be adapted to various GH parameters to achieve full autonomous GH management system.

Temperature and humidity of GH climate can be controlled by ways of adapting heater, humidifier and fan systems. Climate inside the GH can be tuned to its desired values using of a heater system to warm up, humidifier to moisture and a fan system to cool up the climate. Those parameters are very important and related directly to the growth of plants which is highly affected by temperature and humidity variation (Korner and Challa, 2003). The sunny weather cause to increase the indoor temperature and crop damage (Wang et al., 2006), 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 (Pawłowski et al., 2009).

For perfect variation of those parameters, a two threshold values must be declared so that optimal climate parameters inside the GH must simulate the natural variation of those outside and not to be constant all the time. The two threshold values proposed were 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 adapt the optimal variation of those two parameters during the day and night time within the predefined setting values. Many parameters affects temperature and humidity and cause the deviation of their values from the setting range values. For example, diurnal temperature of crops like tomato and cucumber has range of 24-30°C while night temperature is 8-15°C (Park et al., 2011).

Figure 1a shows the architecture of the system of this research, in which the coordinator (MGHSN) of the implemented star network topology uses embedded Fuzzy inference system.

![CWSAN-GH Network topology based on FIS](image)

(a) CWSAN-GH Network topology based on FIS

![Abstraction of cognitive WSAN on GH climate control](image)

(b) Abstraction of cognitive WSAN of Greenhouse climate control

Fig. 1: Cognitive wireless sensor-actor network architecture
The collected and processed data will be sent by the sensor nodes to the MGHSN, the received data will be used by the FIS to conclude the output commands for the actuator nodes. Finally, the actuator nodes perform the actions using Pulse Width Modulation technique (PWM) of controlling. In this context, a single-hop scheme is used to send the sensed data and the action control commands wirelessly from the nodes to the brain of the network MGHSN. Architectural block diagram of the system is shown in Fig. 1b.

**FUZZY LOGIC APPROACH**

In this research, the adoption of Fuzzy Logic (FL) approach to control problems with actor WSN is due to a number of reasons. Its algorithm occupied small portion of memory, short time of execution, it requires less mathematics than other controlling approaches. The FIS approach is more robust even when the parameters and constants are not optimum in values and can be used when complete knowledge of the plant is absent or it can change dynamically. The FL approach is more intuitive, mimics the way people think and can be tuned for various control (Zadeh, 1993; Ross, 1999).

**Fuzzy inference system:** A Fuzzy Inference System (FIS) is the main unit of the fuzzy logic system. The decision-making is an important part in the entire system. The FIS formulates suitable rules and based upon the rules the decision is made. This is mainly based on the concepts of the fuzzy set theory. The inputs can be either fuzzy inputs or crisp inputs; the outputs it produces as a controller are usually fuzzy sets. When the FIS is used as a controller, it is necessary to have a crisp output. Therefore in this case defuzzification method is adopted to best extract a crisp value that best represents the fuzzy set (Yager and Zadeh, 1992; Xinhan et al., 2002).

**FIS structure:** The FIS consists mainly of five processing tasks as shown in Fig. 2. The function of each process block is as follows:

- A rule base process containing a number of fuzzy rules depending on the sectoration of inputs values and output values
- A database process which provides the membership functions of the fuzzy sets used in the fuzzy rules
- A decision-making process unit, depending on the rules, it performs the inference operations
- A fuzzification interface process conclude the degrees of matching with linguistic values based on the crisp inputs
- A defuzzification process interface produces the output based on the transformation of the fuzzy results of the inference engine

The FIS of GH climate control consist of a fuzzification, knowledge base and defuzzification. Fuzzification is the process of conversion the crisp input of temperature and humidity into fuzzy sets. Knowledge base construction based on the rule base and database of the temperature (warm, hot, very hot, cool, cold) and humidity (low, ok, humid) of the GH for specific plant. Defuzzification which is the process of producing real values depending on conversion of fuzzy values (Yager and Zadeh, 1992).

