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INTEGRATING SOIL PH MEASUREMENT INTO AN INTERNET OF THINGS APPLICATION

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Abstract

The paper presents a device for soil pH determination on-site and remote transmission of the result. Soil pH is an indicator of the soil quality because it affects plant growing. Normally, soil samples are taken from the field and tested in-door in aqueous solutions using ISO 10390: 2005 specification. However, it was an increasing demand for on-site measurements materialized in a plethora of stand-alone devices. Most of them offer a narrow range of pH values, e.g. 3 to 8, because the majority of plants has an optimum range between 5.5 and 7.5. The Internet of Things exigencies have led to design a node of multiple sensors including soil pH measurement with an increased precision. Therefore, it was used a sensor for hydrogen ion activity measurement based on glass membrane as a junction between the soil solution and a reference solution. The probe was calibrated using pH known solutions and then tested on different soil samples - all data being remotely collected. The results emphasized the capability of the device to measure the soil pH on-site and to send it to remote.

Key words: *environmental monitoring, internet of things, precision agriculture, soil pH, wireless communication.*

INTRODUCTION

Precision agriculture and Agriculture 4.0 concepts imply, among other things, more data to the farmer. These require a lot of sensors that will generate information. One of the most important parameters is soil pH. As known, soil pH can change during the year due to rainfall, quality of the water used in irrigation, fertilizers, pesticides, root respiration and decomposition of organic matter by microorganisms. Also, soil pH depends on temperature and moisture conditions and can vary to with the soil depth. Temperature changes the chemical activity of the hydrogen ions (H^+), so the measurements of pH must include the temperature correction to a standard temperature of 25°C. The whole variation of a soil can vary up to a unit of pH within a year, which is quite a lot, since, for example pH 6.4 is a slightly acidic soil, while pH 7.4 is a slightly alkaline one. Therefore, the information must arrive in time to the farmer in order to take corrective measures.

Currently, soil pH determination is done in laboratories on samples of mixed soil in an aqueous solution; although very accurate, the method is costly, takes time, and the distance from authorized laboratories which could be several tens of kilometers reach a price that farmers will not pay. It is an increased demand for a competitive solution for continuously soil pH monitoring from remote. Practical solutions have emerged on the market based on indicators, colorimeters or different types of electrodes sensitive to H^+ activity (Plotog et al., 2016), but the lack of these methods is that data is available randomly and it is eventually inserted manually in a database. The accuracy of these cheap devices is poor.

As the Internet of Things (IoT) technology emerges, all sensors are required to be automatically controlled from the distance and integrated in environmental monitoring systems. There are mentioned remote sensing (RS) methods based on bare-soil images and spectroscopic reflectance of soil samples for soil survey, mapping, and quantitative soil-property characterization (Yufeng et al., 2011), one work claiming that for pH, the soil map and the RS estimate were nearly as accurate (Roelofsen et al., 2015). The methods, which imply satellite and aerial imagery or other non-contact nature of measurement, are costly.

There are mentioned real time and maped-based approaches using vehicle-based on-the-go soil sensors for measuring soil properties including electromagnetic and even electrochemical sensors for pH determination (Adamchuk et al., 1999). Another work states that automated soil sampling system could be used to estimate soil pH on-the-go (Adamchuk et al., 1999). The data can be sent to a remote center through the vehicle communication station. The disadvantages of the method: the values could not be as accurate as a laboratory test, the vehicle could not access any place and the data is available discontinuously.

In this context, the paper presents the way the authors have solved the objectives they have proposed: in-field soil pH determination with incresed accuracy and the reception of data at a remote center using wireless communication technology.

The pH sensing is part of a more complex device for monitoring environmental parameters such as air (temperature, relative humidity, harmful substance concentration, wind speed and direction), soil (temperature, relative humidity, pH, macronutrient content) and lighting level. The goal was to build an automatic system dedicated to coordinate and streamline all resources and factors involved in optimizing agricultural crops.

