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RESEARCH ARTICLE

THE IMPACT OF GREENHOUSE ENVIRONMENTAL CONDITIONS ON THE SIGNAL STRENGTH OF WI-FI BASED SENSOR NETWORK.

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Abstract

Because greenhouses are controlled sites for agricultural production, environmental conditions such as temperature, relative humidity, carbon dioxide level and solar radiation must be kept at a certain level for plant growth. Therefore, indoor environmental parameters must be constantly monitored in order to take precautions when necessary. Thanks to the technological advancements in recent years, wireless sensor networks have been widely used in monitoring and controlling systems. In addition to monitoring environmental conditions, wireless sensors are used to irrigation, ventilation and heating equipment and in Internet of Things applications. Greenhouse environment is different from external climate, and sudden climatic changes such as high relative humidity and condensation of moisture may occur due to various cultural activities. As a result, some problems may be encountered in data transfer over wireless networks. Therefore, this study analyzes the impact of greenhouse environmental conditions on the data transfer performance of wireless network.

The study was conducted in a greenhouse with a floor area of 150 m^2 where side walls were covered with double layer polyethylene (PE) with a gap of 5 cm and roof was covered with single layer PE covering material. The main station was positioned outside the greenhouse. Sensor nodes were positioned 20 meters away from the main station within the greenhouse. The research lasted for 20 days between March 20 and April 10. Temperature, relative humidity and signal strength values were transferred to the main station every five minutes thanks to the micro-processor software. The obtained data were used to statistically assess the signal strength performance of sensor nodes. The findings demonstrated that high relative humidity influenced signal strength positively while high temperature influenced signal strength negatively.

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Introduction:-

Environmental conditions such as temperature, relative humidity, carbon dioxide level and solar radiation must be kept at a certain plant for plant growth in greenhouses. Greenhouse climate may exceed suitable values due to environmental conditions and plant activities, which leads to unfavorable results for production. For instance, plants

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may dehydrate due to stoma, which causes evaporation and increases the relative humidity in the greenhouse. A relative humidity higher than 85% in a greenhouse environment paves the way for the development of fungal pathogens. Therefore, it is of vital importance to monitor environmental conditions in greenhouses. Nowadays, wireless monitoring devices offer a practical solution to this problem because they do not require wiring. It is possible to measure environmental values at any point within a greenhouse. In addition, it is possible to position as many sensor nodes as necessary and thus obtain high resolution spatial data.

Used in various aspects of modern daily life, wireless sensor networks (WSN) are used to obtain data which account for environmental indicators ranging from urban environment and natural resources to sensitive ecologies (Gubbi et al., 2013). WSN consist of low-cost, low-power and multifunctional sensor nodes which usually communicate in short distances (Akyildiz et al., 2002). The data obtained by nodes can be directly transferred to the main station, which is the main target, or indirectly over another node by jumping. The communication strength and distance of low-power nodes are limited.

In today’s world, new technological developments in hardware and communication protocols, Internet technologies and evolution of universal data processing make it easier to design, control, install and maintain low-cost and low-power systems by using standard protocols. In addition, these promise more advanced and smart agricultural applications (Ferrandez-Pastor et al., 2016). This technology uses network sensors and thus offers an agricultural transformation by increasing the utility of information in the production chain (Rose et al., 2015). One of the numerous fields of use for sensors and sensor networks is agriculture (Aqeel-Ur-Rehman et al., 2014).

In the field of agriculture, WSN may help

1. collect weather, plant and soil data
2. monitoring of distributed land
3. grow various plants in a single land
4. apply different fertilizers and irrigation for different land in a single parcel
5. grow different plants under different weather and soil conditions
6. offer proactive solutions instead of reactive solutions (Abbasi et al., 2014).

