Test Implementation of a Sensor Device for Measuring Soil Macronutrients

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***Abstract*—Continuous cropping without adequate measurement and provisioning of soil nutrient may endanger the sustainability of agriculture. Soil nutrient measurement is greatly required for proper plant growth and effective fertilization. Existing methods of soil testing are costly and time consuming. In this paper, we have developed a sensing system using high precision, wide spectral range Photo Diode (PD), low spectral-width Light Emitting Diode (LED), microcontroller, analog-to-digital converter (ADC) for measuring soil macronutrients. We have integrated a GPRS modem with our sensing unit for remote data collection to a server. A cell of 5.5 mm path length is used to contain soil solutions. The resolution of 0.1-20 mg/100g has been used as standard solution. The test samples are taken from different farmlands and the results are compared with those obtained by a color chart judgement after laboratory analysis. The results found from our proposed system has good level of agreement with the laboratory results.**

I. Introduction

Production of a crop depends on the interaction between the soil and plant properties. Maximization of production of crops is reflected by the biological, chemical and physical condition of the soil. Root absorbs required amount of nutrients and water from the soil where biochemical reactions take place. Plants rate of nutrient absorption depends on the minerals available in the soil. Production of crop degrades with the insufficient rate of supply of any necessary nutrients. Although the requirement of a particular nutrient is determined by the plant growing in the soil, some of the nutrients are necessary for almost all the plants in great amount known as Macro moles or Macronutrients [1].

Root environment of the plant can be changed by supplying nutrients outside the soil which is commonly known as fertilization. However, proper distribution of fertilizer is necessary for the proper crop production. Over and under provisioning of fertilizer can greatly reduce the harvest production rate. Traditional fertilization system in Bangladesh relies on farmers experience in cultivation and weather condition. This type of manual fertilization without proper justification of soil condition is error prone. Again control of soil environment is also necessary for preventing ground water pollution. To get the correct amount of nutrients to be provided and to choose the right crop for multiple cropping in the same land, we need to measure the actual amount of nutrients present in the soil [2], [3].

The most common method used for soil nutrient measurement is based on usage of color-developing chemicals [4],[5]. To analyze the soil component, chemical reagents are used which produce specific color reacting with particular type of nutrients. Then the degree of presence of that nutrient is measured by estimating against a color chart where value for a particular degree of darkness or color-depth is given. Since this judgment is done manually by the tester, the value always fluctuates and accurate quantitative analysis is not possible by this method. To investigate the developed color solutions a spectrophotometer can be used. However, the system using spectrophotometer is complex, needs expert operator, and the price is not within the reach of common people [6].

In this paper, we have developed a sensing unit for measuring soil macronutrients using Photo Diode (PD), Light Emitting Diode (LED), Microcontroller, AD converter, GPRS modem etc. LEDs are used as light source. Light rays form LEDs are passed through the soil solution prepared by the chemical reaction of reagents with soil nutrients. Degree of presence of any nutrient can be measured by the deepness of the color of the prepared soil solutions. PD collects the light beams passed through the solution which can be used to calculate the presence scale of the nutrients.

We have designed a system which accommodates the sensing hardware (includes LEDs, PD and cell assembly) and the control and communication interface. The values are measured in Vdc (voltage level) by the sensing hardware converted to volumetric units to measure macronutrients. We have made a chamber where plastic cubic cells containing soil solution can be placed by the farmers. No prerequisite knowledge and expertise is required.

The rest of the paper is organized as follows. The Section II describes some of state-of-the-art works related to our topic of interest. In section III, architecture of our pro-

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posed circuit containing sensors and modem is described. In section IV, work flow of our proposed sensing system is addressed in details. In section V, the comparison between laboratory result and our obtained result calculated from sensors reading is shown. In section VI, conclusion along with the direction for future research have been provided.

II. Related Work

Precision agriculture can be defined as - the improvement of crop performance and environmental quality by applying technologies and agronomic principles for managing spatial and temporal variability associated with all aspects of agricultural production. Precision agriculture focuses to the optimization of the field level management. It aims to solve problems that can be categorized into 3 groups: *Crop science*, *Environmental protection*, and *Economics*. Precision agriculture helps in dissemination of gathered information to the farmers, mostly living in rural areas, that can be applied in their crop production methodologies and the policy makers to plan long-term priorities [7].