**Fuzzy inference methods:** The most important two types of fuzzy inference method are Mamdani's fuzzy inference method which is the most commonly seen inference method. Another well-known inference method is the Takagi-Sugeno-Kang method (TS) of fuzzy inference process. The main difference between the two methods lies in the consequent of fuzzy rules. Mamdani fuzzy systems use fuzzy sets as rule consequent whereas TS fuzzy systems employ linear functions of input variables as rule consequent. All the existing results on fuzzy systems as universal approximators deal with Mamdani fuzzy systems. The Mamdani method expect the membership functions of the output to be fuzzy sets, after accumulation task, there is a fuzzy set for each output variable that needs defuzzification process (Yager and Zadeh, 1992; Zimmermann, 1991).

**Greenhouse temperature and humidity control:** FIS used with sensor data inputs sent by the sensor nodes which are deployed inside the GH of 3×6 m² area with four nodes of temperature and humidity sensing. Each node performs a predefined task before deliver data to MGHSN.

The primarily in designing the FIS is to choose the inputs sensors and the output actuators (Ross, 1999). Two main sensors used with FIS which are the temperature and humidity sensors and three actuators types.
As shown in Fig. 2, 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 up and low than the average values while inputs of set two is the same as set one except it is for night setting (T_setN, H_setN, T_devN, H_devN). The current reading of temperature and humidity (T_c, H_c) forming 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 defined as:

- **Crisp input:** $T_{\text{day}}$, $T_c-T_{\text{setD}}$, $H_{\text{setD}}$, $T_c-H_{\text{setD}}$
- **Crisp input:** $T_{\text{night}}$, $T_c-T_{\text{setN}}$, $H_{\text{setN}}$, $T_c-H_{\text{setN}}$
- **Crisp output:** Heater, Fan and Humidifier, delivered power expressed by PWM

**Fuzzy membership function:** Based on the definition of input and output craps, membership functions of fuzzy logic will be determined. Figure 3 shows crisp input of the temperature (T) which divided into four regions while crisp input of Humidity (H) into three regions. The crisp output consist of three regions and to be used mutually 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 $(\pm T_{\text{dev}}, \pm H_{\text{dev}})$ 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 of providing optimal solution for the specified crop based on working experience knowledge and plant requirements. Adjusting these values was controllable and easily, resulting in tuning the outputs to be more adequate with the requirements of the crop.

**Simulation:** The process of simulation is to adjust the parameters of FIS so adequate output values can be achieved for the actuators devices. The simulation start

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Fig. 3 (a-e): Membership functions for inputs and outputs

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Fig. 4: Defuzzification output of temperature and humidity

Table 1: Temperature and humidity fuzzy logic rules

<table>
<thead>
<tr>
<th>Temperature</th>
<th>LT</th>
<th>NT</th>
<th>HT</th>
<th>VHT</th>
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<td></td>
<td>He_Off</td>
<td>He_Off</td>
<td>He_Off</td>
<td>He_Off</td>
</tr>
<tr>
<td></td>
<td>Fan_OFF</td>
<td>Fan_OFF</td>
<td>Fan_Med</td>
<td>Fan_Med</td>
</tr>
<tr>
<td>NH</td>
<td>Hu_OFF</td>
<td>OFF</td>
<td>Hu_OFF</td>
<td>Hu_OFF</td>
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<tr>
<td></td>
<td>He_Med</td>
<td>He_Off</td>
<td>He_Off</td>
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<tr>
<td></td>
<td>Fan_OFF</td>
<td>Fan_Med</td>
<td>Fan_Med</td>
<td>Fan_Med</td>
</tr>
<tr>
<td>HH</td>
<td>Hu_OFF</td>
<td>Hu_OFF</td>
<td>Hu_OFF</td>
<td>Hu_OFF</td>
</tr>
<tr>
<td></td>
<td>He_Max</td>
<td>He_Off</td>
<td>He_Off</td>
<td>He_Off</td>
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<tr>
<td></td>
<td>Fan_OFF</td>
<td>Fan_Med</td>
<td>Fan_Med</td>
<td>Fan_Med</td>
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with defining the input and output crisp which is two for crisp input and three for crisp output, then define a set of twelve rules to define the output crisp. The Smallest Of Maximum (SOM) technique is chosen, it is depend on the output distribution to conclude the smallest of the maximum values as a crisp output number (Cavallo et al., 1996). This is computed as follows:

```
Function out = defuzz(x, mf)
    temp = x(find(mf==max(mf)));
    [jk, wh] = min(abs(temp));
    out = temp(jk);
    return;
End
```

