Design and Implementation of a Wireless Sensor Network for Precision Agriculture Operating in API Mode

Jorge Granda-Cantuña, Carlos Molina-Colcha, Sergio-Enrique Hidalgo-Lupera, Christian-David Valarezo-Varela
Facultad de Ingenería y Ciencias Agropecuarias
Universidad de las Américas
Quito, Ecuador
{jorge.granda,marcelo.molina,sergio.hidalgo,christian.valarezo}@udla.edu.ec

***Abstract*—This paper presents a Wireless Sensor Network (WSN) solution applied to Precision Agriculture (PA) capable of collecting real time data on different parameters related to agriculture. The technological advances related to this activity are of great importance since agriculture is considered an economic and social pillar essential for the wellbeing of society. In addition, the growing demand for real-time information in the agriculture field has driven the development of efficient wireless communications via sensor networks. WSN provides low cost, low energy consumption, easy to implement solution in places of difficult access for the implementation of wired networks. Precision agriculture is a way to optimize resources and improve cultivation through the collection of relevant information through the deployment of sensor networks, providing government authorities with statistical information to make appropriate decisions based on reliable data. The present research describes the design, implementation and validation process of a WSN technological solution which can collect information related to humidity, environment and soil temperature, atmospheric pressure, level of luminosity and UV radiation; this information is relevant to determine optimal parameters for cultivation and farming methods using IoT technologies for Big Data analysis at the government level.**

***Keywords*—IoT, Big Data, EGovernment, Wireless Sensor Network, Precision Agriculture. Zigbee, API**

I. Introduction

Agriculture is one of the most important pillars for the development of society, constituting a fundamental element for the economy of many countries. In [1], precision agriculture technology is applied to increase the production and quality of the crops. In the case of Ecuador, nowadays an important part of the country's productive capacity is linked to products such as bananas, coffee, shrimp, or cocoa. To leverage the available resources efficiently as well as the optimization of agricultural production, it is necessary to implement new methods for monitoring and measuring agriculture parameters focused on preventing economic losses associated with the lack of information and control over crops. Heat and radioactive stress effects are measured in [2] using remote and proximal sensing techniques. Climate change has a certain impact on the quality of crops, which can cause economic volatility and losses for a certain country in the agricultural sector. Most of the crops are not monitored using technological tools. WSN have been implemented to enable efficient irrigation [3]. PA provides the tools to help optimize resources for cultivation through the constant monitoring of specific parameters such as environment and soil temperature, atmospheric pressure, level of luminosity, and UV radiation using wireless sensors networks; the aforementioned sensors can obtain data on a determined geographic area where crops are cultivated and provides farmers with valuable information aimed at making better decisions.

EGovernment services implement the processes for integrating advanced information and communications technologies (ICT) [4].

Wireless Sensor Network (WSN) is a technological solution part of an ICT framework currently being applied in areas related to medical [5], bio-technology [6], natural disasters [7], health [8], [9], public safety [10], and national defense [11].

WSN technology support farmer activities by optimizing resources, improving the quality of products, preparing the environment for agriculture and reducing the costs associated with the management of crops. Environmental applications for WSN include Fire detection [12], [13], agriculture [14], among others.

WSN are based on low energy consumption elements which are able to collect information, process such information and transmit it by means of wireless communications to a central processing unit called Coordinator Node. A WSN algorithm was developed by [15] for cluster head section. Due to the characteristics of wireless sensor networks, its use in the agriculture field is a valuable technological solution since it can collect information on different parameters with its sensors. The WSN solution described in this paper implements Digimesh protocols which allow communications between different nodes in a mesh topology. Once the Coordinator Node receives the information, it saves all the data in a remote database where all the information can be displayed through a Graphic User Interface to different users including government officials or decision makers. Each node is capable of searching