For achieving sustainable agriculture maintaining and for minimizing any country's economic losses and environmental impacts, proper management of essential soil nutrients play a vital role [8]. Technology plays an expedient role for the improvement of environment and for achieving the economic goals. Precision Agriculture (PA) - based geospatial technologies, such as global positioning system, geographical information system, remote sensing, geo-statistics and variable rate applications can be used for obtaining efficient nutrient management in crop fields [9]. To optimize fertilizer use efficiency by overcoming the problem of over and under fertilization, variable rate fertilizer application, one of the basic tenets of PA has been shown in [10]. This technology is mainly used for increasing the crop production and crop quality as well as to reduce resource wastage and promote stewardship of the environment. Soil productivity, spatial and temporal variability in crop is mainly influenced by both intrinsic and extrinsic factors. In intrinsic factor, soil forming factors such as parent material, climate, topography and time are mainly included. In extrinsic factors, farm management practices and maintenance operations are mainly included [11]. Generally the soil property varies a lot with respect to space and time. The distribution of soil nutrients is mainly affected by natural condition, which plays a major role in the agriculture system [12]. The variability in soils mainly depends on natural conditions. Slope, aspect and evaluation are the landscape attributes, which significantly control the soil properties and in turn plant growth [13]. On any scale including areas, fields and regions within the field and even in few millimeter spacing, soil variation can largely occur [14]. For achieving higher efficiency in nutrient usage, spatial and temporal data, which are an integrated approach, is necessary. For removing these types of problem, a computer based system can greatly improve this condition. Users can make informed agronomic and economic decisions, by observing the relevant information. To analyze soil nutrient distribution, geo-statistics, neural networks, regression trees and fuzzy logic systems have been used recently [15]. For understanding nutrient dynamics within crop fields, the deployment of these techniques is very useful.

In paper [20], the authors have considered the problem of observing soil moisture development by means of a wireless network of in-situ sensors. They have shown that at the price of small approximation error they can expressively lessen energy consumption by captivating a sparser set of measurements. The efficiency of this mixture is authenticated through widespread numerical tests over actual soil moisture data and through assessment with the Gaussian measurement matrix as well as a closed-loop method. They have showed that with these selections they can accomplish very squat approximation error at no more than 10 percent of the usual sampling rate. In paper [21], the authors have modeled Suelo, a fixed networked sensing scheme designed for soil monitoring. They also mention a significant challenge for Suelo is that numerous soil sensors are integrally fragile as well as frequently produce inacceptable data. This method permits users to use accessible sensors deprived of sacrificing data integrity, though diminishing the human capitals required. In [22] many nutrients meters cost (Nitrate, Potassium, Sodium, Calcium, LAQUA meters) are given. The main problem of this nutrients meters is that they are not automatic. It needs human intervention for measuring micronutrients/macronutrients. In other hands our proposed system is fully automatic where no human intervention is needed.

III. Sensing System Circuit Design

The complete circuit consists of several parts. At the center of the circuit is a PIC16F877A IC which provides the necessary resource for computation and communication among the other components. It is quite faster (200 nanosecond instruction execution) yet easy to program. The PIC16F877A features 256 bytes of EEPROM data memory, self programming, an ICD, 2 Comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI) or the 2-wire Inter-Integrated Circuit (I^2C) bus and a Universal Asynchronous Receiver Transmitter (USART). Hence it is ideal for designing a system involving analog data acquisition with digital control and GPRS interface [16].