where, defuzz is a user defined function to generate the defuzzified output (out) of a membership function (mf) positioned at associated variable value (x). The output of the rules is simulated and the result has been studied and analyzed. The membership functions will be fine tuned to adjust the result; simulation has been repeated for different tuning setting of temperature and humidity thresholds values until a satisfied result is obtained for diurnal and nocturnal settings. Table 1 shows the fuzzy logic rules of the system. Figure 3 depicted the defuzzification of the error input of Temperature, Humidity and the output variable for Fan, Heater and Humidifier. Sample of the Crisp outputs are shown in Fig. 4.

COGNITIVE WSAN EMBEDDING FIS

The coordinator node of the GH will be fused with FIS to form MGHSN that acts as a brain of the WSAN which is the cognitive part of the network. The whole network now has the ability to sense and react in a way that mimics the human behavior. This made the Cognitive WSAN based GH climate control. 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 5 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," etc., it has to be given only in crisp quantities. These crisp quantities are thus obtained from the fuzzy quantities using the defuzzification method discussed above. A detail program can be provided by authors. 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 obtained the output in any required form. This make the FIS within WSAN is successful approach to achieve the cognitive of the new era of WSAN.

**Wireless sensor-actor network model:** Many factors must be studied in advance of designing and implementation of sensor network. The CWSN-GH design has been studied and implemented with careful consideration of the following factors:

- **Fault tolerance:** The reliability of the sensor network is the ability to sustain the functionality of the network whenever sensor node fails to work due to obstacle, poor power supply or node hardware fails. In this design of CWSN-GH network the fail of one node will not affects widely the performance of the network, this is due to the averaging algorithm run in the MGHSN, so other sensor node average reading can substitute the faulty node. On the other hand, the MGHSN has the routine to detect node failure when four consecutive batch of reading not arrived from that sensor node

- **Scalability:** The number of sensor and actuator nodes can be extended easily with CWSN-GH. It has been used only seven nodes while new sensors or nodes can be attached to the system with consideration of area spatially distribution and density of sensor nodes

- **Production cost:** The overall cost of the network has to be kept low as possible, with preserving the efficiency of the work. The CWSN-GH based on Jennic 32-bit processor and mainly on high efficient sensor of temperature and humidity. The cost for commercialize product will be low-cost effective

- **Sensor network topology:** WSN made of high number of nodes densely need optimal handling of topological maintenance. CWSN-GH uses the star topology which is simple and efficient, fit matches and low power consumption for GH application

- **Operating environment:** Sensor nodes are densely deployed either very close or directly inside the phenomenon to be observed. The sensor nodes deployed in GH under consideration of moisture environment leads to have sensors location enough far away from earth, side wall and ceiling, so accurate GH climate relative humidity and temperature can be inspected

- **Power consumption:** The main critical issue in designing WSN is the power consumption (Liang et al., 2011). Data aggregation can be considered as a power efficient technique for collecting data in WSN. It is minimize the total transmission cost of transferring the information to the sink node of the network (Ma and Yoon, 2005; Hu and May, 2006; Shan et al., 2011). Solar energy can be cooperated to reduce the power consumption of WSN through activating the nodes or acting as a source of battery recharging of the nodes (Nallusamy and Duraiswamy, 2011). For GH application the MGHSN and actuator nodes has plugged to main power point while the sensor nodes powered by 750 mAh li-ion battery. The sleep mode power consumption technique has been used. Transmission happens periodically every 10 min. The transmitted data encoded to shortage the total packet length

