Precision agriculture using remote monitoring systems in Brazil

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Abstract— **Soil and nutrient depletion from intensive use of land is a critical issue for food production. An understanding of whether the soil is adequately treated with appropriate crop management practices in real-time during production cycles could prevent soil erosion and the overuse of natural or artificial resources to keep the soil healthy and suitable for planting. Precision agriculture traditionally uses expensive techniques to monitor the health of soil and crops including images from satellites and airplanes. Recently there are several studies using drones and a multitude of sensors connected to farm machinery to observe and measure the health of soil and crops during planting and harvesting. This paper describes a real-time, in-situ agricultural internet of things (IoT) device designed to monitor the state of the soil and the environment. This device was designed to be compatible with open hardware and it is composed of temperature and humidity sensors (soil and environment), electrical conductivity of the soil and luminosity, Global Positioning System (GPS) and a ZigBee radio for data communication. The field trial involved soil testing and measurements of the local climate in Sao Paulo, Brazil. The measurements of soil temperature, humidity and conductivity are used to monitor soil conditions. The local climate data could be used to support decisions about irrigation and other activities related to crop health. On-going research includes methods to reduce the consumption of energy and increase the number of sensors. Future applications include the use of the IoT device to detect fire in crops, a common problem in sugar cane crops and the integration of the IoT device with irrigation management systems to improve water usage.**

Keywords— precision agriculture; internet of things, agri-tech, remote monitoring

I. PRECISION AGRICULTURE

Precision agriculture can be defined as a set of crop management techniques created to optimize agricultural production to enable the efficient management of the soil, the quality of the environment and the crops according to the unique conditions of each planting area [1]. The crop area that was traditionally homogeneously managed are now organized into several small areas, each section receiving the appropriate treatment in order to increase crop production [2,3]. Precision agriculture also requires the monitoring of natural and local resources of each growing area [4] in order to minimize the impact on the local environment and resources, and also to promote a sustainable food production [5]. For sufficiently large farms it is useful to use georeferencing information technologies to map the resources of each area [6].

Early developments in precision agriculture focused on collecting data on soil and local climatic conditions using vehicle-connected sensors (on tractors and harvesters which operate in field activities such as soil preparation, fertilizer application, harvesting, or by hand-operated portable devices,), or by satellite imagery. Data processing was carried out at defined time intervals that may no longer reflect the conditions of the soil or the crop at the moment of decision-making [7]. Although much of the data collection in the field are still carried out sporadically by vehicle-connected sensors, the necessity to control the use of agricultural inputs and to maximize the production using the minimum quantity of agricultural defensives, while at the same time not damage the environment in the productive area in real-time are key motivators for the development of technologies applied in the crops [8]. Recently there are several studies using drones [9] and a multitude of sensors connected to farm machinery to observe and measure the health of soil and crops during planting and harvesting [10,11]. The sensing technologies, the geographic information system (GIS) and GPS are important technologies to precision agriculture [12].

Current precision agriculture devices are expensive and typically require a high level of technical training to utilize and interpret the large array of information generated making it difficult for poor uneducated farmers to apply them to crops [13]. With the advancement of low-cost IoT devices the possibility to develop custom made devices that are simple, designed with a particular set of functionalities to reduce cost, and are situated within crops, make it easier for these farmers to adopt. This paper describes a real-time, in-situ agricultural IoT device designed to monitor the state of the soil and the local environment. This device was designed to be compatible with open hardware and is composed of sensors for temperature and humidity of both soil and the environment, electrical conductivity of the soil, luminosity, GPS and a Zigbee radio for data communication. Customized central software received data from all devices and automatically located each sensor on a map using GPS. The device is powered by solar collector which charges a battery that allows for continuous monitoring of the soil and also, to send data to the central software. The data is transmitted using open

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standard protocols which make it possible to integrate the data with any algorithm or third party platform or system.