IV. System Usage Model

The other components of the circuit are described below:

- *Power supply:* This section contains a voltage regulator circuit which is mainly designed to provide +12V and

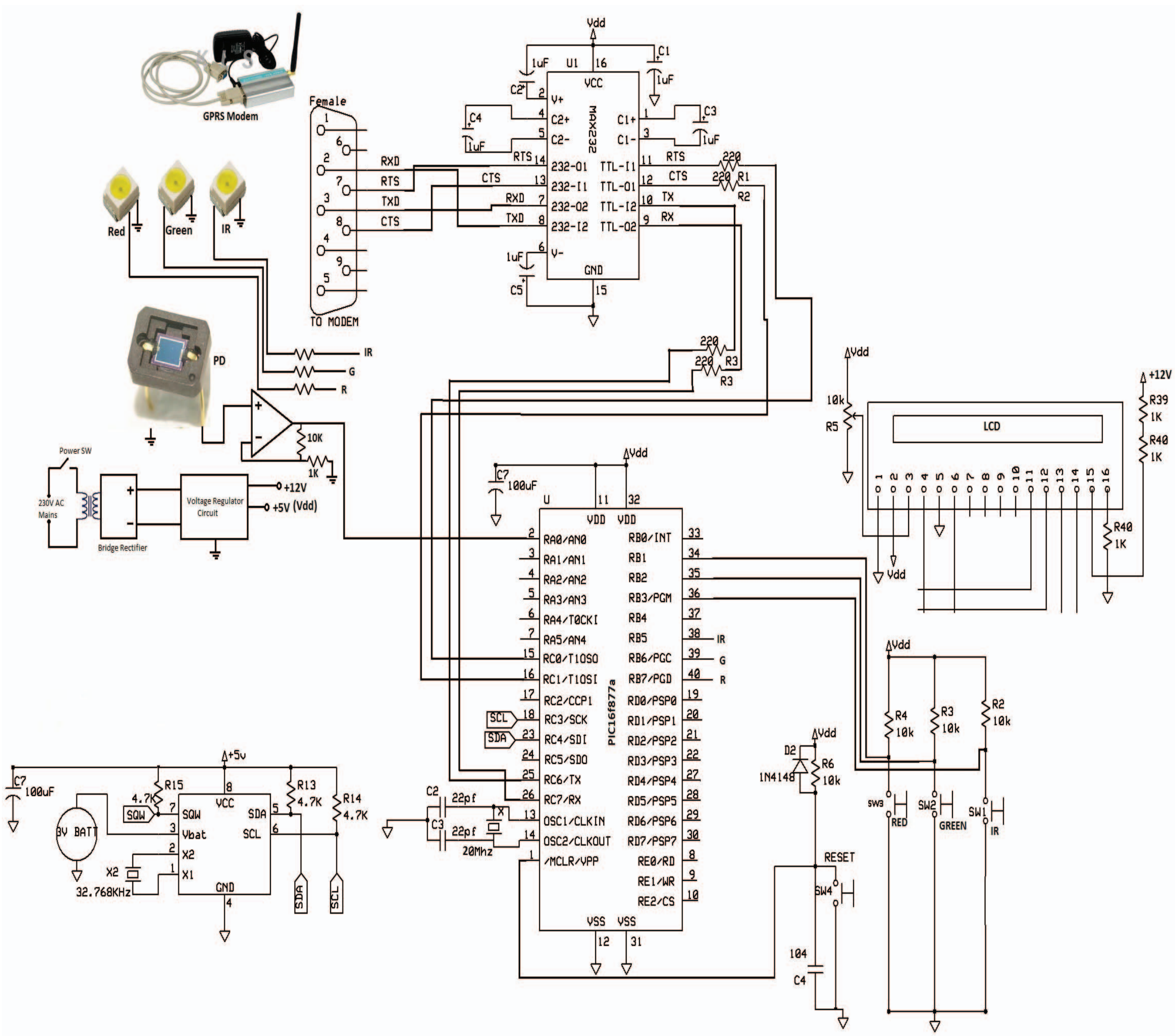

Figure 1. Soil macro-nutrient detection circuit

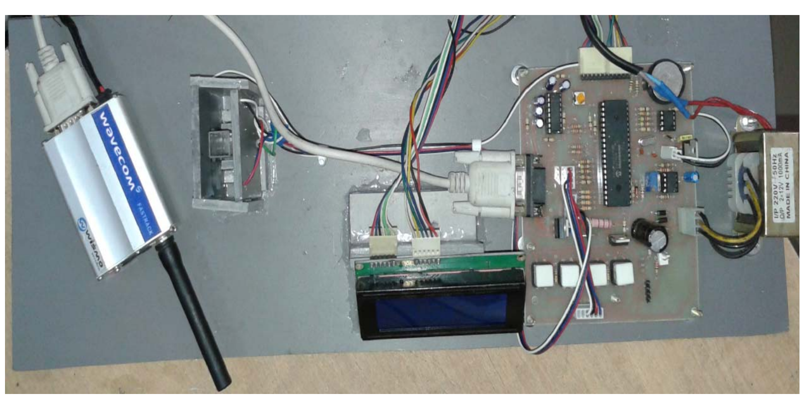

Figure 2. Experimental setup in the BSMRAU chemical laboratory

