Optical sensor based soil nutrients and pH level measurement system

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A pH and major soil nutrients (namely, nitrogen, potassium and phosphorous) measurement system based on optical sensing has been designed and constructed. By illuminating white light on the water solution of the soil sample added with certain reagents the optical sensor detects the color of the solution. The detected color, which appears as voltage signal, is compared with stored database and upon further processing the microcontroller calculates the level of pH and amount of nitrogen, potassium and phosphorous of the soil. The system has been thoroughly tested using different varieties of soil samples and comparing the measurements against the measurements from existing techniques used by the soil scientists. The difference of measurement is extremely small which is perfectly acceptable for agricultural applications. The digitized measured data can be displayed or sent to the computer for further processing and storage.

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1. Introduction

With the continuously booming population in limited arable land area, for many agro-based and densely populated countries like India, Bangladesh etc the way to move forward is to devise innovative technologies for agriculture. This work focuses on the application of information and communication technology (ICT) in the agricultural sector. Information and communication technology has got tremendous thrust recently and it is the time to work on its application in agriculture to accrue the benefits from its recent advancements. Although we have entered into the information era there seem to be very scarce or no existence of digital records relating to soil in many developing countries. Making measurements of soil nutrients and pH level in different parts of the country over long period of time and keeping these data in computer storage are important not only for agriculture but also for environmental and other studies.

Knowing the pH level and amount of major nutrients of the soil i.e. nitrogen, potassium and phosphorous is highly important for agriculture and plantation. Without such knowledge, proper care of the soil and appropriate application of the fertilizer are not possible which can result in less production or damage to the soil fertility [1]. According to the farming management concept of precision agriculture, various parameters on which crop growth is related to, such as, the soil nutrients, water consumption, humidity, air temperature etc are measured in order to optimize the growth environment of crops [2–5]. Meanwhile, different techniques mainly based on basic electro-chemical methods have been proposed for measuring the concentration of nutrition elements in soil. For example, by measuring the changes in the conductivity of soil samples [6-7] measured some major elements of soil nutrients while [8] used colorimetric process to make these measurements. Reference [9] introduced a fiber optic sensor based soil nutrients measurement system while a fiber optic pH meter based on colorometric principle was presented in reference [10]. Soil chemical properties were measured by using ion-selective electrodes in [11-12] while in [13] micro fluidic detection of nitrate ion was performed using electro-chemical foam electrodes. More detailed description of other techniques to measure the concentrations of both common elements and rare elements has been given in [14-15]. However, most detectors mentioned above are limited to large-volume sensors, complex chemical detection methods or experimental conditions. Also many of these measurement systems lack appropriate interfacing to the computers which is essential for further processing and storage of the measured data.

In this work we developed and constructed an optical sensor based soil nutrient and pH level measurement system which can be integrated to the computer system. The measured data can be displayed and can also be sent to the computer for further processing and storage. We validate the correctness of this newly designed system by comparing against the existing measurement system. With such soil nutrients and pH level measurement system it is possible to systematically keep the records of nutrients and pH level of soils of different areas and over very long period of time which will be useful for research on agriculture and environment.

2. Optical sensor based soil nutrients and pH measurement system

2.1. Design of the system

We have designed and developed a smart soil nutrients and pH level measurement system with broad range of features. The system is based on colorimetric as well as optical principles. In the water solution of the soil sample certain chemical agents are added. By illuminating white light the color of this solution is detected by optical sensors and then by calibration and further processing amount of nutrients and pH level of the soil are obtained. The system has the ability to store the measured data as well as to display it. Design of the measurement system is shown in block diagram in Fig. 1.