MATERIALS AND METHODS

In order to meet the proposed objectives it was designed an electronic module which interface a pH sensor to a microcontroller to read the data and to send it to remote by means of a radio-frequency (RF) block (Figure 1). This approach allowed to implement a complete IoT application for agriculture. Since the main requirement for an IoT application is the low power, the circuitry was designed around a low power 8-bit AVR RISC-based microcontroller, ATmega2560, Microchip Technology. Generally, the largest power consumption in an IoT application is the RF block, therefore, it was selected the long-range low-power technology wireless platform that is the top technology choice for building IoT networks, LoRa. In addition, it uses a license-free spectrum.

The pH probe was a silver/silver chloride sensor, Atlas Scientific LLC, which can measure pH of solutions in the range 0-14 with the resolution +/- 0.0001 (Device #1). It has been chosen this type of sensor because the manufacturer states that the pH probe may have in the soil indefinite placement. The life expectancy of the probe is more than 2.5 years without maintenance.

The Signal conditioning block adapts the analog signal from the output of the pH sensor into a digital signal to be applied to any microprocessor that supports UART, or I2C protocol.

The power supply block assures the voltages for the electronic circuits from a solar cell panel and a rechargeable battery.

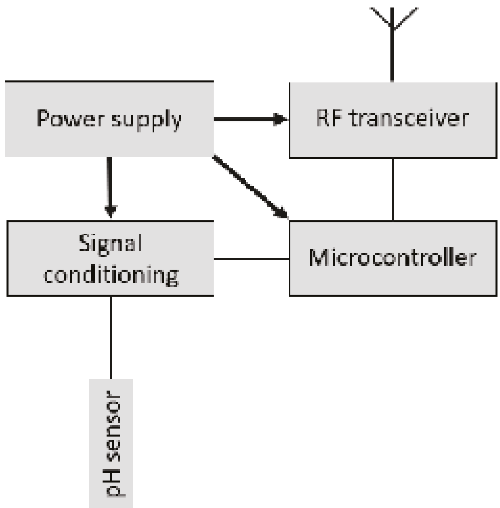

Figure 1. The block diagram of the electronic module for in-filed pH measurement and data transmission to remote

On the reception side of the data it has to be used a Wi-Fi gateway connected to a laptop to store and process the information.

The goal of the experiment was to collect the data regarding the soil pH from a remote center in real time and to analyze the accuracy of the measurement.

The soil pH determination shall be compared with the measurements made by other devices:

I) EC500, a pH - Conductivity meter from the EC510 kit, Extech Instruments/FLIR Systems, which has a pH range between 0.00 to 14.00, as benchmark ((Device #2);

II) A cheap 3-in-1 moisture meter with light and pH test function for gardening, which offer a pH range between 3.5 to 8, Shenzhen Xing Ying Da Industry Co (Device #3).

Before starting the experiments the pH sensor was calibrated. The measurements were performed in the laboratory area on flower soil mixed with water at room temperature (25°C). According to the manufacturer's recommendations the measurement of the soil pH should be preformed with a delay of 25 minutes after the immersion in the mud.
In the Figures 2 and 3 there are presented the pH devices used for comparision.

Figure 2. EC510 conductivity testing kit including: EC500 meter, 3 calibration standards, 3 pH buffer pouches plus rinse solution