978-1-5386-2521-7/18/$31.00 © 2018 IEEE

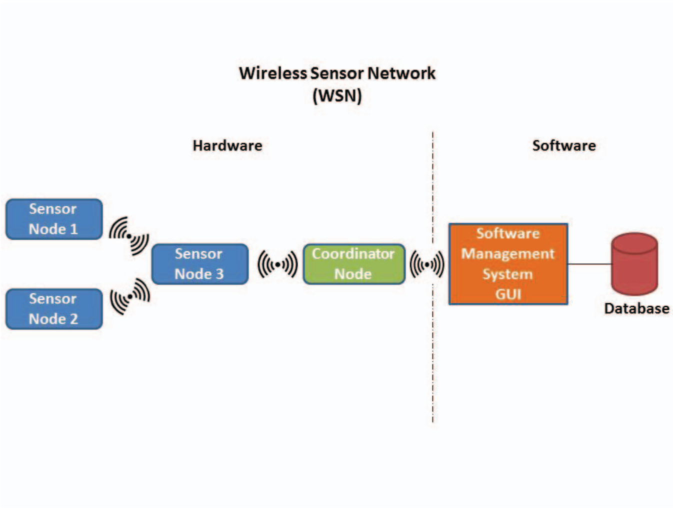

Fig. 1. WSN system interconnection diagram

the best way to send the information to the Coordinator Node. In [16] a region-based static clustering protocol is applied in order to provide an efficient coverage in a defined agricultural area. Digimesh is a proprietary mesh networking protocol with flexible and homogenous sensor nodes capable of expanding into bigger networks. This protocol operates in two frequency bands, 900 MHz and 2.4 GHz, and supports AES encryption. The sleeping mode feature reduces power consumption and increases battery life. The aforementioned features highlight the reasons why the Digimesh networking protocol represents a robust solution for the implementation of WSN in addition to its simplified network configuration and large frame payloads.

The WSN proposed in this paper consists of the following components: 3 main nodes, Coordinator node, Software Management System (SMS) with a Graphical User Interface (GUI) and a database. The first node contains luminosity, UV radiation, and pressure sensors; the second node has relative humidity and temperature sensors for both soil and environmental conditions. A third node provides routing functionalities, establishing a mesh network with alternative routes in case of the collapse of any of the aforementioned nodes. The sensor node data reaches the Coordinator Node where it is then stored in a database and displayed to the user via a Graphic User Interface (GUI) as shown in Figure 1.

The WSN configuration included the implementation of API mode, which allows a complex communication to be established between nodes, not possible in transparent mode. In API mode, the communication is based on sending packets with a given size and in a defined order.

The paper is organized as follows: in section 2, the design of the WSN network design is presented. Section 3, describes the user interface. In section 4, the validation test results are presented and discussed. Finally, in section 5, the work is concluded with some remarks.

II. Design of the WSN Network

The WSN solution proposed in this paper consists of three nodes, one coordinator node which acts as a gateway and software management systems. A sensor node is comprised by the following hardware components: Sensing unit, Processing Unit, Communication Unit, and Power unit [17].

A. Node Structure

Node 1 consists of the following components:

- BH1750 light sensor It is a digital light sensor displaying values of measurements in Lux (lumen/m^2), which represents the intensity of light per square meter. The sensor has a measuring range from 1 to 65535 Lux, and delivers a digital output in I2C format.
- BMP085 pressure sensor The BMP085 module is a sensor that provides measurements of atmospheric pressure. There are various factors that influence the air such as temperature, humidity and wind pressure. The module presents a great immunity to electromagnetic noise, high accuracy and linearity, an ADC, a temperature sensor (used to compensate for pressure measurements) and a control unit which utilizes an E2PROM memory from which you can include values of compensation to increase the precision of the measurements made
- ML8511 Ultraviolet Sensor The ML8511 module is a sensor for ultraviolet (UV) light measurements. It provides an analogue output proportional to the amount of UV light detected. Ultraviolet radiation is not visible to the human eye since it is in the range from 10 nm to 400 nm, where its spectrum has beneficial and harmful effects on humans. One of the main applications of UV radiation is the sterilization of medical instruments.
- Arduino Uno Arduino is a microcontroller based on the ATmega328P chip, and characterized mainly because it has 14-pin input / digital output, 6 analog inputs, USB connection and is very simple to use.
- XBee S2C It's a radio module manufactured by Digi International. It provides wireless networking and communication functionalities among devices; it supports high rate transmission and low latency. The Xbee S2C has an indoor range of 60 m and 1200 m outdoor range with the option to establish a mesh network.
- GPS NEO- 6 Module This GPS module belongs to the family of receivers GPS NEO-6, which are characterized by its good performance. It comes with an antenna and it does not need more accessories to work. It provides the information such as: latitude, longitude, date and time.
- Li-ion 18650 Batteries The power for each of the nodes is provided with rechargeable Li-ion 18650 batteries, with a capacity of 5000 mA.

