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Evaluation of energy consumption and environmental conditions of a wireless network automated fly trap of greenhouse tomato plants

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ABSTRACT

Emerging wireless networks have become a useful tool for agriculture fields and greenhouses. An accurate monitoring of pest insect population in greenhouses allows to take proper decisions on biological control applications. Treatment success, strongly rely on early detection of population sprouts and pest dynamics. A simple PVC trap was designed using infrared-phototransistor modules using light and molasses as attracting baits. XBee modules operated the trap, detecting automatically the flies using an innovative capacitor as a counter; the module acquired the capacitor voltage after ten minutes and transmitted its value to a gateway. One node is connected to each of the four traps distributed in selected locations within the greenhouse and the information gathered every ten minutes is sent to a gateway composed of an Arduino ONE board, that stores the data and transmits SMS (Short Message Service) to a smartphone. SMS were sent when the first fly was caught and when a certain threshold of flies is detected within the four nodes. The wireless system was evaluated inside a tomato greenhouse, measuring the temperature and relative humidity inside the trap every 5 minutes during ten days; temperature was also monitored outside the trap. Temperature within the trap was found to be 1°C colder at noon at measurements taken 2 m over the soil within the tomato crop. The effect of power loss in the transmission signal as it crosses through plant biomass was studied. Tomatoes reduced signal transmission to 15 m, while leaves reduced transmission to 25 m, so a PVC tube was added to the trap in order to lift the XBee module over the crop. Energy consumption was optimized using only two white LEDS for attracting flies from 7 to 10 PM. Energy dosage could be optimized by controlling the lightning period based on the trap temperature.

Keywords: energy consumption, automated trap, wireless communication, transmission distance, tomatoes

INTRODUCTION

Pests and insects are attracted towards plants because they discharge volatile biological amalgams. Plants undergo various mechanisms by themselves for self-defense and their counter effect towards insect-attack varies depending on multiple factors of damage. An accurate and timely monitoring of pest insect population for crop protection, allows to take proper decisions about chemical and biological control applications [1]. Treatments success at farm level strongly rely on early detection of population sprouts, pest population levels and their dynamics. Pest population levels during crop season are routinely monitored by means of adhesive traps disseminated through the field, where insects remain stuck when attracted by color lures [2] or odorous baits such as sex pheromone [1].

The most popular method to collect data from traps, consists on performing repeated field surveys. Visual observation of traps is carried out by a human operator, recording the number of captured insects [3]. The periodicity between two consecutive surveys is usually between 15 to 30 days. This method has two main drawbacks as it is labor intensive (costly) and all monitoring traps cannot be synchronized to measure the target pest population.

Probe traps are cylindrical tubes with perforations in the upper section through which insects drops into the trap. These traps have a pointed tip for easy insertion into the place where insects live, and have been redesigned several times using newer and less expensive plastic materials [4]. Instrumentation was developed to estimate probe trap catches automatically [5], and an autonomous monitoring system was designed to count insect pests in paddy fields [6] by using rotten fruits and brown sugar yeast baits to attract the insects. Visual lures including ultraviolet, fluorescent, incandescent and LED illumination attract the insects to the traps [7,8]; insects are then counted using image processing techniques, before a GPRS/GSM module transmits the data. A Pomotrap [9] for Integrated Pest Management consists of an envelope with a defined shape, where a sticky pad and a pheromone dispenser is inserted. The system presents a commercial acquisition and data transfer system composed of a programmable smartphone, a 3-Mpixel integrated camera and the Symbian operating system [10]. Data is periodically transmitted to a remote server using a GPRS network

A WSN-MS composed of a number of nodes and a gateway [11] provided a unique, wireless, and easy solution for multiple-point spatial monitoring tasks. During the deployment of the system, each paired neighboring sensor node was separated between 9 and 15 m. The area covered approximately 2 ha (19 735 m^2) using 17 WSN-MSs that contained 198 sensor nodes; there was one sensor node per 99.68 m^2 (9.98 m x 9.98 m). The ZigBee transmission modules were coupled with an automatic pest counting trap, its counting controller, a luminance sensor, temperature and humidity sensors. Successful pest insect monitoring allows taking proper decisions and control strategies at a farm or at district level, based on continuously updated spatial maps of pest insect population levels. This spatial maps are retrieved to a server from a distributed network of sensor wireless units transmitting from the field [10]. To achieve this, a set of measuring stations have to be deployed in the field.