Figure 3. 3-in-1 plant flowers soil tester pH tester/ moisture meter/light meter

The experiments were performed in the laboratory of the company; the temperature was around 25°C ± 3°C.
Since the rezult of the measurements performed with the Device #1 are available only on a remote display where the data can be stored and processed, while the other two devices needed a local operator for readings, the following method was proposed:
- three equal amount of aqueous solutions were prepared and measured with all three types of pH meters; each solution had a different pH covering most of its scale: acidic, neutral and alkaline;
- three equal amount of mixed soil and aqueous solution were prepared and measured with all three pH meters;
- it is supposed that samples equal amount of the same soil mixed with three different aqueous solutions change their properties regardless the measuring instrument;
- the recorded data from the Device #1 will be analyzed and discussed.
The following three solutions were prepared: alkaline (pH 13.2 on both devices, ALKALINE indication on Device #3), approximately neutral using running water (pH 7.82, pH 7.88 and slightly over 7 on Device #3) and acidic (pH 4.5 on both devices, 7 on Device #3).
The solutions were poured into equal pots with soil and the devices were infiltrated into the created mud. The automatic reading period of the pH values for the Device #1 was set to 10 minutes; at the same time the values of the other devices were noticed by an operator.

RESULTS AND DISCUSSIONS

The data from the pH sensor could be read on the monitor of a laptop (Figure 4). The pH sensor and the laptop were placed in two different rooms of the company.

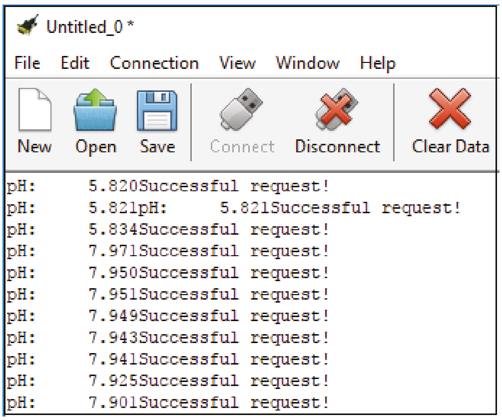

Figure 4. An extract from the print screen on the laptop monitor

This prove the main parts of the designed electronic module - microcontroller and LoRa transmission - work correctly.
The interconnection between the computer and the pH sensor device offer the possibility to

transmit several commands: the period of continuous readings, the single reading mode, start/stop of readings in order to save power, mathematical compensation of pH readings with temperature.

The results for neutral domain are displaying a slow variation for Devices #1 and #2, while Device #3 shows always a value between 7 and 8 (Table 1).

Table 1. Determination of soil pH with three different devices for neutral domain

Time [min.]	Soil pH		
	Device #1	Device #2	Device #3
0	6.939	7.27	7 - 8
10	6.960	7.20	7 - 8
20	6.958	7.22	7 - 8
30	6.945	7.14	7 - 8
40	6.942	7.16	7 - 8
50	6.958	7.08	7 - 8
60	6.864	7.07	7 - 8
70	6.849	7.01	7 - 8
80	6.850	7.03	7 - 8
90	6.850	7.02	7 - 8
100	6.855	7.01	7 - 8
110	6.854	7.12	7 - 8

Their graphical representation is presented in Figure 5. The measurements performed with the EC500 meter have a greater margin of variation when it is immersed in the mud. The difference between the maximum and the minimum values of soil pH is 0.260 while for the Device #1 is 0.111. However, this is an improper use of the probe it has to be used only for aqueous solutions.

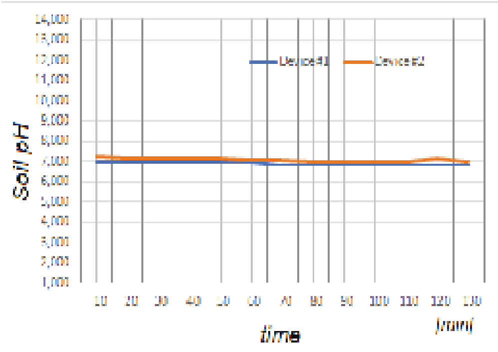

Figure 5. Graphical representation of soil pH measurement for near neutral domain

For both very strongly alkaline solution and the moderately acidic solution the measurements have shown that the soil pH has decreasing values. The Device #3 indications were ALKALINE for the first case and 7 for acidic. A graphical representation of the cumulative measurements using the Device #1 is presented in Figure 6. The measurements were performed during a period of more than 3.5 hours. The slowly decreasing trend of the measurements is due to the gravitational leakage of the water from the created solution into the soil. This is a situation that is also encountered in practice.