**System realization:** The system of CWSAN-GH has been built with a star topology of a coordinator, sensor nodes and actuator nodes with temperature, humidity and light sensors. This topology is common, easy to implement and maintain. It is used widely for control applications that eager to prolife its operation depending on limited power supply (Akyildiz et al., 2002). The sensor nodes equally spatial separated inside GH. It performs data aggregation and applies average-threshold algorithm before sending the data. The samples data will be processed using average-threshold algorithm. The sampling will be collected and averaged 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 sent towards the coordinator. A threshold of the difference between the
current average reading and the previous average reading was 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 MGHSP; this will reduces the total power consumption by reducing the time of transmission due to short packets length.

Average-threshold algorithm where 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 min for each node in time slot criteria. The function of the sensor nodes is periodically to implement three main tasks as depicted in Fig. 6.

Data gathering module, where the sensor nodes data acquisition circuit is periodically samples the sensor for data (every one minute). The samples will be accumulated and averaged by Data processing module. Only valued data will pass to Report block buffer. Lastly, during this task, sensed data are transmitted to the MGHSP.

Greenhouse sensor node (MGHSN): This Node is the Brain-coordinator of the network. This node has to manage the network initialization and control mechanism. It is embedded within the following tasks:

- Initiate the network and Maintain its operation
- Periodically stimuli 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 embedded within MGHSP for diurnal and nocturnal controlling of temperature and humidity
- Activating the actuator nodes

Figure 7 depicted the main steps of CWSAN-GH architecture flowchart as its start with the Brain node.
(MGHSN) that organize and initiate the network, listen for nodes data and combine these data with light, temperature and humidity sensor reading of its own, then guide the proper calculated values to the FIS while FIS working, all nodes be in sleep mode of operation. The decision come out with a code packet send to actuator nodes with PWM power consumption technique, those activated actuator nodes will drive power to the attached devices to tune up the climate towards the requirements values within the Greenhouse. This procedure will be repeated and continue as long as the same setting value has been assigned prior to unchanged working status.

The MGHSN has a light sensor used to sense day or night time. Based on this, the FIS will use the predefined set values of day/night operations. The FIS is a set of sub processes carried out in small amount of memory which can acts on temperature and humidity crisp inputs and their setting values within predefined tolerance. The essential matter is not to keep the GH climate parameters constant all the time. The block diagram shown in Fig. 8 clarifies the main activities carried out within the CWSN-GH.

**Actuator node:** Two type of actuators used. Temperature and Humidity actuators, as shown in Fig. 9, are used to activate the Heating and Humidifying system. This actuator triggered by ON_HEATER packet sent by the MGHSN to Heat Active Actuator Node. This packet contains the ON action and the ON_Duty cycle time. The actuator 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 actuators used to adjust the climate inside the GH by means of heating, humidifying or ventilation. The humidifier, temperature and fan actuators nodes have been hardware interfaced to GH assistance devices. The MGHSN addresses one or more of that node for period of time of actuation.

The heating and humidifying systems are connected to the node as described by the actuator node circuitry in Fig. 9a. Fan system interface circuitry shown in Fig. 9b. 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 Jenmic wireless microcontroller) makes implementation easy and power consumption can be radically reduced, the MGHSN will pool the nodes for data every 10 min. The sampling frequency of pooling could be varied according to the importance and parameter valuable change behavior. Nodes will be in sleeping mode between pooling periods.

**Sensors:** The SHT75 sensor shown in Fig. 10 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 JN51-48 SIF_D and SIF_CLK. The mode of operation flips from sleep mode to active mode on measuring status, hence sleeping mode is crucial parameter for low power consumption concepts.