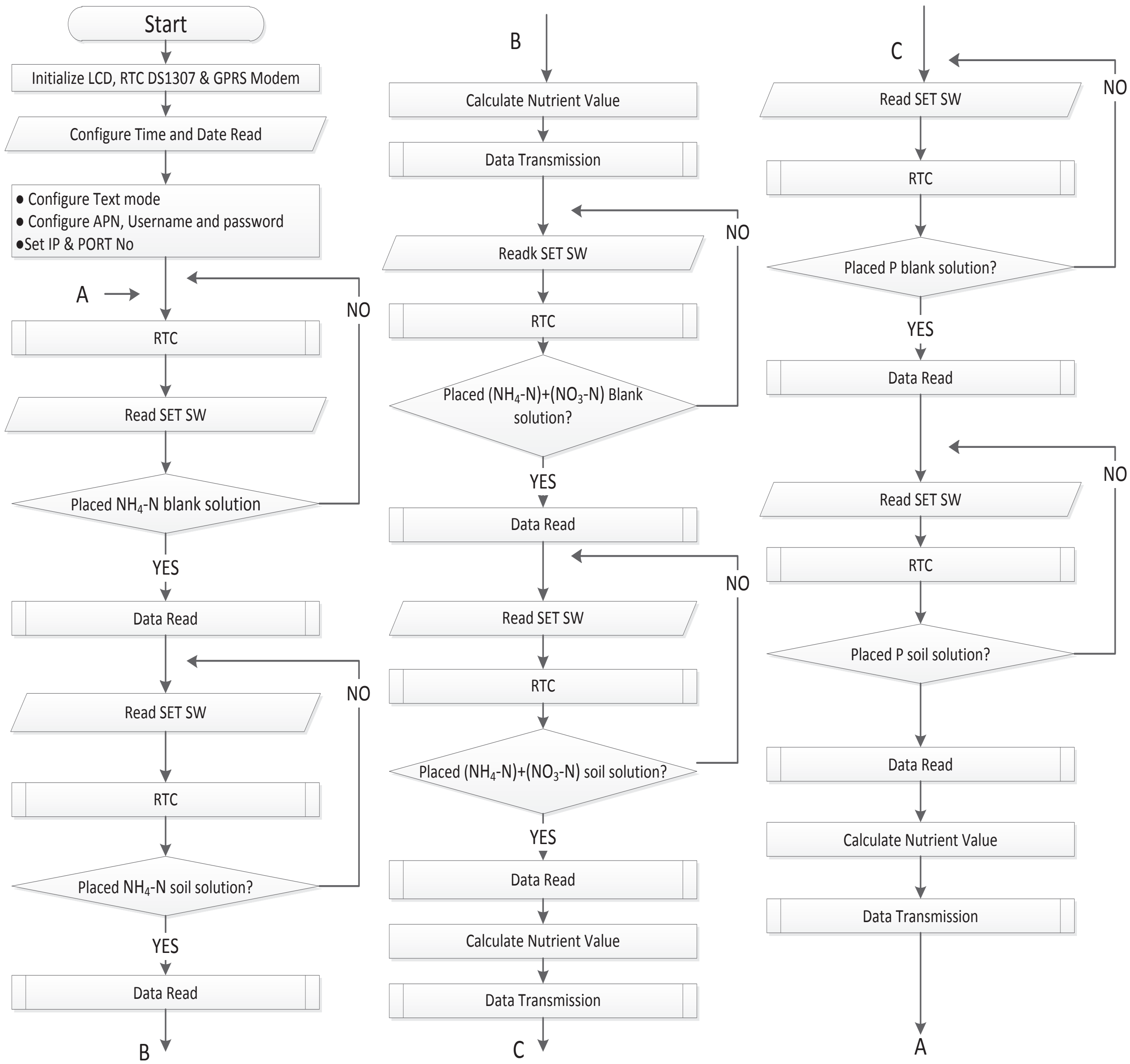

Figure 3. Working procedure of the developed sensing system

+5V input voltage to the components requiring external power. Most of the circuitry and PIC16F877A IC are powered from +5V whereas the modem can either be powered directly from mains or from +12V from this power supply circuit.