The present study examines the design of a wireless system for fly monitoring in a tomato greenhouse crop. An end node was connected to one of the four traps at the greenhouse and the information sent to a gateway that stores the data and transmits SMS when the first fly is caught. The SMS message is also sent when a certain threshold of flies is detected within the four nodes. Environmental conditions as temperature and relative humidity outside and inside the trap were monitored continuously for 24 hours and the transmission attenuation caused by plant's foliage and tomatoes analyzed.

MATERIALS AND METHODS

The experiment carried out from December 2015 to date was conducted at a greenhouse located at the experimental field of "Tlapeaxco" at the University Autonoma Chapingo, located at 19° 29' N and 98° 53' W, at an altitude of 2250 m in Texcoco, Mexico. The naturally ventilated greenhouse is 20 m long, 8 m wide, and 6 m high at its central ceiling. Eight lines of tomatoes having each 35 plants -spaced 50 cm between them- were planted in pots with tezontle (volcanic rock) as substrate.

The system should perform an efficient pest monitoring process using a wireless system distributed within the greenhouse monitoring area. The main advantages of the system are: high scalability, operation inside greenhouses or in large plantation extensions, low-cost wireless system, and low-power consumption with null zero maintenance during the operational life of nodes. This new trap should have a control signal to turn on a simple application system, and a SMS system to alert the producer when the first fly has been detected.

Trap design

The trap was designed to attract white-flies using white light [12] during the night and a liquid bait composed of grape juice mixed with 10% of molasses. Once the juice and the molasses are mixed, the liquid it is introduced to a plastic dispenser in the bottom of a cylindrical trap constructed of white PVC and painted of yellow color as a natural attractor; the bait has a sticky consistency where flies remain stuck. These traps have an inverted funnel so that air can flow and a net avoids that flies escape. A 10W solar photovoltaic panel charged a small package battery of 12 V and 36 Ah.

Two holes (0.5-cm in diameter) were drilled on the trap body 5 cm over its bottom. The holes' function as the fly entering pathway, being each hole surrounded by four LEDS, two white LEDS outside the cylindrical PVC tube and the other two infrared LEDS inside the trap. The function of the white LEDS is to attract the insects, having its spectral peaks at 456 nm (blue) and 548 nm (green) [12]. This trap has two pair of infrared-photoelectric sensors fixed to a cooper tube, Fig. 1. The infrared emitting diodes emits radiation and works together with a phototransistor to detect flies or insects and each infrared diode has to be properly aligned to the phototransistor sensor [12]. The light path from emitter to receiver covers the entrance to the trap (Fig. 1) and it is interrupted when the insect body passes.

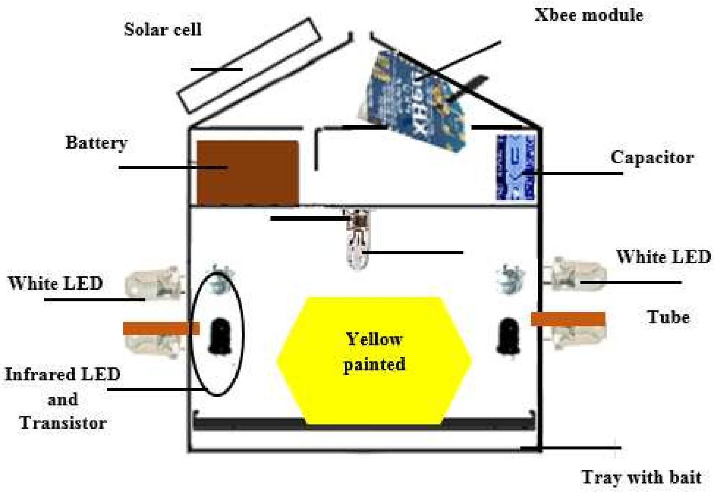

Fig. 1. Electronic trap components with its counting capacitor and lights for attracting flies.