Node 2 contains:

- Soil SHT11 humidity and temperature sensor This sensor consists of an integrated circuit for high precision measurements of temperature and relative humidity, which

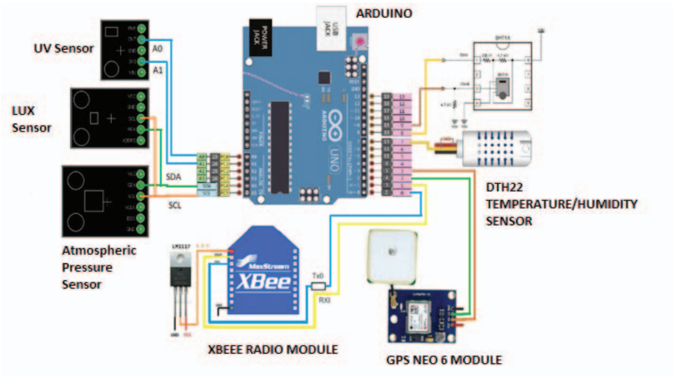

Fig. 2. WSN interconnection diagram

provides a digital output for easy reading and interpretation, thus the obtained measurements are fast and immune to external conditions.
- Sensor temperature and humidity DTH22 It is a digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and displays the data using a digital signal on the data pin (no analog input pin). It is quite simple to use, but it requires careful synchronization to take data. The only drawback of this sensor is that you can only get new data once every 2 seconds.
- Arduino One
- XBee S2C
- Module GPS NEO - 6 M-0-001
- Batteries Li-ion 18650

Node 3 consists of:
- XBee S2C
- Batteries Li-ion 18650

B. Coordinator Node

This node is responsible for receiving the information from the other three sensor nodes, stores the information in a database and displays such information to the end user via the GUI. Figure 3 depicts the interconnection features between the UV, Lux, Atmospheric Pressure, Temperature and Humidity sensors and the Arduino microcontroller, Xbee S2C antenna, and GPS module.

C. Methodology

The goal was to perform measurements at different sites using wireless sensors which acquire data in real-time. Real-time characterization was performed in [18]. Following systems engineering design and implementation best practices, a test plan and documentation procedures were considered. Information such as date, time of the measurements and node location using the GPS module on the WSN system was recorded. A mesh network topology was used implementing Xbee S2C devices, and configured in API mode. Data obtained by the sensors was transmitted in framed packets to the Coordinator Node and displayed in the GUI. Fig. 8 shows the algorithm diagram for the WSN system.