**Light dependent resistance (LDR):** The LDR is very useful sensor for Dark-light application. Normally it has very high resistance of few of Mega ohms in darkness and when subjects to light its resistance dramatically decrease to a few of kilo ohms. This simple and cheap sensor circuit shown in Fig. 11 used to interrupt the MGHSN for day/night time which affects the FIS day-night decision. The circuit tuned using potentiometer of 10 kΩ to adjust the proper sensitivity of sensing dark/light phenomena.

**Wireless sensor network technology:** The hardware platform was built using new single chip 32 bit wireless
Fig. 9 (a-b): Actuator node interface circuit (a) Heater and Humidifier interface circuit (b) Fan interface circuit

Fig. 10: SHT75 sensor with I2C connection to the wireless microcontroller (JN5148)

This microcontroller can be loaded with ZigBee PRO stack. The ZigBee stack was built above the MAC and PHY layers of IEEE 802.15.4. ZigBee technology is low cost, power consumption is low and low data rate of maximum 250 Kbps. It's 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 its data to the main node to be processed by FIS and a proper actuation command follow 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 GH.

Economical and compact wireless sensor nodes has been developed using Jennic wireless node. It consumes 18 mA at receiving status while 15 mA at transmission status with ±3 dBm. The 32 bit wireless microcontroller
Developers to integrate their embedded application and the ZigBee PRO stack into a single efficient and low power consumption integrated chip (NXP, Data Sheet).

Network nodes deployment: The CWSAN-GH network has been built with star topology of one MGHSN and four sensor nodes with three actuators nodes. As Fig. 12 demonstrate the spatial location of sensor node. The MGHSN hanged into the middle of GH of 3.5 m above earth. The three actuators nodes were deployed 2 m height and connected directly to the actuators devices. The temperature/humidity SHT75 sensor board nodes deployed 1 m away of side wall and 2 m away front/rear side of GH. The fan/door actuator nodes have same function of ventilation which opens the door, then open activate the fan simultaneously.

Periodically the nodes wake up and send its data to MGHSN in a response to a beacon packet sent by the MGHSN, each node wakeup, turn on sensor, collect data and then turn on the transceiver for sending the queued processed data, then back to sleeping mode.

RESULTS

Zigbee is considered the most hopeful for wireless sensor networks. It is low power consumption and simple network configuration (Wang et al., 2006). Using of ZigBee protocol will provide seven granted slots that is enough for the deployed sensor nodes. Hence, CWSAN-GH can get benefit of zero collision occur during the communication process, assuming that the interference with other communication systems is less than to affect the performance of the implemented system.

The proposed CWSAN-GH has been carried out within a GH sample, where many types of salad vegetable have been cultivated in northern Malaysia. The network built with one GH block to gather information of temperature and humidity and apply optimal solution depending on sensing and actuation system inside the GH. The quality of link is high due to short distance and the existence of line of sight LOS path between sensor nodes and GHMSN with all nodes performing with transmission of packet rate above 95%. Xia et al. (2007) encountered that packet loss rate remain less than 10% when transmission power is set to 0 dBm on different nodes. Packet loss varies nearly from 0 to 100% of area between 9 and 13 m. The CWSAN-GH nodes spatially distributed fairly enough to achieve very low packet loss and because of using of granted slots which assure of high communication reliability that yields of packet loss rates less than 2%.
The humidity and temperature sensor used in CWSAN-GH system is of type SHT75. Its high accuracy sensor type provides 0.3°C tolerance and 1.8% RH. The use of precise sensors in GH will tend the system performance and affects directly the crops health and then its productivity. Park et al. (2011) used sensor with 3.5 RH and 0.5°C tolerance.

The sensor nodes apply average-threshold algorithm which enhance the overall system showing. Data aggregation within WSNs gained high attention since the power consumption can be reduced when the amount of wireless communication data being reduced (Hu and May, 2006). The CWSAN-GH system proposed of averaging and thresholding algorithms of the sensed data over 2 min period. The payload of the transmitted packet will be either 6 bytes or one byte (No Change) encoded data while the favorable timing control scheme proposed by using of Zigbee network based beacon interval.

