USING WIRELESS SENSOR AND ACTUATOR NETWORKS IN PRECISION AGRICULTURE UNDER EGYPTIAN ENVIRONMENT

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ABSTRACT

The agricultural sector consumes most of the water resources (greater than 70 %), and with the increase in local and global demand for water, as a result of population growth and the lack of water resources, the world has turned to use modern methods of agriculture or precision agriculture to increase the efficiency of water use in productivity. Wireless Sensor-Actuator Networks WSANs in agriculture provide the opportunity to monitor and control various environmental and field parameters.

The study focused on the use of WSANs in the agricultural sector and proposed: (1) Design a wireless sensor unit using an Arduino board, and Xbee3 module (sensor mote), a wireless control unit (actuator mote), and design a wireless network to sense and control some parameters (irrigation system). (2) Design a software program to collect and save various environmental and field parameters in a central database, and wirelessly control the Irrigation system. (3)Implementing an open field experiment to use the proposed system which was carried out on marjoram plants (Majorana hortensis, L. family Lamiaceae), at El-Kasasin Research Station in Ismailia Governorate, which belongs to Agriculture Research Center in the Department of Medicinal and Aromatic plants. All data collected were

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statistically analyzed to study the proposed system to reduce water use and increase productivity.

Keywords: precision agriculture, WSAN, Arduino board, Xbee3 module.

INTRODUCTION

The fast revolution in communication network and sensors technology paved the way to the next generation on wireless sensor networks. The coexistence of both sensors and actuators clarifies the main characteristics of Wireless sensor/actuator networks (Tiwari, *et al*., 2015), (Modieginyane, *et al*., 2018) WSANs, which have advantage of feedback, which is the main element in any control system as shown in figure (1). Using WSANs give the chance of developing wireless control system applications, where they will become the backbone of most control applications allowing a new degree of distributed control.

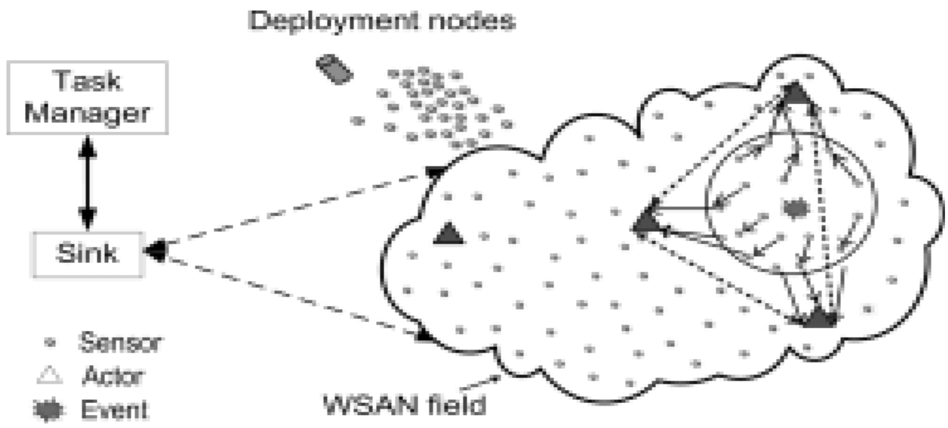

Figure (1): Wireless sensor/actuator network WSAN distributed system source (Modieginyane, *et al*., 2018)

Wireless sensor/actuator network WSAN, conquered all fields whether environmental monitoring, agriculture, healthcare, and military application.

The Wireless Sensor-Actuator Network WSANs are a distributed system of sensor and actuator nodes that connected via wireless networks. Sensors acquire data about the physical world, such as the environmental or physical systems, and send it to controllers/actuators via single-hop or multi-hop communications. The controllers/actuators use the information they receive to affect the behavior of the environment or physical systems.

WSANs have the ability to revolutionize the promotion of existing control applications (Sukhdev, 2013). They are likely to become the backbone of many control applications, which allow new levels of distributed control, and the remote distributed interactions with the physical world that made easier by this way, when compared to wired systems, which are now the most popular.