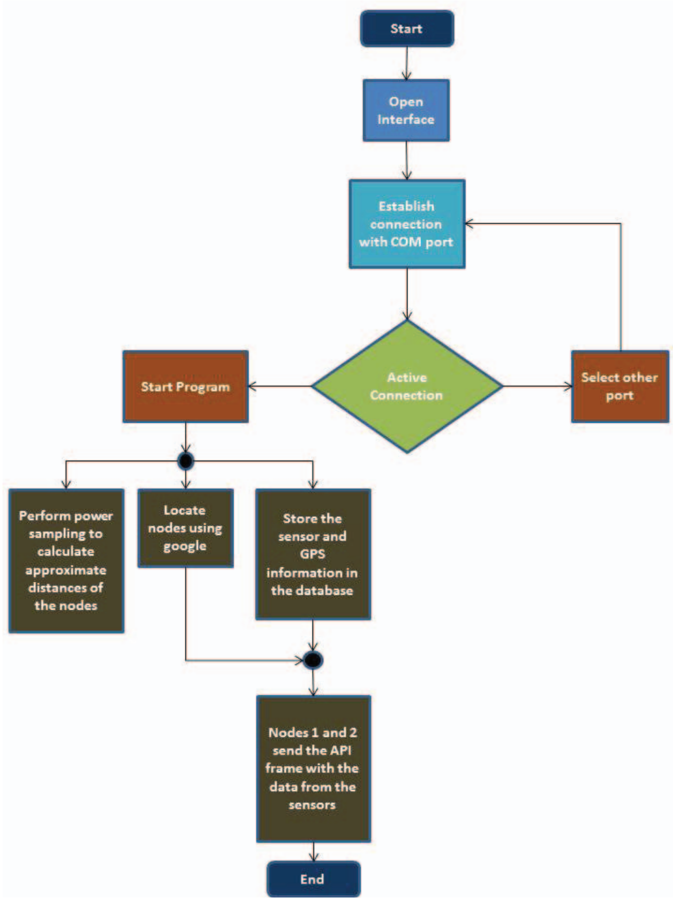

Fig. 3. Algorithm diagram

III. User Interface

A. Software Management System (Software de Gestion)

The GUI was designed using Visual Studio with C programming language #; this interface is divided into several tabs that display different information as required. Once the program is executed, the port connected to the Coordinator node must be selected, and then it starts receiving frames.

The sensor tab presents information on the measurements performed by the sensors and is divided in node 1 and node 2 as depicted in figure 4. The request for information was set up in 7 seconds for each node; however, this value can be modified, taking into account the time it takes each sensor to make a measurement. As a result, each of the nodes information will be updated every 14 seconds.

GPS node 1 and GPS node 2 tabs present the coordinates of the respective nodes as well as an image taken from Google maps with the specific location of the nodes.

As shown in figure 5, the RSSI (Received Signal Strength Indicator) tab displays power measurements at various distances taking node 3 as a reference point; subsequently a constant is calculated which is used to calculate the approximate distance from the Coordinator Node to each of the three nodes. To obtain node power information it is necessary to request the RSSI values using AT command, this value is returned by

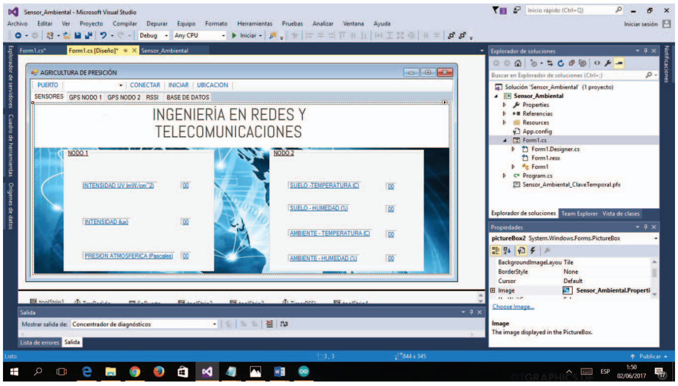

Fig. 4. Sensor Information

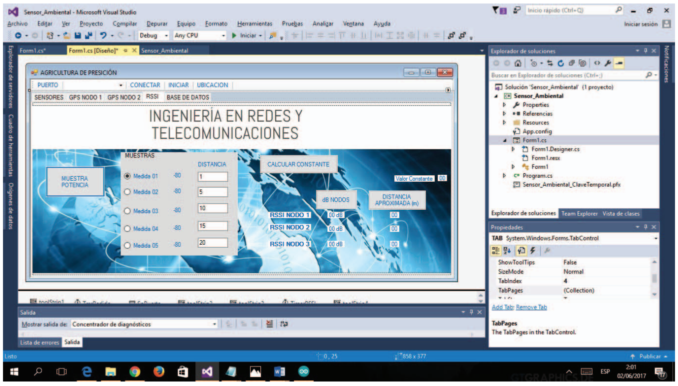

Fig. 5. RSSI and Distance Information

Fig. 6. Database Information

each node using the raster API; it is necessary to interpret the plot to extract the value of RSSI.

B. Database

The Database was developed in SQL. Information received wirelessly from the sensors is saved in the database, allowing remote users to access such information in real-time.

The database tab presents information stored in the database; this information corresponds to the coordinates of the nodes at the time of measurement and data obtained from measurements obtained by the sensors per Figure 6.