II. IoT in Precision Agriculture

IoT devices enables network communication, data acquisition through sensors and actuators, and distributed processing in a low-cost hardware which operate for long periods of time using low-powered batteries [14]. Agriculture is one of the primary industries that have embraced IoT applications since wireless sensors networks composed of devices that can work in coordination to cover broad spatial areas. The advantages of collecting data to support decision making in real-time to control field devices (e.g. irrigation) enables the creation of a robust and fault tolerance system [15]. Several IoT devices have already been applied to agriculture settings to monitor soil conditions such as PH and humidity through a wireless sensor network (ZigBee for mesh network) or using cellular communication system's global system for mobile communications (General Packet Radio Service (GPRS). Such devices communicate with a system supported by web technologies and using open Application Programming Interfaces (API) or even third-party APIs to offer georeferencing services to support decision-making [7,16,17,18]. The proposed prototype (figure 1) was designed only with open hardware and open source software, and it could be built with usual components for prototyping. This study investigate whether such components could be organized in such architecture to be effective in precision agriculture.

Fig. 1. Monitoring node prototype

A. Parameters to monitoring

Soil health is an essential element to be monitored as unbalanced water and nutrients levels may compromise the quality of the crop [19]. In order to design an IoT device to monitor crops a number of essential parameters need to be considered. These can be categorized into four types of parameters: the visual, physical, chemical and biological. The visual parameters include changes of color of the soil, dust, water uptake or growing of weed that could be monitored by cameras or satellite images. Physical parameters include, among others, soil density, texture, humidity and soil temperature. Usually, such parameters are measured in the laboratory using several methods as described in [20] and [21]. Chemical parameters include pH, electrical conductivity and nutrients concentration usually measured in field or laboratory tests [21]. Biological parameters measure the presence of microorganisms and their influence on the soil quality are typically detected through laboratory testing. [22,23]. The prototype proposed in this paper will monitor two physical parameters (soil temperature and humidity), one chemical parameter (electrical conductivity) and three physical parameters (temperature, luminosity, and humidity). All parameters are sent to a web platform at regular intervals in order to analyze the data.

III. The proposed IoT Device

The proposed system is composed of three main components: monitoring node, central node, and the cloud. The monitoring nodes are installed in the several places in the field with sensors to monitor both soil and the environment. These nodes connect and send data to the central node using ZigBee network. The central node store data from all monitoring node and send them to the cloud through the internet. The central node in the cloud has a web-service with functions to receive data from the central node and recover data from database, among other functions.

All nodes has a solar panel to provide enough energy to make system working and also charge a rechargeable battery of supply output 2500mAH and 3,7V. For that the available solar panel had a supply output of 10W with 6V. All nodes also has a Raspberry Pi 3 model B with current drain between 5mA to 10mA and up to 750mW. The sensors used in this prototype are broadly available in several countries, which permits this system could be built in anyplace with the same hardware specification. The cost was taken into consideration and the chosen sensors provide accuracy measures and measurement range to provide useful data to several soil modelling used in agriculture.

B. Monitoring node

The monitoring node (figure 2) is composed of a Raspberry Pi that controls data acquisition and ZigBee communication between monitoring nodes and between monitoring node and central node (mesh network). The power source of the monitoring node is a solar panel that charges a battery designed to operate for several hours without the need to recharge. All sensors and GPS are connected in digital and analogic inputs in the Raspberry Pi shield and all software is written in NodeJS (open source). One sensor is used to measure all parameters of the soil with the specification in table I [24].

TABLE I. Soil sensor specification

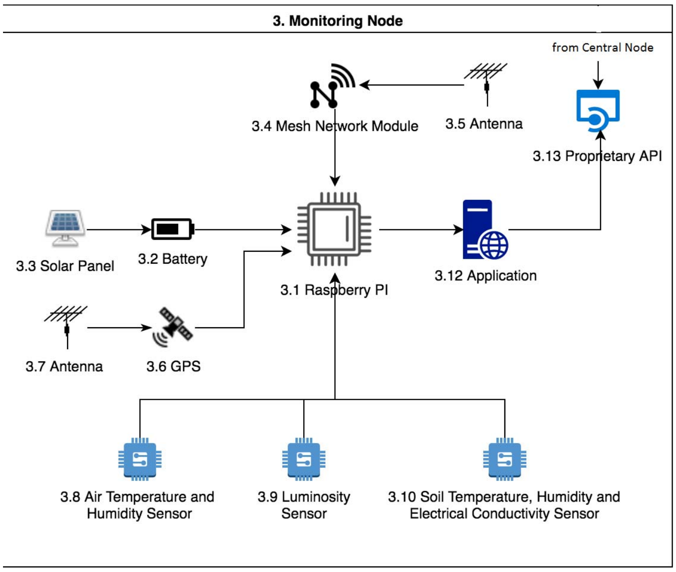
Measurements	Soil temperature, humidity, electric conductivity
Precision	Temperature: ± 1°C Volumetric water content (Topp equation): ± 0.03 m3/m3 Electric conductivity in mineral soil < 10dS/m Electric conductivity: ± 10% of 0 to 7 dS/m
Measure speed	150ms
Electrical Characteristics	Supply voltage: 3,6V Current drain (during measurements): 0,5mA - 10mA Current drain (while asleep): 0,03mA