Applying WSANs in agriculture sector opens another field of technology, which is Precision Agriculture or Smart Agriculture. Precision Agriculture (PA) means how to optimize the resources usage to enhanced agricultural production and reduce the environmental impacts (Pawlowski *et al*., 2009). The main challenges in precision agriculture are estimate the growth of crop, and the strategic timing responses to crop production variations.

The target of this work is designing two types of motes:

(1) The sensor mote to sense some field parameters (soil moisture – temperature – humidity).

(2) The actuating mote to control some field parameters (control on irrigation system). Also, designing a wireless sensor actuator network to monitor the field parameters such as the soil moisture, temperature, and humidity also, to make change in some field parameters (in this work controlling the irrigation system). The measured and the control data sent wirelessly by xbee3 module to the central computer. The suggested software program includes three tabs forms, (1) the data logger/monitor tab form, (2)irrigation control tab form, (3) configuration tab form. The software program installed on the central computer to configure, monitor, and control the field parameters. The sensing and the control data saved in central database.

SYSTEM REQUIREMENT AND ARCHITECTURE:

This work is divided into four stages, designing the sensor and actuator mote (node), designing the wireless sensor actuator networks WSANs, designing software program to manage the WSANs, and applying the suggested system on real open field experiment to test the system and study the effect of using WSANs in the agriculture.

1) Design the sensor, and actuator mote: This work has two types of sensor mote, soil moisture mote, and temperature and humidity mote. The main block diagram of sensor node illustrated in figure (2).

The sensor mote has limitation in power, processing, and memory. It consists of four main parts, sensing module, processing module, communication module, and power source.

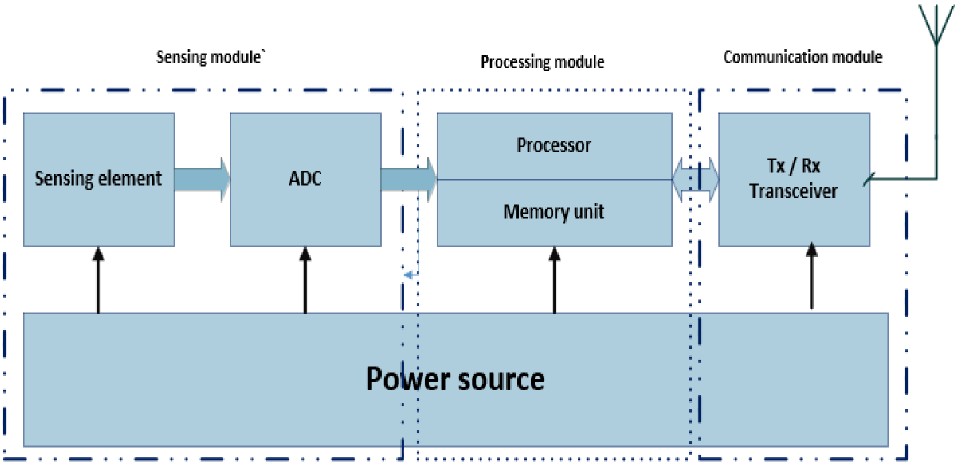

Figure (2): Sensor mote block diagram

This work constructs the sensor mote using:

Microcontroller board: arduino uno

Sensor element: soil moisture sensor for soil moisture mote, and temperature and humidity sensor DHT11 for temperature/humidity mote.

Communication module: Xbee3 module.

Power source: 9 volts battery.

This work has also, actuator mote to control the suggested irrigation system, the actuator module consists of four main parts, actuator module, processing and control module, communication module, and power source as shown in Actuator mote block diagram figure (3).