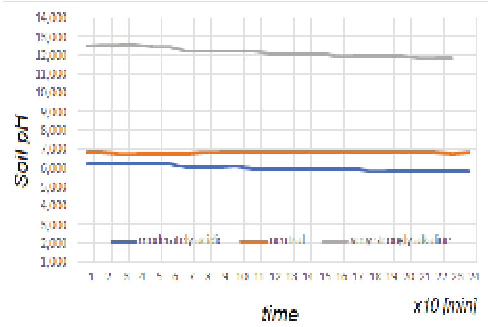

Figure 6. Graphical representation of soil pH cumulative measurements for Device #1

It is supposed that during the laboratory tests the pH values will tend to fixed value due to the limitation of the container with the soil.

In order to test the repeatability of measurements it was recorded the variation of the pH values received from the Device #1 during a longer period. As it can be seen in the Figure 7, during 9 hours the soil pH values were practically constant. It is a real situation because the solution was almost neutral and during the period of test the conditions in the laboratory were unchanged and no other material was added.

The lack of extremely values proves the high quality of the pH sensor.

Although it is supposed that the pH sensor will stay in the soil much longer time than tested above, in order to make correct determinations it will be created around it a mixed solution using pure water (pH 7) every time when desired.

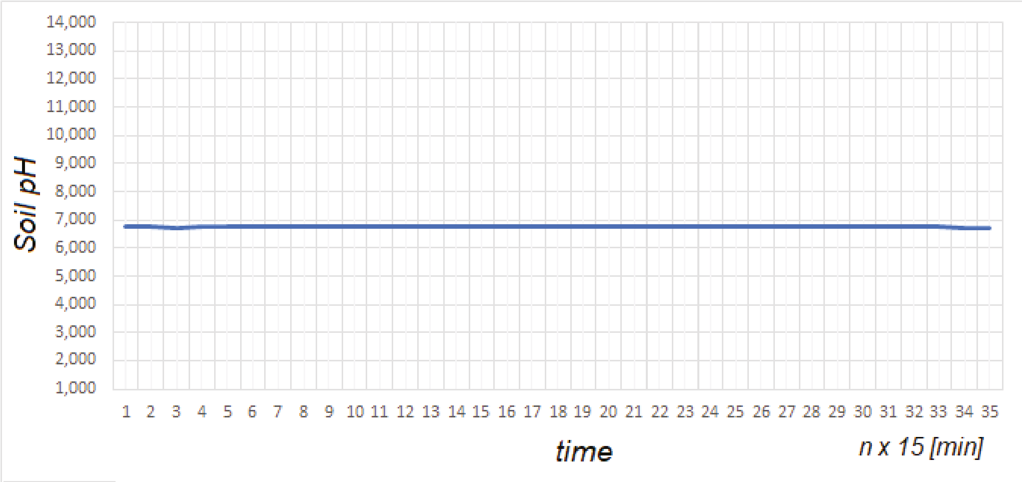

Figure 7. The graphical representation of pH measurement performed with Device #1 during 9 hours

The practical implementation of the pH measurement and the remote transmission of the data is presented in Figure 8.

Figure 8. View of the multi sensors device with autonomous energy and wireless communication including soil pH measurement

CONCLUSIONS

In-field soil pH determination and remote transmission of the values in real time was proved.
The data can be stored and processed on a computer placed anywhere in the cloud.
The numerical values of the pH measured by the proposed device were similar compared to a standard pH instrument for different aqueous solutions. The extrapolation of the measure-ments to the soil mixed with water has to be confirmed by a specialized laboratory.
The pH sensor device could be programmed to enter single reading mode, standby mode and multiple readings with different periods of readings.
The measurements using inexpensive 3-in-1 device did not prove to be realistic.
The designed pH device can be interconnected to other systems for parameter monitoring in agriculture that have UART or I2C protocol capability.

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