Many WSN applications were implemented in the field of agriculture (Abouzar et al., 2016; Sui and Baggard, 2015; Wang et al., 2016). Ferentinos et al. (2014) proposed a design and operation methodology for the use of WSN in greenhouses. Zhou et al. (2013) controlled greenhouse irrigation system with ZigBee wireless network protocol and PID controllers. Liu et al. (2016) developed an intelligent monitoring system for greenhouse environmental conditions. Wu et al. (2014) reported that their smart early warning system for agricultural purposes could be used for various practical applications such the remote control of a water pump. Shi et al. (2013) developed a rapid, stable and low-power system that can be easily installed and expanded to monitor environmental parameters at a micro level. Wang et al. (2007) developed a wireless sensor node system to measure temperature and relative humidity parameters. Yang et al. (2008) developed a RFID based, integrated and multifunctional remote sensing system for the management of seedling production in a greenhouse. Lea-Cox et al. (2007) proposed a low-cost environmental monitoring and control system in a greenhouse environment with WSN. Damas et al. (2001) remotely controlled numerous water distribution valves with WSN in large irrigation fields in Spain and reported that this system reduced water consumption by 30% -60%. Ehlert et al. (2004) reduced fertilizer consumption by 10%-12% by using WSN for nitrogen fertilization in proportion to plant growth. He et al. (2011) developed a fertilization algorithm and decision support system thanks to the data obtained by wireless sensors with IEEE 802.11 Wi-Fi protocol. Zhang et al. (2004) analyzed plant health by measuring temperature, ambient humidity and light with wireless sensors. Gang (2006) reported that a system with Bluetooth technology instead of conventional data collection systems offered advantages for greenhouses. Kolokotsa et al. (2010) developed a smart environmental and energy management system for greenhouses to monitor ambient light, temperature, relative humidity, CO2 concentration and external temperature and control ambient climate in a greenhouse with fuzzy logic control.

Numerous studies have been so far conducted in order to analyze the impact of environmental conditions on the signal strength for wireless networks. In these studies, some researchers underlined the importance of temperature for signal strength while others associated signal strength with humidity. In addition, some researchers reported that other environment factors influenced signal strength (Bannister et al., 2008; Bezerra et al., 2015; Boano et al., 2013; Capsuto and Frolik, 2006; Chen et al., 2016; Garcia et al., 2009; Latal et al., 2016; Markham et al., 2010; Ortega-Corral et al., 2014; Rao et al., 2016; Thelen et al., 2005; Xie et al., 2016).

Greenhouse environment is different from external climate, and sudden climatic changes such as high relative humidity and condensation of moisture may occur due to various cultural activities. Some problems may be encountered in data transfer over wireless networks. Therefore, this study analyzes the impact of greenhouse environmental conditions on the data transfer performance of wireless network.

Material and Method:-

In this study, ESP8266 microcontroller modules which support IEEE 802.11 Wi-Fi protocol were used for data transfer while SI7021 sensors were used to measure temperature and relative humidity. The sensors were combined with microcontrollers, and a Li-ion (lithium ion) battery was used as a power supply. Additionally, the battery was charged by a solar panel and charging module within the greenhouse. The system is shown in Figure 1.

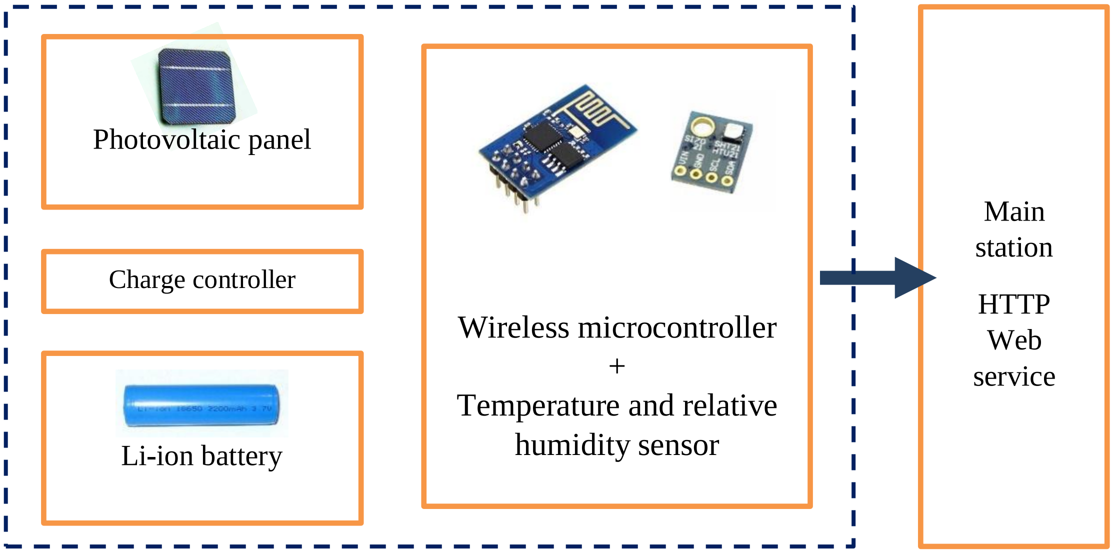

Figure 1:- Wi-Fi based wireless sensor node model.