TABLE I
ML8511 SENSOR TEST CHARACTERISTICS

Test Site Coordinates	-0.3660, -78.5550
Site Altitude a.m.s.l	3085 metros
Number of Measurements	3
Nodo ID	1
Test Date	May 31,2017

TABLE II
ML8511 SENSOR TEST

Test Time	UV Radiation Index
13:35	5
13:47	5
13:55	5

IV. RESULTS

A. Validation Tests

To verify the correct operation of the sensors, several tests were conducted as follows:

UV Radiation

The ML8511 sensor detects light with wavelengths between 280-390 nm. This range covers both spectrum UV-B (315 - 280 nm) and UV-A (400 - 315 nm), where UV-A has a greater penetration index but UV-B has more energy. The ML8511 analog output is linearly related to the intensity of UV (mW/cm2).

Measurement performed by the UV ML8511 radiation sensor is expressed in mW/cm2, and is critical to determine the intensity of UV radiation that exists; it should be considered that high values of UV is detrimental to health. There are a total of 9 UV monitoring stations in Quito, Ecuador. In this case, the validation test was carried out in the INIAP Experimental Santa Catalina station.

ML8511 Sensor Test Characteristics Test Site Coordinates -0.3660, -78.5550 Site Altitude a.m.s.l 3085 metros Number of Measurements 3 Nodo ID 1 Test Date May 31,2017 ML8511 Sensor Test Test Time: UV Radiation Index 13:35 5 13:47 5 13:55 5

Luminous intensity

In order to validate the data acquired by the BH1750 Sensor which is integrated in node 1, it is necessary to make a comparison with other calibrated equipment; these tests were performed in environmental engineering lab at the University of the Americas located in Quito, Ecuador. The lab test equipment lux meter brand Scientific, reference model 850007 was used for sensor validation tests

To perform the validation of the luminous intensity data from node 1, 4 measurements were performed in different spots in the laboratory. The measurement unit is expressed in Lux; it should be remembered that the luminous intensity results depends on the intensity, area, and angle of incoming light. The lab 850007 sensor outputs luminous intensity (Iv) data in foot-candle units, so it is necessary to perform the

TABLE III
COMPARISON BETWEEN 850007 AND BH1750

Test ID	850007	850007	BH1750	% Variation Margin
Test 1	16,2	174,37	178	3,6
Test 2	0,8	8,61	9	0,4
Test 3	21,6	232,5	228	4,5
Test 4	10,5	113	119	6

TABLE IV
COMPARISON BETWEEN TA440 AND DTH22

Test 1	46,5	21,9	47	21
Test 2	44,4	22,6	44	22
Test 3	41,5	21,5	41	21

conversion to Lux (Ev - Illuminance Index) for comparison purposes with the BH1750 sensor; the distance is measured in meters. The conversion formula is as follows:

$$E_v = \frac{I_v}{D^2} \quad (1)$$

Where:
E_v is the illuminance index
I_v is the luminous intensity
D is the distance

Table 2 shows the results obtained after comparing the lab equipment sensor 850007 and the node sensor BH1750. The variation margin goes up to 6%.

Atmospheric pressure

Atmospheric pressure is measured by the BMP085 sensor and the results are delivered in Pascal (Pa) units. At sea level, atmospheric pressure is typically higher; the atmospheric pressure is 101200 Pa. On the other hand, if the altitude increases, atmospheric pressure decreases. In Mount Everest, the atmospheric pressure is 38200 Pa. In Quito the atmospheric pressure typically ranges between 71500-72000 Pa,

The measurements obtained with the BMP085 sensor reflect an average atmospheric pressure of 72589.90 Pa; this value is within the typical range of atmospheric pressure in Quito. It can be inferred that the sensor is operating properly.

Ambient temperature and humidity

Node 2 collects relative humidity and temperature data through the DTH22 module. Sensor data was compared with the TA440 (anemometer brand airflow) calibrated lab test equipment in order to determine if the values recorded by the node 2 sensor are correct. Validation testing was conducted at the University of the Americas environmental engineering laboratory.

As it can be observed in table 3, the difference in the relative humidity between the sensors is 0.5% on average and the temperature is 0.5 °C. Given that module DTH22 has an accuracy range of temperature 0.5 °C and 2% moisture, it can be concluded that the DTH22 sensor measurements are accurate.