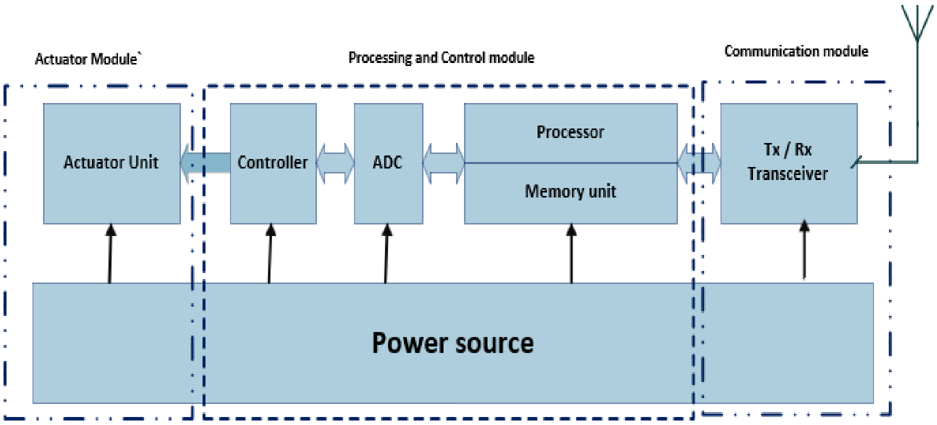

Figure (3): Actuator mote block diagram

The actuator mote has more computation and communication power capability and enough energy budget relative in sensor node (Sukhdev, 2013), (Kulandaivel, *et al*., 2012). But in general, resource constraints are still the main challenge for sensor and actuator node

The construction of the actuator mote in the work consists of:

Microcontroller board: arduino uno

Actuator module: electrical water valve (controlled by relay module).

Communication module: Xbee3 module.

Power source: 9 volts power source.

2) WSNs versus WSANs: WSANs are not only an enhancement for Wireless Sensor Network WSN but also go beyond. WSANs are a new generation of WSNs. Both WSANs and WSNs shares in many aspects and concerning, like connectivity, reliability, scalability and energy efficiency. The main difference between WSNs, and WSANs is the coexistence of sensors and actuators in WSANs. It can reveal the difference between the two types of sensing network by describe the types of applications which defines WSNs or WSANs. The application in which needs enhancing the monitoring selecting of WSNs are better. But the application which needs performing actions interacting with the physical world selectin WSANs are better. In general, the coexistence of the actuator in WSANs is the essential feature as a part of the network. The coexistence of actuator in WSANs has the advantage of change the physical world, while WSNs has not this advantage.

The main challenge in WSNs is the power consumption, mainly the main concern. On the other hand, meeting the real-time and reliable communication requirements are the main challenge in WSANs (Feng, *et al*., 2007).

WSNs are required in many applications (Tiwari, *et al*., 2015), for example, environment monitoring, and product quality monitoring. However, the applications which need the interact with the physical system or environment require WSANs.

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Coexistence of both sensors and actuators in WSANs, give them advantage of feedback, which is the main element in any control system. By using WSANs the chance of developing wireless control system applications is possible, where they will become the backbone of most control applications and allowing a new degree of distributed control.

The applications which use WSANs have many advantages better than which use wired application in many aspects like installation and maintenance, mobile operation, and monitoring and control of equipment in hazardous condition (Murugeswari, *et al*., 2014).

3) Wireless sensor / actuator networks topology: The main topologies in WSANs are sink base topology, and Multi Hop Sink Based topology as shown in figure (4).

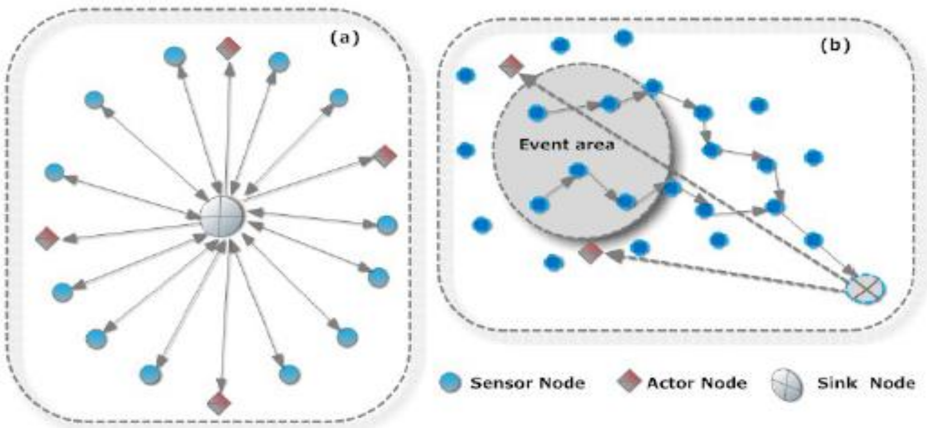

Figure (4): (a) Sink Based WSAN Topology,
(b) Multi Hop Sink Based WSAN

This work used sink base topology to design its network. the designed network consists of four sensors motes three of them to sense the soil moisture, and the fourth to sense the temperature and humidity. Also, the network has one actuator mote which controls the irrigation system (Modieginyane, *et al*., 2018).