Wireless microcontroller has 1 Megabyte memory and standard I/O, SPI and UART support. Thanks to its 32 byte low-power requirement, it can operate as an application processor with an output power of +19.5 dBm at 802.11b mode (ESP8266, 2015). SI7021 sensor, which is used for relative humidity and temperature, measures relative humidity between 0%-100% at an accuracy of 3% and a sensitivity of 0.1% while it measures temperature between -10 °C and 85 °C at an accuracy of 0.4 °C and a sensitivity of 0.1 °C (SI7021, 2015). A photovoltaic panel of 10 watt which supplies 0.63 A current with a voltage of 21.6 was used in the study. A Li-ion battery of 3.7 volt with a capacity of 3400 mAh supplied current for wireless sensor node.

Microcontroller software was developed using Arduino 1.6.5 IDE and C++ programming language. This software was used to read sensors every 5 minutes. In addition, functions defined in the microcontroller software development library were called back to measure sensor node, battery voltage and wireless signal strength in millivolt and dBm. Measurement data were packed in JSON file format and transferred over wireless network using HTTP web service in the main station.

The study was conducted in a greenhouse with a floor area of 150 m^2 where side walls were covered with double layer polyethylene (PE). The main station was positioned outside the greenhouse. A battery was used as a power supply in order to eliminate problems in data transfer. A photovoltaic panel of 20 W and parallel grid supply was used to charge batteries. The sensor node was positioned 20 meters away from the main station between plant rows.
Raspian GNU/Linux operating system was used on the mini computer card in the main station. Nginx web server and MariaDB database were used on the operating system. The software developed in PHP language was used as a web service to transfer data from the sensor node to the database. At the end of the research, the data stored in the database were exported in data table format.

SPSS 22 statistical analysis software was used for data analysis. The main elements of the system in the research area are shown in Figure 2.

(a) (b)

Figure 2:- (a) Sensor node (b) Main station

The relative humidity and temperature values in the greenhouse were calculated via Equation 1 (Sensirion, 2008).

$$AH(t, RH) = 216.7 \times \left[\frac{\frac{RH}{100\%} \times A \times exp\left(\frac{m \times t}{T_n + t}\right)}{273.15 + t} \right] \quad (1)$$

Here, *t* is temperature (◦C), RH is relative humidity (%), *m* = 17.62, *Tn* = 243.12 °C and *A* = 6.112 hPa.

Findings and Discussion:-

The signal strength of wireless data transfer devices are defined as RSSI (Received Signal Strength Indicator) in decibel (dBm). A low value indicates a poor signal quality while a high value means a strong signal. This value typically varies between 50 dBm and -90 dBm. In order to identify the impact of relative humidity in a greenhouse on the data transfer between greenhouse computer and sensor node, the correlation between the sensor node signal strength and greenhouse indoor relative humidity values is given in Figure 3.