- *Clock and RTC:* PIC16F877A has been manufactured to operate in different clock condition. High speed clock with external 20MHz crystal has been used in our system. Real time clock (RTC) is designed using DS1307 with the backup 3.3V battery to maintain time and date in case of power failure. The DS1307 is most popular for it's excellent time keeping with leap year correction [17].
- *Optical sensor components:* Optical sensor consists of a PD and LEDs. Optical sensor components for detecting the deepness of color solution are connected with the PIC16F877A IC pins. Three different LED of color Green, Red and Infra Red are connected which are powered on at a specific time gap. High-precision industrial and medical grade photo-diode has been used

to detect the light coming from narrow spectral range LEDs. This results a voltage across the PD which is then amplified by a non-inverting active amplifier and feed to the PIC16F877A IC.

- *Switches:* User interactions before and after placing soil sample solution is maintained by the switches. There is also a "RESET" switch used to reset the whole circuitry.
- *Display:* Hitachi HD44780 LCD has been used to show user interaction information, ADC value with its corresponding macronutrients. This 4×20 character LCD displays each character in 5×7 pixel matrix. The command register stores the command instructions given to the LCD. LCDs are economical; easily programmable; have no limitations of displaying special & even custom characters and animations [18].
- *Modem component:* A modem is connected with the PIC16F788A IC to send the collected data after pre-defined interval to the data server where data from different fields are stored. The modem is connected by a RS232 serial port. A MAX232 is used to convert signals from an RS-232 serial port to signals suitable for PIC16F877A. The MAX232 is a dual driver/receiver and typically converts the RX, TX, CTS and RTS signals. Here the drivers provide RS-232 voltage level outputs (approx. 7.5 V) from a single + 5 V supply via on-chip charge pumps and external capacitors [19].

In this experiment, we have measured intensity contribution from three LEDs (Red, Green & IR) using high precision photo-diode. Ten ADC sample values we are getting for different LEDs which we have averaged to produce representative ADC value (sensor data) for each LED. We have collected sensor data for blank solution (reference solution) and also for soil nutrient with reference solution from which we have calculated the difference between these sensor data to get the contribution of soil nutrient in sensor data. These data is actually mapped into soil nutrient with the help of laboratory analysis of soil nutrients.

The workflow of proposed circuit is shown in Figure 3 and Figure 4. First the whole circuit needs to be powered on and configured. LCD is initialized, RTC DS1307 and GPRS modem is reset. Actual working time for data reading is configured. Access point name (APN) needs to be configured. Next IP and port address for the communicating device needs to be provided.

After initialization is complete, data from the sensors are collected and transmitted. The process of data collection and transmission is recycled continuously. The start of data collection and transmission is marked by the working point *A*. First, working time and data are read and displayed. Next the wavelength of red LED is checked. Then blank solution without soil sample is placed before the PD and rays of red LED are transmitted through it, i.e. reading of blank solution is taken. This reading of blank solution works as