Wireless system

In the greenhouse (figure 2) four nodes were installed using a simple star topology, measuring temperature (AD0-temperature), insect presence (AD3-capacitor charge), and humidity (AD1- relative-humidity). The end nodes use the ZigBee radio interface of an XBee-RF module with maximum transmission power of 50 mW and a sensitivity of -102 dB_m. These modules have a theoretical line of sight range of 100 m when using a 5 dB_i dipole antenna. Each XBee module was connected to the SHT75 (Sensirion, Switzerland) temperature and HR sensor, sampling data every 5 minutes during ten consecutive days. The information was saved on a Micro SD Storage Micro SDTF module compatible with ARDUINO UNO. The variables are communicated directly with the gateway node, that acted as a coordinator receiving the values from the sensor nodes.

Once the transmission light is interrupted it generates a 20 ms pulse through the digital output DIO2 (pin 18 XBee), which charges the capacitor by 0.25 V. A span lasting 10 minutes is used as the sampling or counting period. If 4 flies crossed then infrared sensor the capacitor will be charged by four 20 ms pulses, resulting in a stored voltage of one volt. After the fifth minute, the XBee reads the capacitor voltage and if it is higher than 5 volts it transmits the data. The capacitor is shorted through a transistor that is turned-on with DIO4 (pin 11 XBee). In this mode of operation, the XBee works as a counter considering a maximum density of four flies per minute.

Node 1 was placed 500 cm away from the rear wall of the greenhouse, and hanged at a height of 190 cm from the soil; the edge of the tomato foliage was encountered 150 cm away. Node 2 was positioned at a height of 190 cm and at a distance of 80 cm to the western side wall. Node 3 measured the crown layer at a height of 300 cm in the opposite side of Node 1. Node 4 was in the middle of the greenhouse block 820 cm away from the entrance door and hanged at a height of 215 cm. The nodes distance varied from 10 to 15 m to the coordinator, which selected a channel through a PAN ID to start the network. The coordinator buffered data packets for sleeping end nodes. Each node woke up and turned-on its radio for 15 seconds, and went then back to sleep turning-off its radio for 9 min 45 seconds. At a time, only one of the four nodes were waiting data request from the coordinator. Temperature inside and outside the trap was monitored to make it comfortable for the flies to come in, as flies will not enter with high temperatures.

Control signals

One of the purposes of the trap was to generate a 10 minute five-volt signal when 10 flies were detected within a 5-minute interval. A Short Message Service (SMS) was sent to the producer smartphone, indicating that the signal was generated. The appearance of the first fly generates also a SMS to alert the producer. The system gateway transmitted in intervals of 30 minutes as it satisfies the demands of lower sampling error, higher precision and lower power consumption [13]. The gateway also saves the information on a SD memory card.

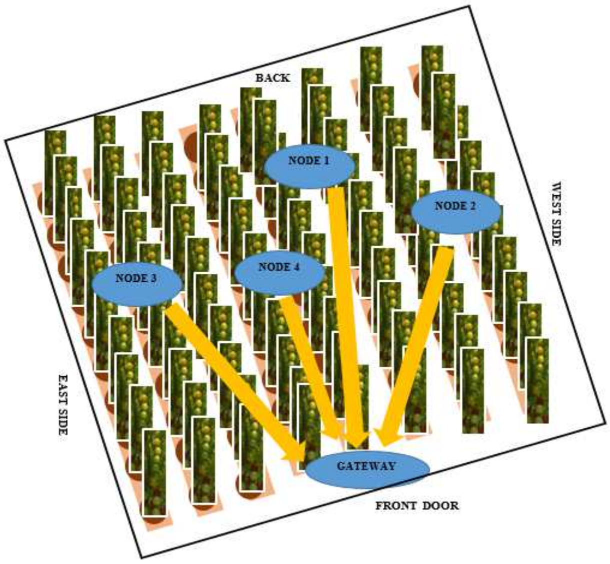

Fig.2. Greenhouse end nodes having each a trap hanging.

Experimental set-up

The experiment carried out at the greenhouse has three main experiments: determine fly activity under environmental conditions, optimize the power consumption of the trap and evaluate the performance of the wireless trap system. In the first one, temperature and relative humidity measurements were acquired inside and outside the traps hang up in places were tomatoes were in production. Fly activity was checked throughout the day and monitored flies were counted.