The sensor mote consists of arduino uno board (Arduino forum, 2021) connected with Xbee3 module (Digi, 2020) through Xbee shield. The sensor (soil moisture, temperature and humidity) is connected through the analog ports. The 9v battery is the power source for this mote. Also, these components are put in plastic case for safety requirements as shown in figure (5) (Modieginyane, *et al*., 2018).

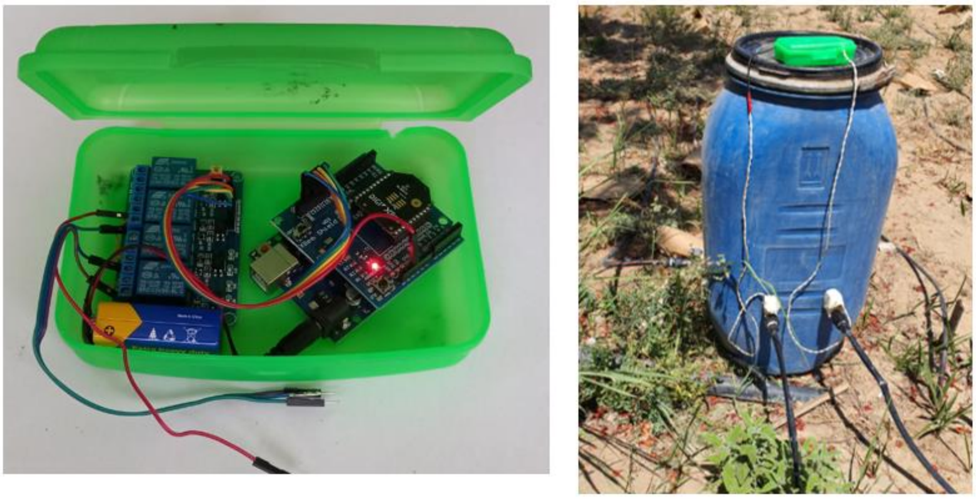

Figure (5): Suggested irrigation system control node in real system

On the other hand, the main components of the actuator mote are similar to the components of the sensor mote except using relay module to control the solenoid valves for the irrigation system as shown in figure (6).

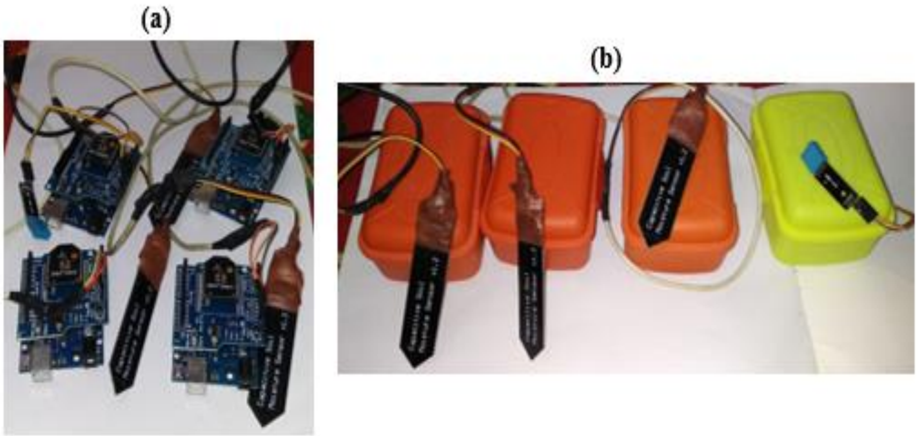

Figure (6): Real picture (a) sensor mote (b) sensor mote in plastic case

4) Design the software program: The Smart Farm Control Program designed to monitor, and control the farm parameters. The main parameters which monitored by the program are the soil moisture, air temperature, humidity. The program also, controls the farm assets, which is the water in this experiment.