Tik et al. (2009) collect data with high degree of redundancy (every 30 sec) within a star network topology, the system worked with relatively high reliability. The variability in the system performance is critical point in real time systems. Sensor network of Tik et al. (2009) suffers some variability in the performance and the minimum success rate of data transmission was 70%. The system reliability of CWSAN-GH is high and achieves settle performance during one week of operation.

The Fuzzy inference system adjusted the heat and the humidity based on the new samples reading once every 10 min. Erratic environment change such as sudden heavy rain during days of test affected the result while normal graduated change shows smooth controlling bias. Various methodologies of heating and cooling techniques applied for greenhouses environment control (Rodriguez et al., 2008; Soto-Zarazua et al., 2011). Chiu (2010) proposed closed loop thermal control system that maintains steady temperature within a GH. He also proposed a remote vision monitoring and control of temperature. CWSAN-GH system applied the modern AI concept with WSAN that save manpower and manage the climate of GH autonomously.

All sensor nodes reading were almost similar with little bit difference with wall side sensor nodes reading during sunny days. Figure 13, 14 shows the average reading of temperature of the sensors attached to the MGHSN and the four sensor nodes of temperature and humidity. The cooling system represented by the ventilation process while using the heater to warm up the climate inside the GH. The 10 min period is enough for homogeneity of temperature within the GH area during ventilation while for heating its seen during the second period of sampling data where the climate temperature reach 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 use 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.

Event based strategy of controlling GH climate parameters reduces the number of actuating the attached climate tuning devices by more than 80% with respect to traditional time based controllers. Event based control system allows reduction of electricity costs and increase actuators lifetime (Pawlowski et al., 2009). 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. (2009) will lead to
eliminate the ability of self warming system, since it will be ambiguous to recognize dead nodes. CWSAN-GH encoded 1 byte payload message to show that 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 provide very efficient way of power consumption, reliable and accurate controlling scheme. PWM has been provided by the output values of FIS.

The Relative humidity indicated by the results shows that increasing the temperature of the environment will affect in lowering the relative humidity while sloping towards cooler situation causes relative humidity to increase. The weather change from sunny to cloudy or rainy affects widely those parameters and hence some spikes shown within the graph. Critical situation for operation when the ventilation system works using Fan, both temperature and humidity will change and hence controlling commands must be ordered for heater and humidifier system to work.

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

CONCLUSIONS

This research paper shows a star ZigBee network based WSAN fused by artificial intelligent controller. The result CWSAN-GH integrated with seven nodes to cover a GH area targeting to maintain temperature and humidity with acceptable tolerance of temperature value and humidity value.

The CWSAN-GH worked for diurnal and nocturnal sets of temperature and humidity climate control. The communication range within 18 square meters with less packet loss due to LOS environments, Granted Slot method of beacon based communication and free area of interference or coexistence of similar communication channels.

The using of Fuzzy inference control embedded with the MGHSN which is the coordinator proves the new trend of using cognitive WSAN within agriculture application. The performance was robust and reliable over the test period. It can easily expand the controlling parameters to get fully autonomous GH controlling system based CWSAN.

The FIS within WSAN system prototype provide real time data monitoring and autonomous with low cost, small size and little bit inference with labor. The work can extend to have center of data connected to GH system for real time data achieving, statistical analysis and monitoring.

SHT75 sensor of temperature humidity provide well matching to this research due to its low power consumption, high accuracy compare to others and availability of sleep mode. LDR sensor used with balance resistance to drive at minimum current during diurnal with full functionality interrupt the MGHSN for day/night event. The MGHSN can be work on low power between beacon intervals and lengthy the life time of the system. The proposed CWSAN-GH can be fully powered by high quality batteries of size AA (750 mAH). Energy efficiency built on sleep/wake up method on a predefined period of time.

The researcher’s contribution is to use the beneficence of FIS and integrated it with WSN. It has small memory size, fast execution, easy to modify and flexibility to count any modification, the result of the work shows its highly recommended to build new generation of intelligent wireless sensor actor network.

REFERENCES