TABLE V
COMPARISON OF MOISTURE AND SOIL DATA

Sample 1	38,3	49	10,7
Iteration 1	37,2	48	10,8
Sample 2	44,2	55	10,7
Iteration 2	43,3	56	12,6

Moisture and soil temperature To measure soil moisture, node 2 integrates the STH11 sensor. For comparison purposes, the node STH11 sensor and lab thermometer (Denver Model) were placed into a full pot of land. According to the results, there is a difference of around 0.4 ° C between the Denver thermometer and sensor STH11 which indicates that the sensor is working properly.

In terms of the relative soil moisture, it is necessary to perform a technical procedure to determine it as accurately as possible, by applying the following formula:

$$H = \frac{S_w - S_d}{S_d}.100 \quad (2)$$

Where:
H is the humidity percentage
S_w the mass of the wet sample
S_d is the mass of the dry sample

The water retention capacity is given by the ratio of the mass of the soil saturated with water and mass of the dry soil sample, for this reason it is necessary to carry out the laboratory tests with two samples and two iterations each.

As we can see, there is a 11.25% percentage of difference on average between the measurements taken by the node 2 sensor and the tests performed with the lab sensor; however, in the laboratory only two samples were considered and two iterations due to the limitations on the availability of resources, this means that the number of samples corresponds to less than a quarter of the recommended samples since it requires a minimum of 10 samples and 10 iterations for different types of soils.

V. Conclusion

With the implementation of a Wireless Sensor Network with a mesh configuration, information can be transmitted via wireless communications at a range of 100 meters outdoors and 20 meters indoors without loss of data from one node to another; the range can be extended by introducing more nodes configured as routers. The data presented in the GUI to the end user is provided in real-time. The only limitation is given by the time it takes the sensors to perform measurements, and transmit to a database to store information. The WSN system was implemented to allow the end user to perform statistical analysis on the obtained measurements and derive useful information about environmental conditions. It was verified that the GPS NEO - 6M module has a latency of 12 minutes to acquire information related to the location of the nodes in an indoor setup; this despite the fact that the manufacturer indicates that the sensor takes about 27 seconds before it presents the first measurements. Although the sensor is accurate, it has difficulties to connect with satellites when it is setup indoors, being far more effective in outdoor conditions. To confirm that accuracy of the data obtained by the node 1 and node 2 sensors, it was necessary to compare the results with precision equipment available in the environmental engineering lab as described in section IV. All the WSN sensors obtained measurements with a minimal difference compared with the reference laboratory sensors with the exception of the SHT11 sensor which presented a 11.25% variation with respect to calibrated laboratory sensor. As a result, it is concluded that the reliability of the results depends on the number of samples taken, requiring a minimum of 10 samples and 10 iterations for different types of soils.

VI. Acknowledgements

The authors wish to thank Jean-Michel Clairand from Universidad de las Américas for editing this paper.

References

[1] S. A. Kumar and P. Ilango, "The Impact of Wireless Sensor Network in the Field of Precision Agriculture: A Review," *Wireless Personal Communications*, pp. 1–14, 2017.

[2] S. F. Di Gennaro, A. Matese, B. Gioli, P. Toscano, A. Zaldei, A. Palliotti, and L. Genesio, "Multisensor approach to assess vineyard thermal dynamics combining high-resolution unmanned aerial vehicle (UAV) remote sensing and wireless sensor network (WSN) proximal sensing," *Scientia Horticulturae*, vol. 221, no. April, pp. 83–87, 2017. [Online]. Available: http://dx.doi.org/10.1016/j.scienta.2017.04.024

[3] I. Mat, M. R. M. Kassim, and A. N. Harun, "Precision agriculture applications using wireless moisture sensor network," *2015 IEEE 12th Malaysia International Conference on Communications (MICC)*, pp. 18–23, 2015. [Online]. Available: http://ieeexplore.ieee.org/document/7725400/

[4] L. Zheng, H. Zhang, W. Han, and X. Zhou, "Technologies, applications, and governance in the Internet of Things," *In proceedings of the Internet of things-Global technological and societal trends*, pp. 141–175, 2011. [Online]. Available: http://books.google.com/books?hl=en{&}lr={&}id=Eug-RvslW30C{&}oi=fnd{&}pg=PA143{&}dq=Technologies,+Applications,+and+Governance+in+the+Internet+of+Things{&}ots=3Sy6ECmAEt{&}sig=NsG7DZSc2Uq{_}SmQhSXB10-89kQU{%}5Cnhttp://books.google.com/books?hl=en{&}lr={&}id=Eug-RvslW30C{&}oi=fnd{&}