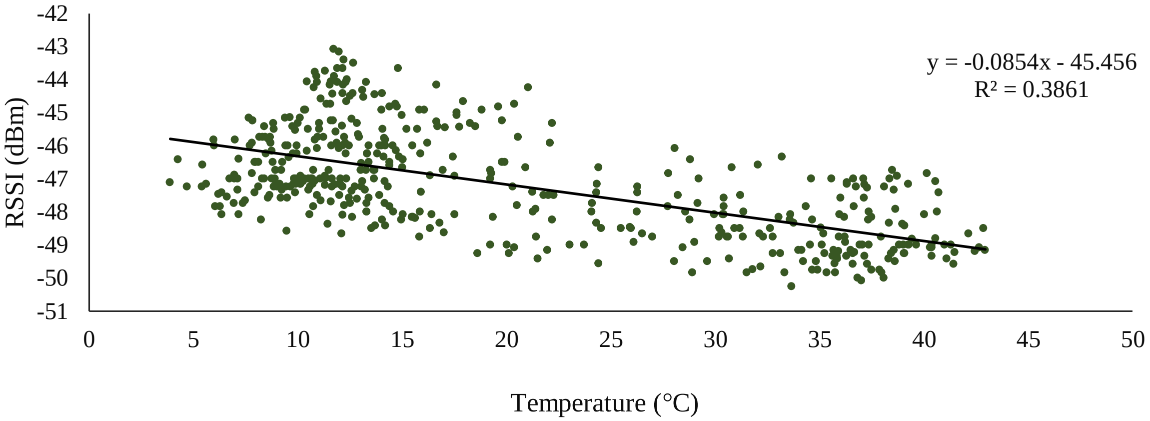

Figure 3. The correlation between sensor node signal strength (RSSI) and temperature in the greenhouse

This figure clearly displays a significant correlation between temperature and RSSI. In general, the temperature is inversely proportional to signal strength, which indicates a negative correlation (dependence). A Pearson correlation analysis was performed to measure this linear dependence, which yielded a correlation coefficient of -0.621. In other words, signal strength is influenced by temperature negatively. The correlation between temperature and signal strength is statistically significant (P<0.001).

Another factor that influences signal strength is humidity. In order to analyze the impact of humidity on the signal strength, the correlation between the relative humidity values and signal strength is given in Figure 4.

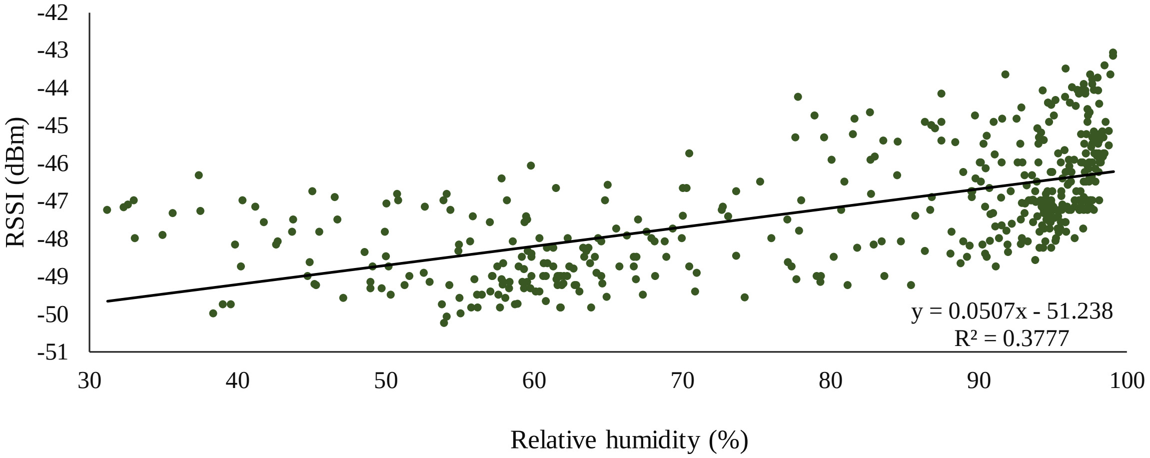

Figure 4:- The correlation between the relative humidity values and sensor node signal strength (RSSI)

It is evident from Figure 4 that a positive correlation exists between greenhouse indoor relative humidity and RSSI. In general, the relatively humidity is directly proportional to RSSI, which indicates a negative correlation (dependence). Pearson correlation analysis measured the correlation between signal strength and relative humidity with a correlation coefficient of 0.614.

Regression analysis yielded $R^2=0.377$ and a regression coefficient of 0.051, which indicates a rise of 0.5 dBm in signal strength compared to a rise in relative humidity by 10%. The correlation between signal level and relative humidity was found significant by 95% (P<0.001). Therefore, it can be stated that a high relative humidity in the greenhouse increases signal strength.

Absolute humidity is the amount of water in gram in a given volume of air. Under normal circumstances, the absolute humidity is inversely proportional to relative humidity and directly proportional to temperature. The correlation between absolute humidity and signal strength in the greenhouse is shown in Figure 5.