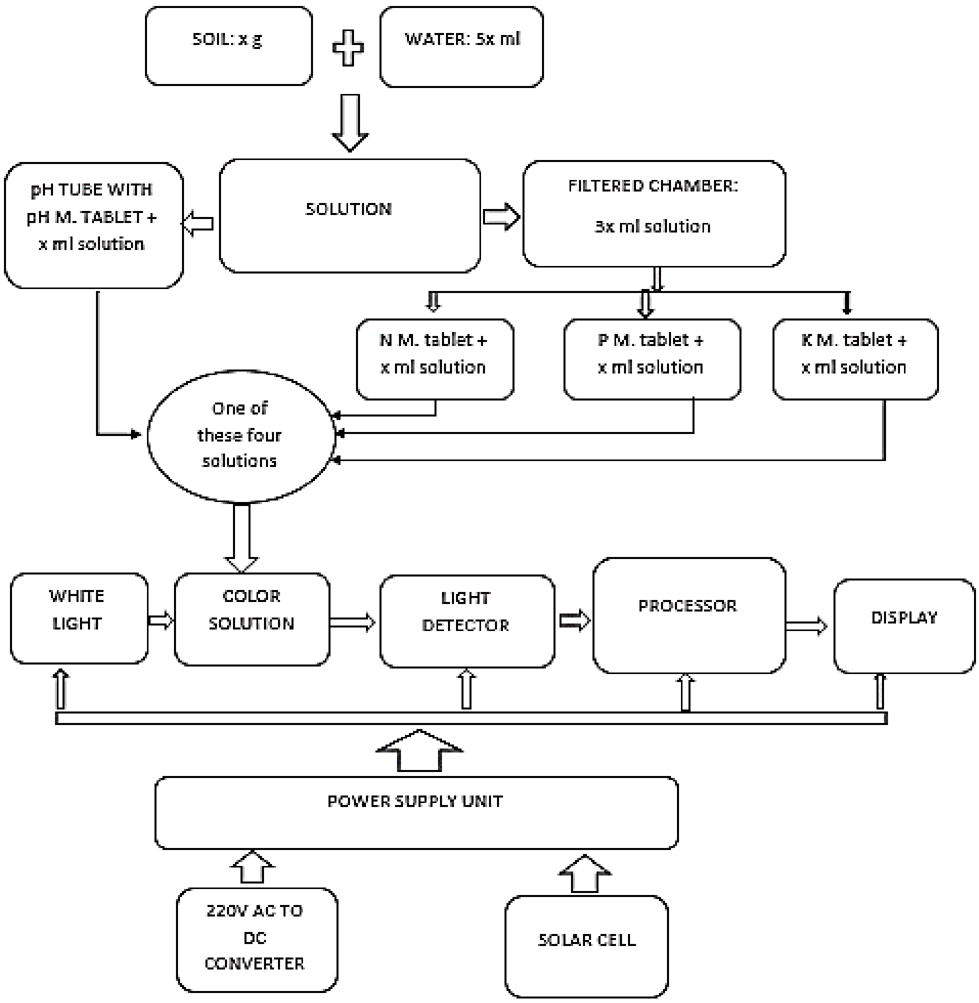

Fig. 1. Block diagram of the designed measurement system

2.2. Hardware implementation

Based on the above design the optical sensor based soil nutrients and pH level measurement system was constructed in hardware. The whole hardware implementation can be subdivided into several constituent units. A solar power charger is used to charge the battery using solar power in case no AC power supply is available as is mostly the case in the field in developing countries. The power supply and control unit (Fig. 2) holds the solar charger, transformer, AC to DC converter, microcontroller and storage battery. This is the main control unit for the electrical part of the system. The AC to DC power supply unit delivers DC power to charge the lead acid battery. In the soil solution preparation unit the soil sample is mixed with water. A rotator driven by dc motor provides the mechanical rotation to prepare soil solution properly. The prepared soil solution is stored in a small storage and then five control switches control the flow of solution in different tubes of the measurement system. Separate tubes are used for pH, nitrogen, phosphorus and potassium. Separated in different tubes the soil solution is then mixed with reagents. Appropriate reagents from commercial soil testing kits are used for measuring pH, nitrogen, phosphorous and potassium. We used Rapitest soil testing kit (Luster Leaf, USA) which includes the reagent for nitrogen that follows Ned method for the measurement, reagent for phosphorus that follows the ascorbic acid method and reagent for potassium that follow the tetraphenylborate method. A dc motor helps to mix the solution completely. An optical sensing unit containing RGB color sensors (Brand: DFRobot, China, Model No. TCS3200) is used in the system. The sensor detects the light of the color tube which is illuminated by a white light and provides light to frequency conversion. A microcontroller is used to do the calibration and other processing and an LCD display shows the measurements. The front view of the overall measurement system is shown in Fig. 3.