Optimization of power consumption analyzed whether the presence of two white LEDs of 5V@10 mA worked better for fly attraction, then a unique internal incandescent lamp of 80 mA. Treatment A, turned-both external white LEDs for 15 minutes and then turned them off for another 15 minutes throughout all the night. In a second analysis (treatment B), only one LED on the outside was turned-on for 5 minutes and turned-off for 10 minutes; after turning it off, the second LED was turned-on for five minutes and there was a period where only the internal lamp was turned on for 10 minutes and both outside LEDS were off. On the third experiment (treatment C) the lamp was turned-on during all the night. During all these three treatments, energy packages were analyzed base on the hours that flies were present, and a completely automatic node controls the energy when it is dark and the temperature between 15 and 35°C.

The performance of the wireless trap communication considers the distance of transmission considering that tomatoes are present in the path, or that leaves are interfering. If interference caused problems the trap was redisigned so that all the information was available at the gateway.

RESULTS AND DISCUSSION

The pulses generated during each fly-detection event are shown in figure 3. For testing the detection operation of the sensing device composed of the pair infrared detector-phototransistor and the capacitor a screwdriver was inserted between the two diodes (transmitter and receiver) simulating that the fly passed through. In the X-axis, time (minutes, seconds and cents of second) was plotted, appearing a pulse when the screwdriver was inserted. The capacitor gets charged and after 5 minutes the voltage is discharged; the synchronization for discharging the capacitor is controlled by the gateway with the request to send signal.

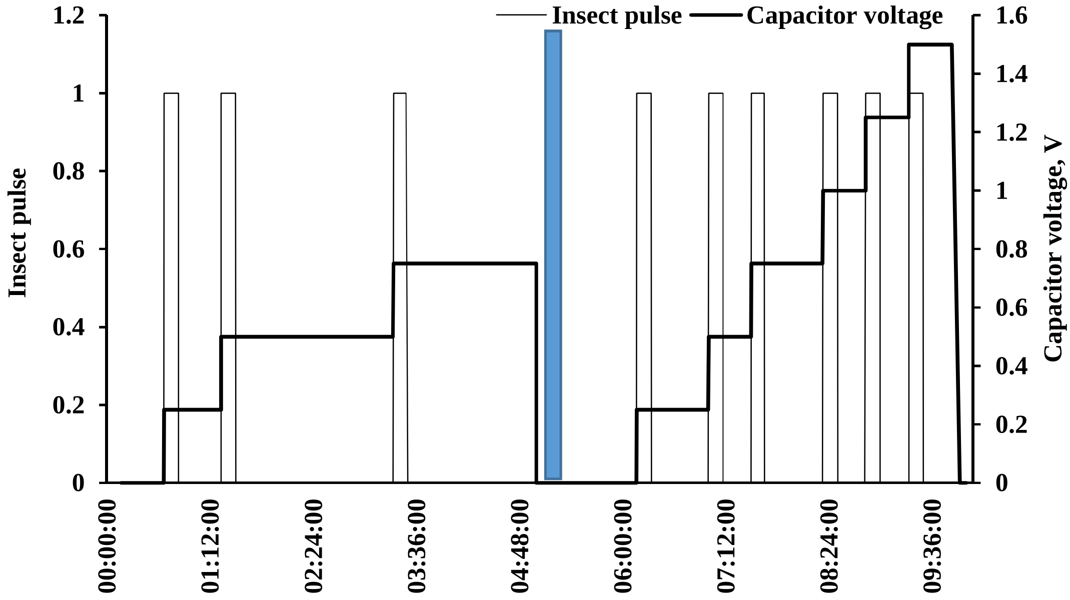

Fig.3. Pulse generated every time that an insect is detected and voltage stored at the capacitor.