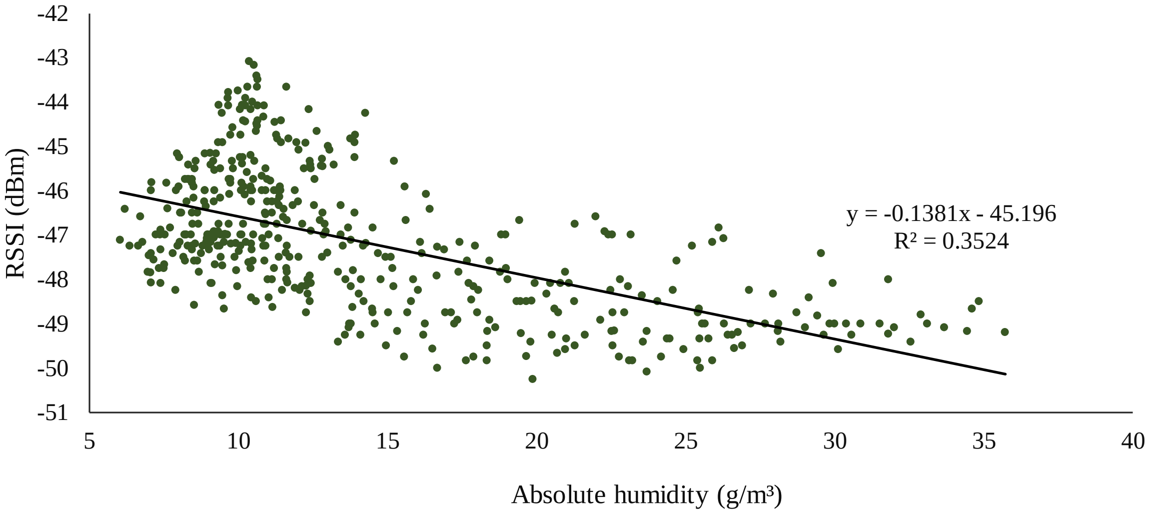

Figure 5. The correlation between sensor node signal strength (RSSI) and absolute humidity values

As shown in the analysis of RSSI-temperature and RSSI-relative humidity correlation in the previous section, increasing absolute humidity causes a loss of signal strength for wireless nodes. A correlation analysis performed to test this hypothesis yielded a Pearson coefficient of -0.593, which confirmed the existence of a negative correlation between RSSI and absolute humidity.

The regression analysis also indicates a significant correlation (P<0.001). The statistical data regarding the correlation between sensor node and relative humidity, absolute humidity and temperature are given in Table 1.

Table 1:- RSSI values compared to temperature, relative and absolute humidity values.

Statistical significance		RSSI-Temperature	RSSI-Relative humidity	RSSI-Absolute humidity
**	P< 0.001			
Pearson coefficient		-0.621**	0.614**	-0.593**
Regression coefficient		-0.085**	0.051**	-0.139**
R²		0.386	0.377	0.352

It can be noted in Table 1 that Pearson coefficient indicates a negative correlation between RSSI-temperature as well as RSSI-absolute humidity. Therefore, signal strength decreases when temperature and absolute humidity values increase. On the other hand, the correlation between RSSI-relative humidity was positive. When regression coefficients are analyzed, it can be observed that a rise of 10 °C in temperature leads to a rise of 0.9 dBm in RSSI and that a rise of 10 gr/m³ in absolute humidity decreases RSSI by 1.4 dBm. In addition, it must also be noted that a rise by 10% in relative humidity increases RSSI by 0.5 dBm. All of these correlations were found statistically significant (P<0.001).

Conclusion:-

This empirical study demonstrates that environmental conditions such as temperature and relative humidity influence wireless signal strength in a greenhouse. This impact is inversely proportional to temperature and directly proportional to relative humidity. However, the impact of changing signal strength on the data transfer also depends on the distance between wireless nodes and main station. It is likely to encounter problems in data transfer when wireless sensors are positional at critical points in terms of distance to main station. Therefore, in addition to temperature and relative humidity, the distance to main station must also be taken into account as for the position of wireless sensors in a greenhouse.

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