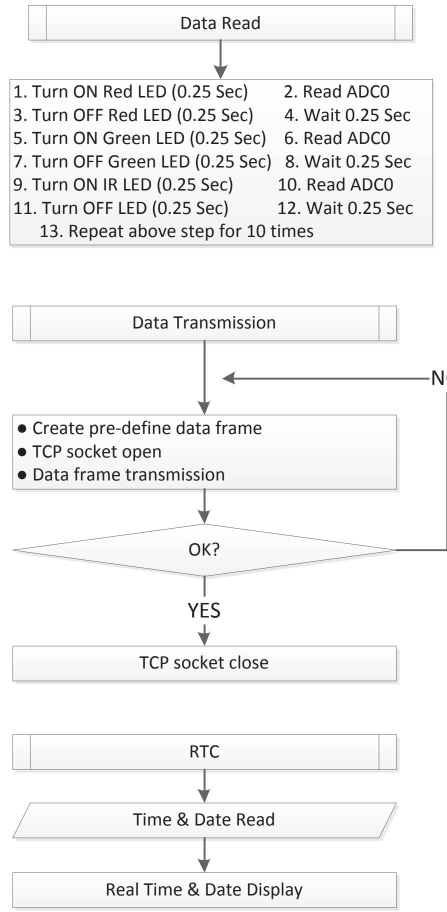

Figure 4. Data reading, data transmission and RTC mechanism

the basis of judging the colored soil sample solution. Then, same procedure is applied for measuring the soil sample under the red LED. The actual value of nutrients present in the soil sample is calculated by comparing the two values and transmitted using the GPRS modem. Then similar task is done for measuring the nutrient values for green and IR LEDs. When reading of each LED is taken several times, 15 minutes of time is waited and then the whole process is re-executed following the reading of current date and time. That is, the data collection and transmission stage goes to working point *A*.

For reading data of each LED, it is lit which takes 0.25 second and the ADC value is taken which determines the nutrient level present in the sample. Then the LED is turned off which also takes 0.25 second. After taking reading from a LED, 0.25 second is waited before taking reading from another LED. Results taken from 10 experiments are averaged to study the stable behaviour.

To transmit and receive data, we need to define a data frame. During each cycle, data from the sensors are inserted into the fields of the pre-defined data frame. Then a TCP connection between the sender and receiver is created and data frame is transmitted over the TCP connection using the methodology described in [?]. After the completion of data transmission, the TCP connection is closed.

V. Test result

We prepared soil solution for measuring three components of the soil; Phosphorus (P), Ammonium Nitrogen (NH_4-N) and Nitrate Nitrogen (NO_3-N). We have used reknowned Olsen's method [24] for standard solution preparation to check the amount of macronutrients in a soil sample.

We have collected ten sets of soil samples from different fileds of BSMRAU (Bangabandhu Sheikh Mujibur Rahman Agricultural University) randomly with the expectation of having different nutrient contents. We have recorded sensor data and calculated soil nutrient contributory sensor data for ten different soil samples. Among the ten soil samples we have characterized five soil samples in the laboratory to obtain the soil macronutrients. We, then, plot each micro content for five soil samples versus its sensor contributory values. These mapping plots are extrapolated with the help of curve fitting tool so that these plots can be used for obtaining soil macronutrients for any unknown soil sample using the sensor data.

Results found from sensors of our proposed circuit and from existing chemical laboratory based techniques are presented in the following figures. In Figure V, Ammonium Nitrogen's ($NH_4 - N$) lab test results and sensor results have shown. The figure reveals the fact that, the difference between the results obtained from laboratory color test method and the developed sensor based method is very small compared to the measurement value.

Figure V shows the comparative study of Nitrate Nitrogen's ($NO_3 - N$) chemical laboratory based test results and the sensor results. In this case, the difference is also very low between the two results. The difference occurs because of not following the exact time intervels in making standard solution and not getting the appropriate color in the laboratory test. Since laboratory test requires human involvement in measuring soil components, it is not a fully accurate method of measurement and a little amount of error is introduced in every measurement.

Figure 7 describes Phosphorus lab test results and sensor results. In this case, the measurements are quite accurate and their variation is negligible. A very little amount of error can also be found in measuring P_2O_5. However, the error can be omitted considering it's amount and scale.

Figure 8 shows the deviation of our experimental results obtained using the photo-sensors from the standard laboratory testing result. The devaition is computed using the following equation:

$$Deviation = |\frac{Lab\ Result - sensor\ Result}{Lab\ Result}| \times 100\% \quad (1)$$