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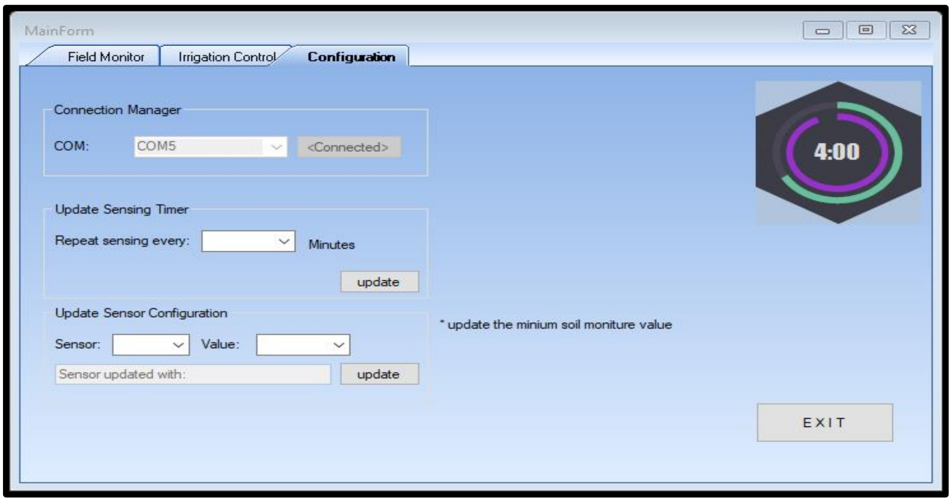

Figure (7): The configuration form to select the communication port, and adjust the irrigation time

C # 2016 writes the program. It designed by an easy way. It consists of one main form, and the main form has three tabs (Sub form). The first tab as illustrated in figure (7) is the configuration form. From “Connection manager” can easily select the communication port, which connected with Xbee3 coordinator module, then press connect to connect the module with the program.

In addition, from “Update sensor timer” it can adjust the periodic time to reconnect with the sensors to sense the soil moisture data from each area and send the data wirelessly to central computer. The last part in this form is “Update sensor configuration” where it can easily select the sensor number and reconfigure the minimum soil moisture for this sensor/area.

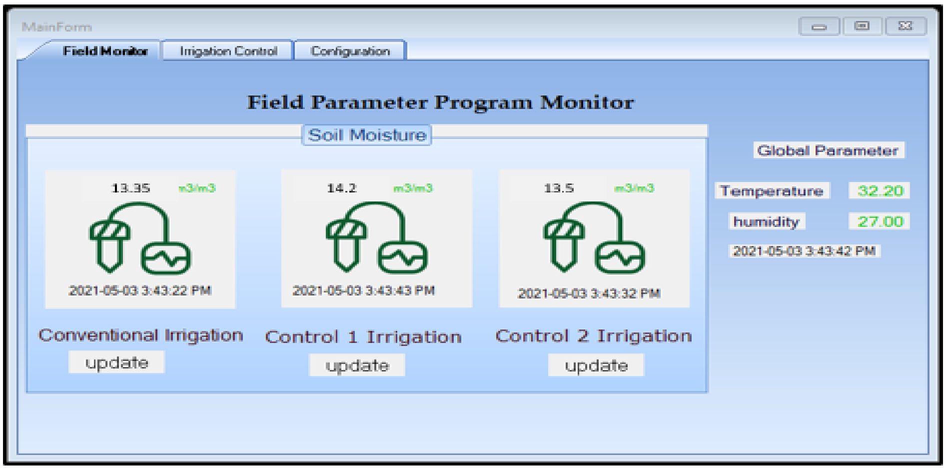

Figure (8): Field monitor tab form to monitor the field parameters soil moisture, temperature, and humidity.