The environmental temperature and humidity are measured for one sensor with the following specification (table II) [25]:

TABLE II. ENVIRONMENTAL SENSOR SPECIFICATION

Measurements	Air temperature and humidity
Range & Precision	Temperature: ± 0,5°C humidity: ± 2% RH temperature range: -40°C to 80°C
Measure speed	2s
Electrical Characteristics	Supply voltage: 3V to 5V Current drain (during measurements): 2,5mA Current drain (while asleep): not informed/measured

Fig. 2. Structure of the Monitoring node



The luminosity sensor measures the amount of light intensity in lux according to table III specification [26].

TABLE III. LUMINOSITY SENSOR SPECIFICATION

Measurements	luminosity
Precision	Lux: ± 1%
Measure speed	120ms

The ZigBee network interface has the specification depicted in table IV. This network interface was able to transmit 250kbps at 2,4Ghz in a distance of 100m without packet loss (although specification of outdoor rage is 90m).

C. Central Node

The central node (figure 3) was designed to be installed on the edge of the crop or even at the farm headquarter and its function is to collect data from monitoring nodes and store them in a local NoSQL database. This database is replicated to the cloud from time to time when the Central node has an available network communication with the cloud. The Central node also has a web interface to allow the farmer to check the system status and has information on the parameters collected from the crop. A Raspberry Pi controls the ZigBee communication between central node and the monitoring nodes, local information storage and the synchronization with the cloud.

TABLE IV. ZIGBEE INTERFACE SPECIFICATION

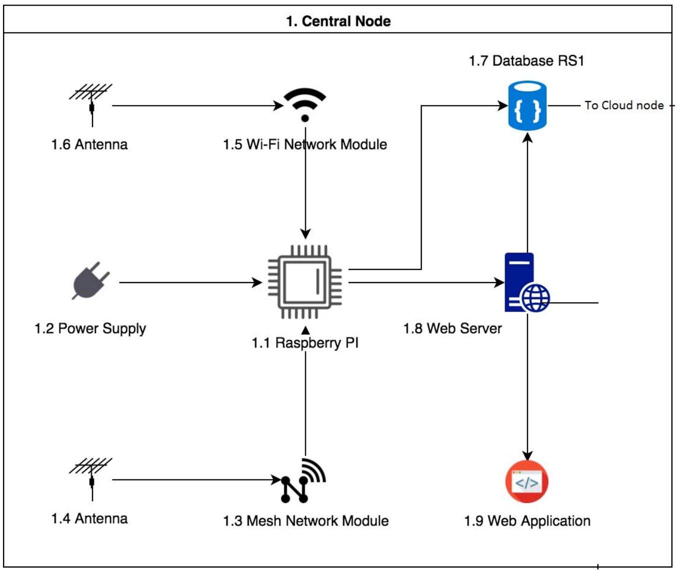
Radio Interface	Indoor range: up to 30m Outdoor range: up to 90m Transmit power output: 1mW (0dBm) Data rate: 250kbps at 2,4GHz
Electrical characteristics	Supply voltage: 2,8 to3,3V Transmit current: 50mA (@3,3V)

D. Node in the Cloud

The node in the cloud was designed with the same technologies of the other nodes. Its role is to organize all information from several central nodes and provide tools to data correlation. All data is stored in a NoSQL database for future application. An API developed for this prototype controls all data exchange, including an open data structure transported in a JSON (JavaScript Object Notation) message. The system has a Web Service interface that control the access to all system parameters. In case of any new sensor or parameter to be acquired, it is just necessary to include the method (software) in the Web Service interface and include a new structure in the database do store the new data/parameter. Such change does not imply in any modification in all other database structure, methods and JSON messages previously developed. The NoSQL database has an open source interface to allow access to data for decision making algorithms.