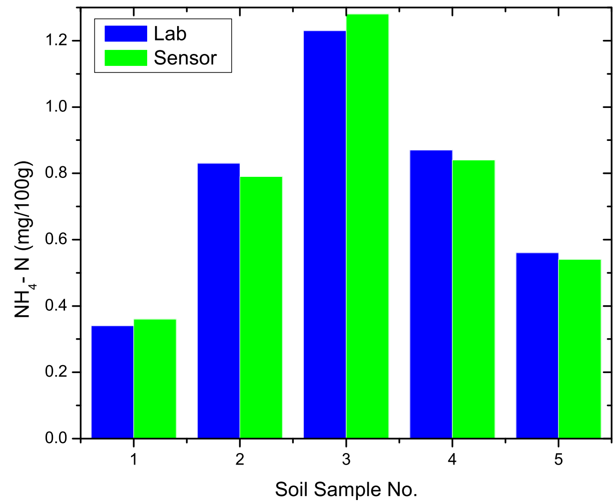

Figure 5. Comparison between lab and sensor data for NH_4-N

The results show that, the amount of error introduced by measuring soil components unsing sensors is very small the amount of error is less than 5% in most of the cases. The reason behind the error is that, the laboratory result is completely operator dependent. Operator matches it with a color chart and this matching procedure sometimes leads to confusion and the value obtained from this process is thus error prone.

In these figuress a comparative study of the results show that almost similar result can be found by applying photo sensors and color solutions. However, it takes less time to test samples since after the formation of color solution only 1 second of time is needed to take the reading of a LED. Our proposed soil macronutrient sensing system, developed using low cost PD, LEDs, Microcontroller, AD converter, GPRS modem etc., is also cost effective. A single complete sensing unit will cost less than 100 USD, which we assume would be within the purchase limit of farmers. Also our sensing system doesn't require expertise to operate.

VI. Conclusion

In this paper, we have presented the architecture of our proposed sensing system design. We have presented the detail working procedure of the soil macronutrient measurements and remote data collection system. The results obtained from our developed sensing system are almost accurate and very close to the laboratory test readings.

However, the measurement using our current sensing system is limited by only three macronutrients of the soil and it requires soil solution, which needs to be prepared in a chemical laboratory. In future, we will concentrate to test more number of soil macronutrients and explore the way to measure the soil nutrients without requiring any chemical laboratory-based solution.

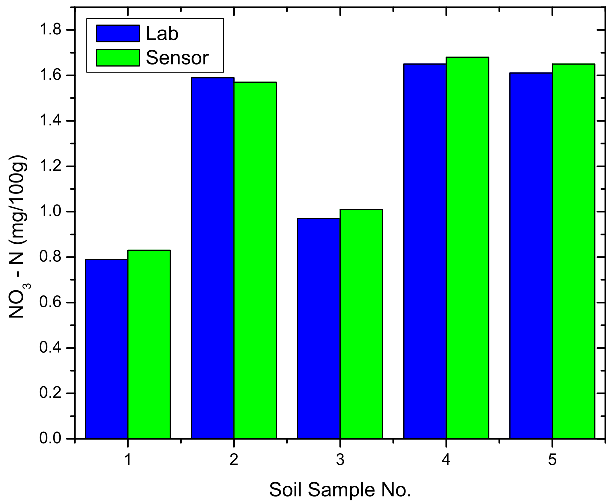

Figure 6. Comparison between lab and sensor data for NO_3-N

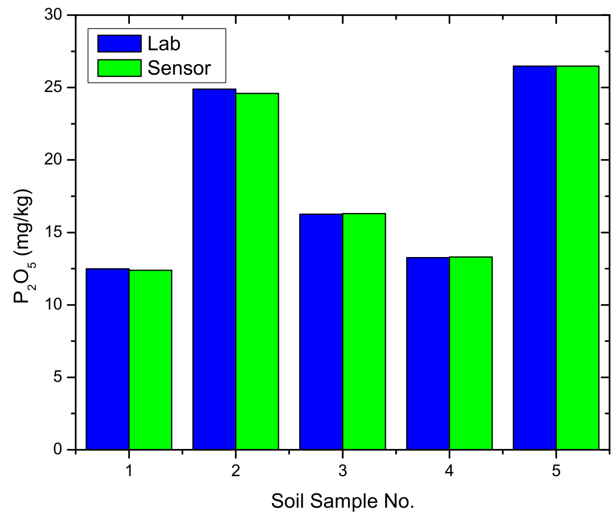

Figure 7. Comparison between lab and sensor data for P_2O_5

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References

[1] C. Jones and J. Jacobsen, *"Plant Nutrition and Soil Fertility"*, in Nutrient Management Module, No. 2, 2001.