Temperature throughout the season, showed temperatures in the greenhouse varying from 5°C to 40°C, being lower at soil level and higher as the sensor was taken towards the top of the tomato plant. Temperature within the trap was higher in the night and lower in the day by one degree centigrade, Fig. 4. Relative humidity increased over 70% for five hours after 3 AM. On the yellow square shown in figure 4, flies do not move around and traps were unable to catch them after 9 pm. Yellow sticky traps were used for catch white flies to monitor natural enemy activity [14]; results were similar showing no flies after 9 PM and during midday. Studies reveal that the largest number of insects affecting agricultural crops is observed between 7 PM and 9 PM [6]. Flies observed in those studies between 2 and 7 AM correspond to only 12%, meanwhile those appearing between 7 and 9 PM were 55%.

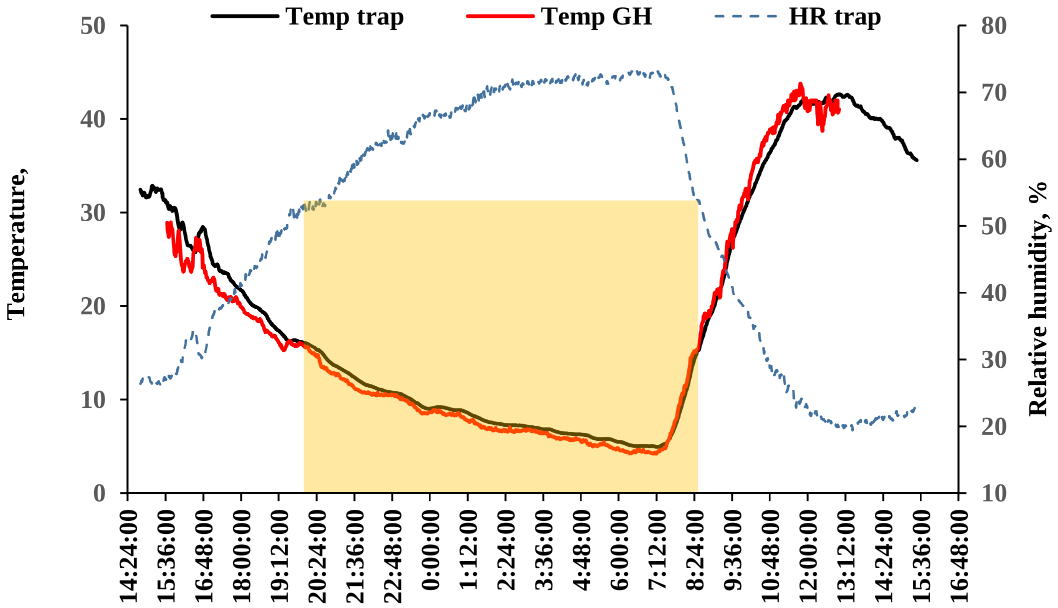

Fig.4. Temperature and HR inside and outside the trap.

Temperature is one of the most important factors affecting the developmental rate through the various life stages of fruit fly [15]. The development, survival and reproduction of fruit flies are also influenced by the species and quality of hosts, especially at the larval stage. Larval development of *Ceratitis capitata* increased in favorable hosts such as mango and tomato [16]. At pupal stage of fruit fly *Bactrocera correcta*, the highest survivorship was 97.25% at 30°C. The percentage of adults emerging from 100 eggs peaked at 77% at 30°C compared to 47% at 18°C. Under all the development stages egg, pupal and larvae, null survival was found below 5°C and over 45°C [17].

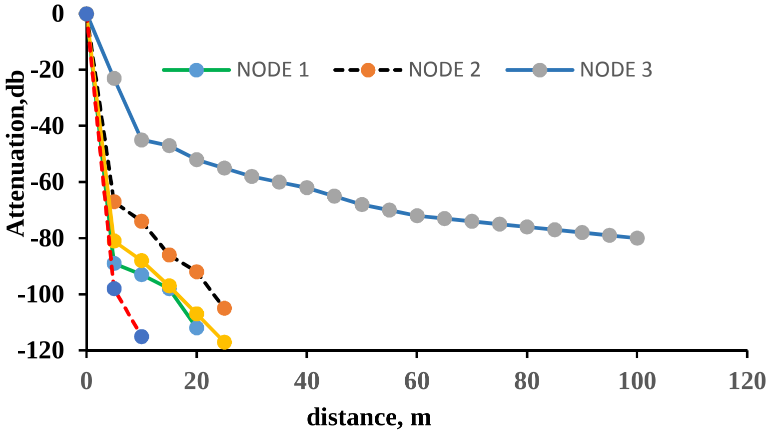

Fig. 5. Transmission distance of each trap/node crossing through leaves and tomato fruits.