The relationship between all nodes of the proposed system is depicted in table V.

Fig. 3. Structure of the Central node



I. FIELD TRIALS

The field trial involved soil testing and measurements of the local climate in Sao Paulo, Brazil. The measurements of soil temperature, humidity and conductivity are used to monitor soil conditions. The local climate data could be used to support decisions about irrigation and other activities related to crop health.

TABLE V. RELATIONSHIP BETWEEN NODES

Monitoring Node	Central Node	Node in the Cloud
Data acquisition by sensors	Storage data from monitoring nodes	Storage data from central node via API
API do query data from sensors	-	-
Mesh network	Mesh network with nodes and WiFi to the internet	Internet communication
Local storage used when communication is lost with central node	Local storage in a NoSQL database	Global NoSQL storage from all central nodes in the farm. Interface to work with decision making algorithms
-	Web interface to monitor the status of the system and query data	Web interface to data manipulation

A. Sensors calibration

All sensors from the proposed device was verified to check whether their measures were correct compared to other measurements devices. The environmental sensors data was compared to a thermometer and a luximeter. The soil sensor was verified with a procedure described in its manual [24]. The table V presents data about sensors.

TABLE VI. SENSORS INITIAL MEASURES

	Monitoring device	Reference
Air temperature	23,5 ±0,5°C	23 ±0,5°C
Luminosity	179,17±0,8 lux	180± 1 lux
Soil temperature	26,4 ±1°C	24,8±0,5°C
Soil humidity	1.18 ±0,06 ε	1.12 ε
Electric Conductivity (air)	0mS/cm	0mS/cm

B. Measurements from the environment

The measurements was obtained during a 4 hour period on one day in São Bernardo do Campo (city in São Paulo neighborhood) and data obtained by the IoT device was compared with available data from two sources: (i) The CPTEC/INPE – Center for Weather Forecasting and Climate Studies; (ii) Weather Underground. The data from CPTEC/INPE was collected in the Mirante de Santana station (in São Paulo city – closest station from São Bernardo do Campo). From Weather Underground the data was collected from a station located in São Bernardo do Campo city. The IoT device is installed in an area close to a dam, and usually the air humidity is higher compared to other areas of the city.

The figure 4 presents the measured air temperature between 13:00 and 17:00 (GMT-3). The IoT device collected one measurement every four minutes.

The measured temperatures were compared to the average temperature of CPTEC/INPE and Weather Underground (table VI). The average temperatures from all sources indicates the similar temperature readings compared to the IoT device. Taking into consideration the standard deviation from sensor, the IoT device could offer to the farmer accurate measurements.

Fig. 4. Air temperature measures

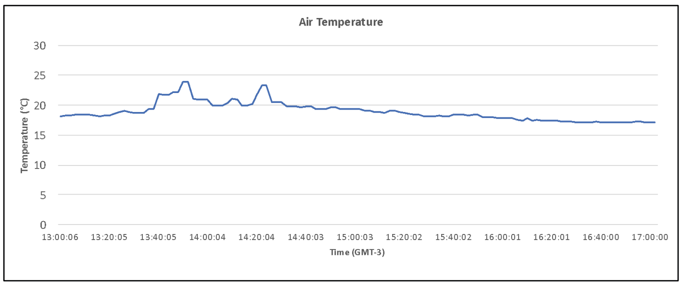


TABLE VII. AIR TEMPERATURE COMPARATION

Day (06/14/17)	Air Temperature - Average (°C)		
Time (GMT -3)	CPTEC/INPE	Weather Und	IoT Device
13:00	19	19	-----
14:00	19	19	19,75±0,5
15:00	19	19	20,6±0,5
16:00	19	19	18,53±0,5
17:00	17	17	17,3±0,5

However, the air humidity measured by IoT device was not the same compared to other sources (CPTEC/INPE did not offered such data) according to measurements presented in figure 5 and table VI.