The second tab is the field monitoring tab as illustrated in figure (8). This tab can monitor the soil moisture for three areas, and some environmental parameters such as the air temperature, and humidity. The last tab in the program is Irrigation control form, which controls irrigation in the field. As illustrated in figure (9). The field includes three areas. Each area can be irrigated by click Start irrigation for the selected area.

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Figure (9): Irrigation control tab form to control the irrigation in each area

IMPLEMENTATION THE SUGGESTED SYSTEM IN AN OPEN FIELD EXPERIMENT:

In this section, testing the suggested system demonstrated from all points of view by applying the suggested system in open field experiment. Where the sensors nodes (soil moisture sensors, and temperature and humidity sensor) are tested to transmit/receive the measured data to the central computer wirelessly through Xbee3 modules and these data are saved in the designed database. At the same time viewing these measured data on The Smart Farm Program GUI. The ability to real time communication between the Smart Farm Program (on the central computer) and the sensors node are checked also in this section. The last stage in this experiment was the ability to control the suggested irrigation system on/off either automatically or manually.

The open field experiment was carried out on marjoram plants (Majorana hortensis, L. family Lamiaceae) it is a leafy plant. It has a great importance in exportation, Majorana hortensis belong to family Labiatae (Lamiaceae), perennial herbaceous plant native to southern Europe and North Africa, the leaves are opposite, seated, oval-shaped, rounded at the top, with a full edge, and the flowers are present in their inflorescences, which are mostly white.

This work is done at El-Kasasin Research Station belongs to the Ismailia Governorate, Agriculture Research Center in the Department of Medicinal and Aromatic plants during one successful season of 2020 as shown in figure (10).

Figure (8): The open field experiment

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This investigation was carried out to set up the suggested system in the open field to study the response of marjoram plants (Majorana hortensis, L. family Lamiaceae) by monitor the soil moisture, some weather data like temperature, and humidity. Also, control the irrigation rates (control, A and B) to improve the vegetative growth production of marjoram plants. The seed of marjoram plant was obtained from the Department of Medicinal and Aromatic plants, Ministry of Agriculture. The seeds were sown in the nursery bed on 15th March, for one season 2020. After 45 days were transplanted in the soil.

The open field experiment is designed to measure the effect of using different irrigation rates on marjoram plants. where one of the most popular experiments in the agriculture field research is applying different level of irrigation to cultivate a certain crop. Typically, the researcher may achieve the experiment on three level 100%, 75%, 50% from quantity of water which the crop usually needs, this value has been calculated from the previous research.

(1) Steps of the experiment:

The schematic view for the experiment illustrated in figure (11).