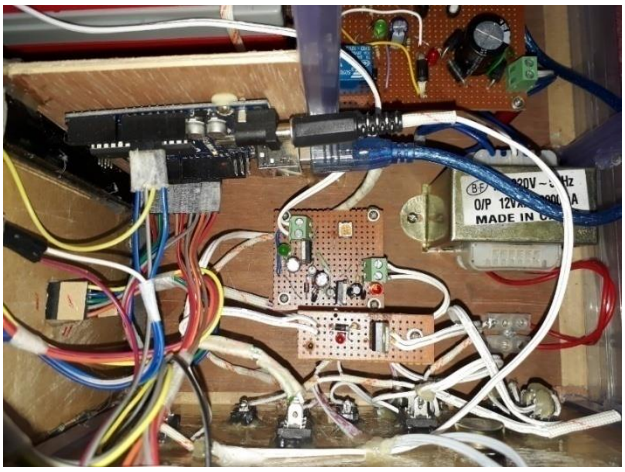

Fig. 2. The power supply and control unit

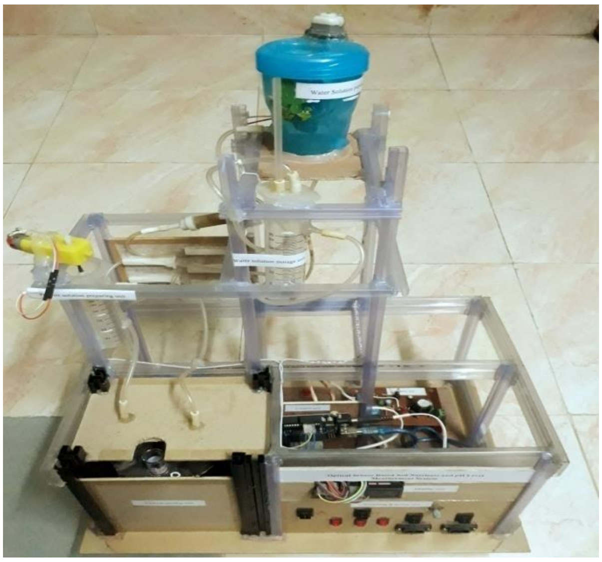

Fig. 3. The overall system

3. Measurement methodology

Function of the designed system to measure pH level and amount of nutrients of a soil sample is described here. *X* gram of soil sample is dissolved in *5X* ml distilled water and a solution is prepared. From this solution *5X/4* ml is taken in the pH tube and *5X/4* ml is taken in each of the nitrogen, phosphorous, potassium tube. The chemical reagent from the soil testing kit is mixed in pH tube and the tube is rotated for 5 minutes. Same procedure is repeated for nitrogen, phosphorous and potassium except that different types of reagents are used for each case. After a while a clear solution is obtained which will ultimately result in different colors which is detected by the RGB color sensor. The sensor outputs provide different frequencies for different colors which are given in Table 1. Different colors correspond to different levels of pH and different amount of nitrogen, potassium and phosphorous. Among different sensors green color sensor provides almost linear output for the color intensity variation. Therefore green color sensor values are adopted here. Appropriate calibration by polynomial curve-fitting is performed to get the values of pH and soil nutrients.

Table 1. Output of the sensors for different colors

Color	Red sensor output (Hz)	Green sensor output (Hz)	Blue sensor output (Hz)
Orange	54	128	112
Red	137	212	155
Blue	182	123	62
Bluish green	150	116	144
Violet	188	161	254
Green	183	154	241
Yellow	283	176	274

Curve fitting for pH level

$$b=-0.0216*c+10.2252 \quad (1)$$

where *c* is the green color sensor output, *b* is the pH level. The fitted curve for the pH level measurement is shown in Fig. 4.

Curve fitting for nitrogen level

$$l=2.2229*c-358.2277 \quad (2)$$

where *c* is the green color sensor output and *l* is the level of nitrogen measured in ppm.

Curve fitting for phosphorous level

$$m=-0.4025*c+104.9489 \quad (3)$$

where *c* is the green color sensor output and *m* is the level of phosphorous measured in ppm.

Curve fitting for potassium level

$$n=1.6576*c-197.7132 \quad (4)$$

where *c* is the green color sensor output and *n* is the level of potassium measured in ppm.