Localised variations in the environment were observed on the day of the experiment which was cloudy and the wind was stronger after 14:00 (from 9,3km/h at 13:00 to 16,7km/h at 16:00), which probably brought humidity from dam compared to the Weather Underground station which is located close to downtown).

Fig. 5. Air humidity measures

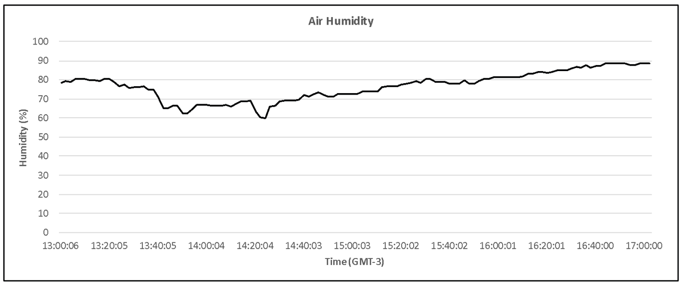


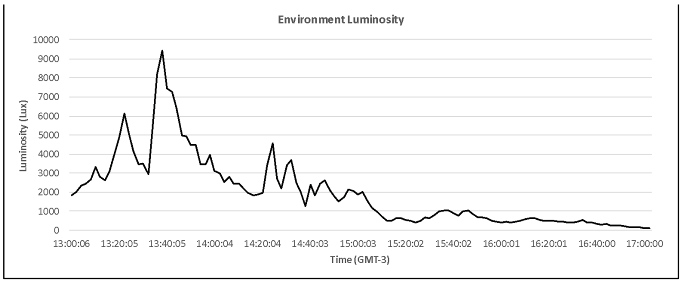
TABLE VIII. AIR HUMIDITY COMPARATION

Day (06/14/17)	Air Humidity - Average (%)		
Time (GMT -3)	CPTEC/INPE	Weather Und	IoT Device
13:00	-----	68%	-----
14:00	-----	73%	74%
15:00	-----	59%	68%
16:00	-----	68%	77%
17:00	-----	79%	85%

With a real-time information from IoT device compared to other information source a decision support system could do a better control of an irrigation system because it would estimate the influence of the humidity in the crop and in the soil.

The luminosity measurements (figure 6) indicates how much solar light the system detected during the tests. According to [27] June is a month with few natural lighting in the area when the system was evaluated compared to other areas in Brazil. Data from CPTEC/INPE indicates that the day of test was a cloudy day, with only some moments with sun. Although CPTEC/INPE did not offer measures about luxes per hours, it can be observed that the most luminous time of the day was in the morning up to 14:00, and after that the whether was cloudy again.

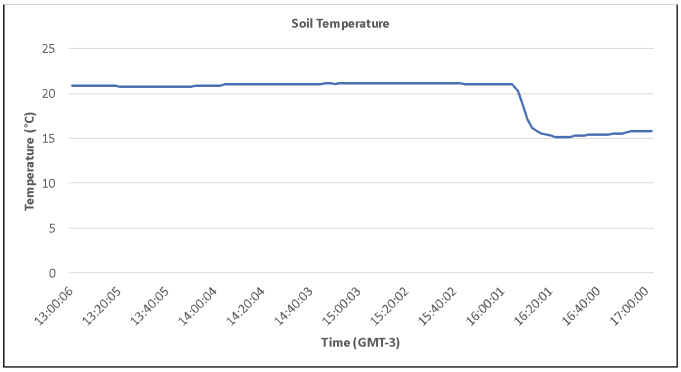
Fig. 6. Environment luminosity measures



C. *Measurements of the soil*

The sensor was initially installed in 10cm depth in a sample of dry soil of 40cm depth. The soil sample was stored in a covered area for two month without any addition of water. At 16:00 the irrigation process started and it was operating for five minutes. As it can be observed in figure 7 the soil temperature was stable before the irrigation process and it decreased during the process and it was stable after 20 minutes.