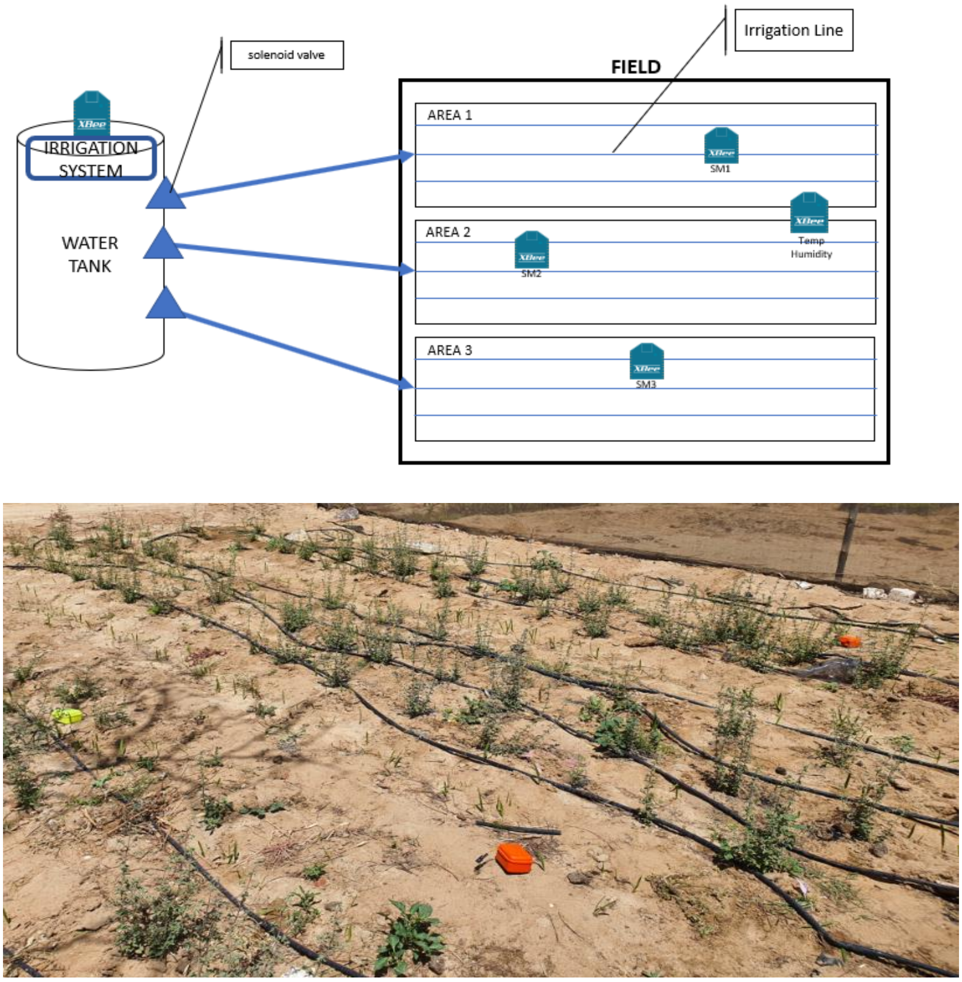

Figure (9): The schematic view for the experiment

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Where it is divided into three areas (AREA1, AREA2, AREA3), and puts one soil moisture sensor mote in each area near any plant in the area. AREA1 uses the traditional irrigation schedule where it is irrigated twice a week. Just before starting irrigation in AREA1 the program saves the soil moisture of this area (LSM1). The minimum soil moisture for area2 is decrease (1%) from the value of soil moisture in AREA1 just before starting irrigation (LSM1). Also, the minimum soil moisture for area3 is decrease (2%) from the value of soil moisture in AREA1 just before starting irrigation (LSM1).

(2) Treatments:

This approach is focused on connecting the schedule irrigation with the value of soil moisture. The experiment was carried out on three levels of soil moisture.

The control treatment (A) is the soil moisture for the area 1 when start irrigation (≈ 12% in this experiment). The treatment (B) deducted 0.01 from the soil moisture of the control treatment (A), and the treatment (C) deducted 0.02 from the soil moisture of the control treatment (A).

- Control Treatment A (≈ 12 %).
- Treatment B (≈ 11 %).
- Treatment C (≈ 10 %).

The compost at the rate (30 m3/fed), 150 Kg/fed super phosphate calcium (48% P2O5), 400 Kg/fed ammonium sulphate (20.5% N), and 75 Kg /fed potassium sulphate (48% KO2) was added for all plants. The amount of

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compost and superphosphate calcium was added during agricultural soil preparation, while the amount of nitrogen and potassium fertilizer was divided into three equal proportions. The first dose was applied 30 days after sowing, the second dose was applied 90 days after sowing, and the third dose was applied 30 days after the first cut. The plants were harvested twice through the growing season. The first cut took place on the first week of August, and the second cut took place on the first week of November. Other agricultural application processors on the plants, depend on the needs of the plants.

(3) The recorded data:

The work selects some recorded data such as Plant height (cm), number of branches per plant, Fresh weight of herb per plant (g), fresh and dry weight of herb per feddan (g), and dry weight of leaves per feddan (ton)

The experimental design was complete randomize design. Thereafter, the usual agricultural practices were followed as recommended. The recorded data were statistically analyzed and treatments were compared using least significant difference L.S.D. test at 5% level according to (Sendecor, *et al*, 1972) by using software (STATISTIX 9.0).