Plants foliage affect wireless communications, as the signal gets attenuated as leaves are water rich objects [18]. Figure 5 shows the difference in transmission achieved by the gateway coming from each node. It can be seen that node 3, that was placed over the crop crown shows an attenuation of 75 dB after 100 m. Transmission of node 1 that crossed through 5 plants attenuated the electromagnetic waves greatly after 20 m and was unable to arrive to the gateway; similar responses were achieved by nodes 2 and 4. A group of tomatoes were put just after the XBee antenna, and transmission was lost after 15 m. ZigBee as the WSN communication technology working inside greenhouses with variable temperature and humidity parameters have a limited communicating distance of 22 meters [19].

Some changes were done to the original trap shown in figure 1 in order to avoid foliage interaction between the XBee node and the Arduino One gateway. A one-and-a-half-meter PVC tube was threaded to the upper side of the trap, fixing the XBee module and the solar cell to the higher tip of the tube. At a height over 3 m, foliage was of no concern anymore and no communication failures were detected.

Energy consumption

The advantages of using the cheap ZigBee technology for this application are that is characterized by self-organization and that it has low power consumption. The acquisition system based on the XBee module is the cheaper and better suited for monitoring processes that do not require to transfer a great quantity of data.

Table 1. Energy consumption of the wireless system and illumination per treatments and insects caught per day

Treatment light control	Wireless energy, watts	Illumination consumption, watts	Total energy, watts	Insect caught per day
A/ All night	4812	10800	15612	7 ± 2
A/ 7-10 PM	2600	2700	5300	7 ± 2
A /Control	1400	900	2300	6 ± 1
B / All night	4812	17424	22236	8 ± 3
B /7-10 PM	2600	4356	7,956	7 ± 2
B /Control	1400	1452	2852	6 ± 1
C / All night	4812	41472	46284	2 ± 1
C /7-10 PM	2600	10386	12986	2 ± 1
C / Control	1400	3456	4856	2 ± 1

Energy consumption for each treatment considering a different control option varies considerably. The use of LEDS instead of the incandescent lamp decreases energy consumption by 74% (41,472 to 10,800 watts). It was also remarkable that the incandescent lamp was the one that attracted less number of insects maybe due to the fact that light was only visible through the tubes and no heat was generated nearby. After knowing that insects are present from 7 to 10 PM, illumination energy consumption was reduced being in treatment A similar to the energy consumed by the infrared diodes and wireless system. The wireless system was taken to sleep from 10 PM to 7 AM. Treatment A and B were the best in attracting the insects and some problems were encountered when bigger insects got stuck in the entrance of the trap, therefore a mesh filter was introduced to avoid big insect to pass through. Energy dosage could be optimized by controlling lightning turn-on period when the trap temperature is ranging within 15 and 40°C. Wireless detectors and transmitters were also shut at temperatures lower than 15°C and higher than 40°C.

CONCLUSION

It can be concluded from this work that new on-going developments in wireless communication technology could give a valuable contribution in facing automatic monitoring of pests. Precise monitoring of insect pests at greenhouses allows to take proper decisions on biological control applications. This automated trap provides a signal and messages to the producer's smartphone to alert him from the presence of flies. Nodes based on XBee modules in each trap were installed using a star wireless topology; temperature, humidity and insect detection data were stored. A capacitor was charged every time a fly entered the trap during a period of 5 minutes. The capacitor voltage was acquired and transmitted by the XBee module every 5 minutes.

The presence of plants and their foliage did contribute in the attenuation of the transmitted radio signal strength, so the trap was redesigned and the XBee module radio raised to a height of 3 meters. Unless, foliage interference can be reduced the distance between the communicating nodes should be limited to less than 25 meters. Also it was noted that temperatures over 40°C and lower than 15°C decreased fly activity, so the traps could be intelligently programmed to reduce power consumption, which provides mainly from lightning for attracting insects.

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