[5] J. Granda Cantuna, S. Solorzano, and J.-M. Clairand, "Noise Pollution Measurement System using Wireless Sensor Network and BAN sensors," *2017 Fourth International Conference on eDemocracy & eGovernment (ICEDEG)*, pp. 125–131, 2017. [Online]. Available: http://ieeexplore.ieee.org/document/7962522/

[6] G. Sahitya, N. Balaji, C. Naidu, and S. Abinaya, "Designing a Wireless Sensor Network for Precision Agriculture Using Zigbee," *IEEE 7th International Advance Computing Conference (IACC)*, pp. 287–291, 2017. [Online]. Available: http://ieeexplore.ieee.org/document/7976803/

[7] M. Qiu, Z. Ming, J. Wang, L. T. Yang, and Y. Xiang, "Enabling Cloud Computing in Emergency Management Systems," *Cloud Computing, IEEE*, vol. 1, no. 4, pp. 60–67, 2014.

[8] A. Pantelopoulos and N. G. Bourbakis, "A survey on wearable sensor-based systems for health monitoring and prognosis," *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, vol. 40, no. 1, pp. 1–12, 2010.

[9] H. Alemdar and C. Ersoy, "Wireless sensor networks for healthcare: A survey," *Computer Networks*, vol. 54, no. 15, pp. 2688–2710, 2010. [Online]. Available: http://dx.doi.org/10.1016/j.comnet.2010.05.003

[10] T. D. Räty, "Survey on contemporary remote surveillance systems for public safety," *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, vol. 40, no. 5, pp. 493–515, 2010.

[11] I. Bayir, "A glimpse to future commercial spy satellite systems," *RAST 2009 - Proceedings of 4th International Conference on Recent Advances Space Technologies*, pp. 370–375, 2009.

[12] P. Ji, C. Wu, Y. Zhang, and H. Chu, "A Wireless Sensor Network Routing Protocol for Fire Estimation in Building," *Energy*, 2009.

[13] J. Granda Cantuña, D. Bastidas, S. Solórzano Lescano, and J.-M. Clairand, "Design and Implementation of a Wireless Sensor Network to Detect Forest Fires," *2017 Fourth International Conference on eDemocracy & eGovernment (ICEDEG)*, vol. 2, pp. 15–21, 2017.

[14] Aqeel-Ur-Rehman, A. Z. Abbasi, N. Islam, and Z. A. Shaikh, "A review of wireless sensors and networks' applications in agriculture," *Computer Standards and Interfaces*, vol. 36, no. 2, pp. 263–270, 2014. [Online]. Available: http://dx.doi.org/10.1016/j.csi.2011.03.004

[15] J. Jeromina and K. V. Anusuya, "Energy efficient cluster formation algorithm and sink relocation algorithm for precision agriculture," *Proceedings of 2016 Online International Conference on Green Engineering and Technologies, IC-GET 2016*, 2017.

[16] S. Maurya and V. K. Jain, "Energy-Efficient Network Protocol for Precision Agriculture: Using threshold sensitive sensors for optimal performance," *IEEE Consumer Electronics Magazine*, vol. 6, no. 3, pp. 42–51, 2017.

[17] A. Chauhan, S. Semwal, and R. Chawhan, "Artificial neural network-based forest fire detection system using wireless sensor network," in *2013 Annual IEEE India Conference (INDICON)*, 2013, pp. 1–6. [Online]. Available: http://ieeexplore.ieee.org/ielx7/6712175/6725842/06725913.pdf?tp={&}arnumber=6725913{&}isnumber=6725842{%}5Cnhttp://ieeexplore.ieee.org/xpls/abs{_}all.jsp?arnumber=6725913

[18] J. Stewart, R. Stewart, and S. Kennedy, "Internet of Things - Propagation modelling for precision agriculture applications," *Wireless Telecommunications Symposium*, 2017.