RESULT AND DISCUSSION

The difference in soil moisture between the irrigation treatments causes a decrease in the number of irrigations per month or season as shown in table(1). The experiment considers irrigation period is 1 hour. And the drop irrigation nozzle gives 4 liter/ hour (i.e., each irrigation dropped 4 liters for each nozzle). By this way the amount of water (liter) per plant for the conventional irrigation can be calculated as follow:

Amount of water/plant each irrigation = (1 hour) × (4 liters/hour) = **4 liters**

The amount of water/plant each week = 4 liters × (3 times/week) = **12 liter/week**

The amount of water/plant each month = 12 liters × 4 = **48 liter/month**

The amount of water/plant through the season = 48 liters × (6 months)

= **288 liter/season**

The number of plants per feddan is 20000 plants. As a result, the total amount of water during the season is equal 288 × 20000 = 5,760,000

= **5,760 m^3 /feddan**

Table (1): Number of irrigations, and water amount during the season

Conventional irrigation	treatment A	treatment B	treatment C
Number of irrigations	72	62	54
Water amount / plant	288 liters	248 liters	216 liters
Water amount / feddan	5,760 m^3	4,960 m^3	4,320 m^3

The recorded data in the experiment are:

- Plant height (cm)
- number of branches per plant
- Fresh and dry weight of herb per plant (g)
- dry weight of leaves per feddan (g)

After collecting these data and studying the statistical analyses. there is a clear significant difference between the different treatment's method on plants (which connect the irrigation with soil moisture data) among the means of various treatments studied by one way ANOVA and LSD at 0.05% level test out. It is clear that there is a significant increase in all recorded data in treatment "C" as compared to the control treatment "A". Where the treatment "C" decreases the consumed water with about 25% and gives an increase in water use efficiency more than 61% compared with control treatment.

CONCLUSION

The proposed system used the wireless sensor and actuator network WSAN in the agriculture sector under Egyptian environmental conditions. it causes an increase in the water use efficiency more than 61% by linking the irrigation with the value of soil moisture data and allows collecting a lot of field and environmental parameters such as soil moisture, temperature, and humidity in the central database. The suggested system succeeded in wirelessly controlling the irrigation system. The human intervention is minimized by using the suggested system, and the farm manager can know about the farm data and external environmental parameters and has complete wireless control on the irrigation system.

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استخدام شبكات الاستشعار والتشغيل اللاسلكية في الزراعة الدقيقة تحت ظروف البيئة المصرية

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المستخلص

يستهلك القطاع الزراعي معظم الموارد المائية (حوالي ٧٠٪)، ومع زيادة الطلب المحلي والعالمي على المياه نتيجة النمو السكاني وقلة الموارد المائية، اتجه العالم لاستخدام الأساليب الحديثة في الزراعة أو الزراعة الدقيقة، لزيادة كفاءة استخدام المياه في الإنتاجية. توفر شبكات الاستشعار والتشغيل اللاسلكية في الزراعة الفرصة لرصد ومراقبة والتحكم في مختلف المعاملات البيئية والحقلية.

ركزت الدراسة على استخدام شبكات الاستشعار والتشغيل اللاسلكية في القطاع الزراعي واقترحت (١) تصميم وحدة استشعار لاسلكية باستخدام لوحة أردوينو ووحدة أكس بي (مستشعر لاسلكي), وحدة تحكم لاسلكية (مشغل لاسلكي)، وتصميم شبكة لاسلكية لاستشعار بعض المعاملات والتحكم فيها (نظام الري) (٢) تصميم برنامج كمبيوتر لتجميع وحفظ المعاملات البيئية والحقلية المختلفة في قاعدة بيانات مركزية، والتحكم لاسلكياً في نظام الري (٣) تنفيذ تجربة حقلة لاستخدام النظام المقترح الذي تم تنفيذه على نباتات البردقوش بمحطة أبحاث القصاصين بمحافظة الإسماعيلية التابعة لمركز البحوث الزراعية بقسم النباتات الطبية والعطرية. تم تحليل جميع البيانات التي تم جمعها إحصائياً لدراسة تأثير النظام المقترح لتقليل استخدام المياه وزيادة الإنتاجية.

كلمات البحث: الزراعة الدقيقة، شبكات الاستشعار والتشغيل اللاسلكية، لوحة أردوينو، وحدة أكس بي.