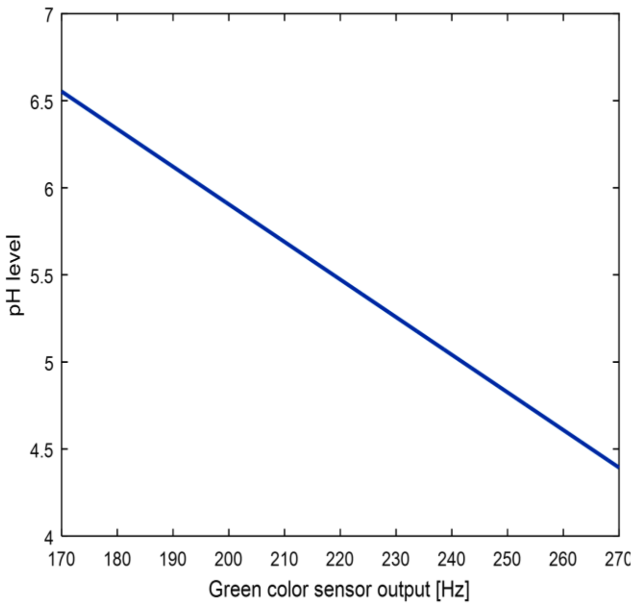

Fig. 4. pH measurement curve

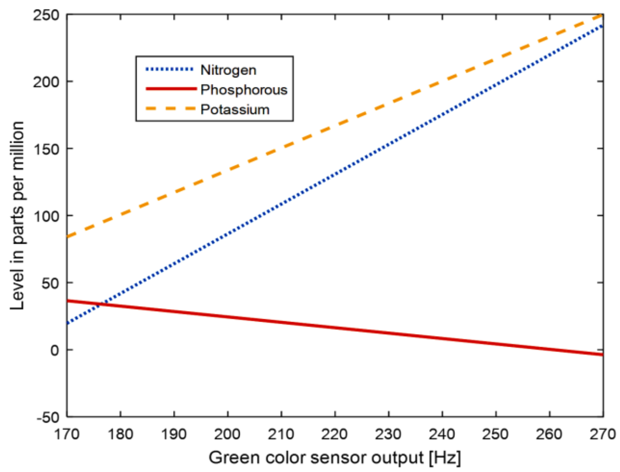

Fig. 5. N-P-K measurement curves

The fitted curves for the nitrogen, phosphorous and potassium measurements are shown in Fig. 5. The microcontroller does these calibrations and calculates pH level and nutrients as functions of sensor outputs. Finally the measured values are shown in the display.

4. Validation of the measurements

The system has been thoroughly tested by measuring the pH level and soil nutrients of different soil samples. To validate we have measured the pH level and soil nutrients of three soil samples using the newly designed system. Then we compared these against the measurements using the existing technique which is commonly used by soil testing professionals. These two measurements are then compared and percentages of error have been calculated. Table-II shows pH levels of the three soil samples by using the optical sensor based measurement system.

For the same soil samples pH levels were also measured in existing technique and percentages of errors of measurements were calculated and shown in Table 2. The range of percentage of error of measurement is 1.82%~2.51%. For agricultural applications such small difference of measurement is acceptable.

Table 2. Comparison of measurements: pH level in soil sample

Soil sample	pH level measured by the designed system	pH level measured in existing technique	Percentage of error
1	6.60	6.77	2.51
2	7.24	7.44	2.69
3	5.95	6.06	1.82

The amounts of nitrogen in soil samples measured using the newly designed system are shown in Table 3. In contrast for the same samples the nitrogen amounts using the existing measurement technique are also shown. Percentage of error of measurement is as low as 1.78% for one of the samples. Since the measurement unit is in terms of one part per million (ppm) such very small difference of measurement is acceptable.

Table 3. Comparison of measurements: amount of nitrogen in soil samples

Soil sample	Amount of N (in ppm) measured by the designed system	Amount of N (in ppm) measured in existing technique	Percentage of error
1	93.35	97.20	3.96
2	60.12	58.21	3.28
3	110.02	108.1	1.78

In the same way amounts of phosphorous and potassium in the soil samples were measured by using the newly designed system and in the existing measurement technique. These are shown in Tables 4 and 5, respectively. Percentages of errors of measurements are also shown in these tables. As before, all the measurements are shown in parts per million (ppm) unit. For agricultural applications the small differences of measurements as shown are acceptable. The measurement system is capable of indicating the amount of nutrients from traces to high quantities. We calculate the pH level and nutrients levels detection range for extreme and moderate green color sensor outputs. For pH level the detection range is 4 to 9.5 and for nitrogen, phosphorous and potassium the detection ranges are 20 - 300 ppm, 60 - 350 ppm and 2 - 120 ppm, respectively. One of the limitations of the system is that it needs to be kept away from direct strong light sources as the ambient light affects the light sensor output. Also the measurement should be performed immediately after preparing the solution so that no sediment is formed.

Table 4. Comparison of measurements: amount of phosphorous in soil samples

Soil sample	Amount of P (in ppm) measured by the designed system	Amount of P (in ppm) measured in existing technique	Percentage of error
1	134.39	130.72	2.8
2	150.91	152.43	1
3	178.80	176.22	1.46

Table 5. Comparison of measurements: amount of potassium in soil samples

Soil sample	Amount of K (in ppm) measured by the designed system	Amount of K (in ppm) measured in existing technique	Percentage of error
1	24.46	25.95	1.95
2	32.49	30.46	3.39
3	28.47	29.40	3.15

5. Conclusion and discussion

We have designed and constructed an optical sensor based soil nutrients and pH level measurement system. When compared with the existing measurement system the amount of difference of the measurement was found minimal. From agriculture and plantation point of view such small variation has no impact and is absolutely acceptable. Therefore we validate the correctness of the newly designed measurement system. The biggest advantage of this system is its ability to digitize the measured data. The measured data can be displayed and can also be sent to the computer for further processing and storage. By this kind of digitization we will be able to observe how the soil is qualitatively changed in different seasons, after growing certain crops, after any natural calamity or over very long period of time. Information on the impact of surrounding environment (e.g. presence of industry), cultivation of certain crops and global climate change on the qualitative change of the soil will be valuable for future research on agriculture and environment.

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