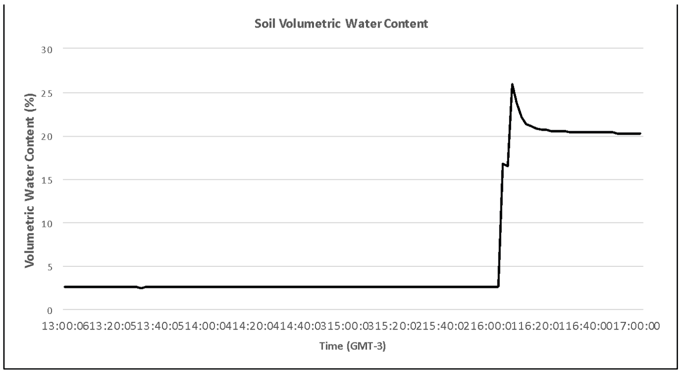
Fig. 7. Soil temperature measures



The figure 8 and 9 indicates that the volume of the water in the soil increased and the conductivity was higher as well. Although it is was not possible to check by other methods the accuracy of the equipment, the reading indicates that the sensor was working as expected according to the specification in [24].

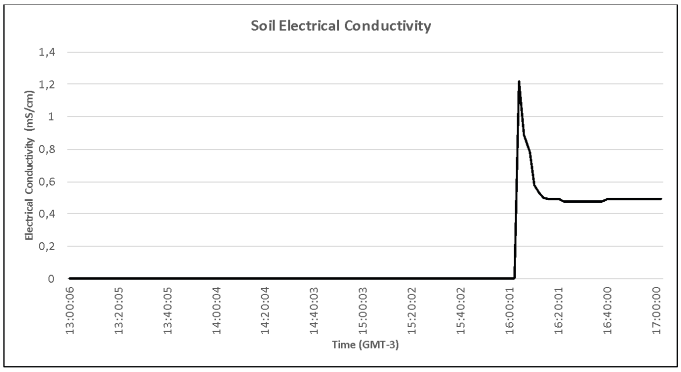
The measurements of figure 8 indicates that soil was dry (around 2.6% of the sample contained water) and 15 minutes after the process the soil volumetric water as stable in 20%. Given the stability of the measurement, this information could be used to model if such level of water is adequate for different type of crop.

Fig. 8. Soil volumetric water content measures



Data in figure 9 is consistent with all other measurements since the conductivity is directly related to the presence of water in the soil. Studies using the same sensor [28,29] present similar results. It could be observed that soil conductivity was around zero in dry soil and changed fast during irrigation process. The peak occurred when the water was concentrated near to the sensor and the measurement was stabilized when all soil was homogeneously wet, since the sensor was located in the middle of the sample. However, such measurements were not verified using methods such as TDR [30].

Fig. 9. Soil conductivity measures



D. *Tests with the battery*

The tests with the battery was done fully charging the battery and activating the IoT device without the solar panel. It was measured for how much time the system could operate without fail. When the measured volts and current in the system did not support the fully operation of the system, it was considered that battery was empty (for the purpose of IoT device). Table VIII indicates the system elapsed time of a typical test.

TABLE IX. BATTERY DURATION

System status	Time
System activation (battery fully charged)	day 1: 18:34 and 53 sec
System deactivation (battery empty)	day 3: 08:27 and 12 sec
System elapsed time	37 hours, 52 minutes and 19 seconds

II. CONCLUDING REMARKS

We have presented a preliminary field experiment of an IoT device for farmers in Brazil. Sensors detected water irrigation processes and the data was transmitted to a central node and then to the cloud. The initial evaluation indicate that the proposed IoT device could detect measurements close to the professional measurement devices and could react to changes in the environment and the soil, using open hardware and prototyping hardware and software developed with open source API. On-going research includes more experiments, methods to reduce the consumption of energy, increase the number of sensors and validation of the results using other calibrated sensors. Soil humidity and electrical conductivity will be evaluated with several kind of soil samples that are used in crops in São Paulo State, and results will be compared to other measurements procedures and techniques. The local climate data could be used to support decisions on irrigation and other activities related to crop health. Future applications include the use of the IoT device to detect fire in crops, a common problem in sugar cane crops and the integration of the IoT device with irrigation management systems to improve water usage.

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