[2] Dr. Stephen R. Gliessman, *"Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture"*, Technical Report published by University of California, 1985.

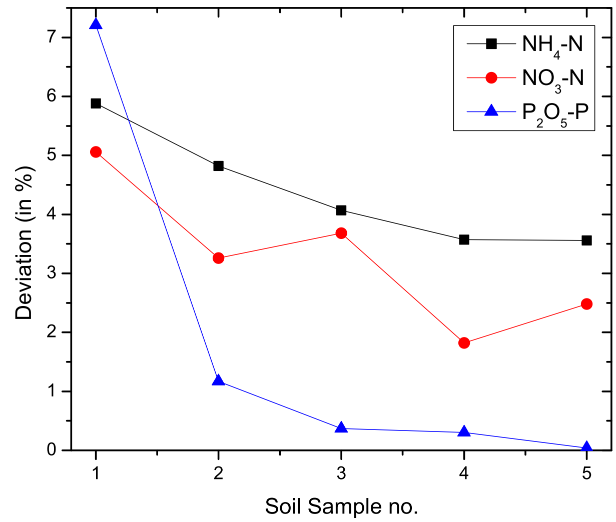

Figure 8. Deviation from laboratory result (in percentage)

[3] M.L. Staben, J.W. Ellsworth, D.M. Sullivan, D. Horneck,B.D. Brown, and R.G. Stevens, *"Monitoring Soil Nutrients Using a Management Unit Approach"*, in PNW 570-E, October 2003.

[4] Carrie A.M. Laboski and John B. Peters, *"Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin"*, in Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin (A2809), 2006.

[5] N. V. Hue, R. Uchida, and M. C. Ho, *"Sampling and Analysis of Soils and Plant Tissues,How to Take Representative Samples, How the Samples are Tested"*, in Plant Nutrient Management in Hawaiis Soils, Approaches for Tropical and Subtropical Agriculture, 2000.

[6] A servey on soil testing,*"http://www.vegetablegardener.com /item/2374/soil-testing-savvy"*, accessed on 15 May 2014.

[7] H. Sahota, R. Kumar, A. Kamal, and J. Huang, *"An Energy-efficient Wireless Sensor Network for Precision Agriculture"*, Int. Conf. on Wireless Communications and Mobile Computing (IWCMC), 2011

[8] Goulding, K., S. Jarvis and A. Whitemore, *"Optimizing nutrient management for farm systems"*. Phil. Trans. Royal Soc. B., 363: 667-680, 2008.

[9] Gebbers, R. and V.I. Adamchuk, *"Precision agriculture and food security"*. Science, 327: 828-831, 2010.

[10] Schirrmann, M. and H. Domsch, *"Sampling procedure simulating on-the-go sensing for soil nutrients"*, Plant Nutr. Soil Sci., 174: 333-343, 2011.

[11] Sun, B., S.L. Zhou and Q.G. Zhao, *"Evaluation of spatial and temporal analysis in the hill region of subtropical China"*. Geoderma, 115: 85-99, 2003.

[12] Atreya, K., S. Sharma, R.M. Bajracharya and N.p. Rajbhandaric, *"Developing a sustainable agro-system for central Nepal using reduced tillage and straw mulching"*. J. Environ. Manag., 88: 547-555, 2008.

[13] Wang, Z.M., K.S. Song, B. Zhang, D.W. Liu and X.Y. Li et al., *"Spatial variability and affecting factors of soil nutrients in croplands of Northeast China: A case study in Dehui County. Plant Soil Environ"*, 55: 110-120, 2009.

[14] Bouma, J. and P.A. Finke, *"Origin and nature of soil resource variability"*. In : Soil Specific Crop Management, Robert, P.C., R.H. Rust and W.F. Larson. American Society of Agronomy, Madison, pp: 3-13, 1993.

[15] Zhang, X.Y., Sui, X.D. Zhang, K. Meng and S.J. Herbert, *"Spatial variability of nutrient properties in black soil of Northeast China"*. Pedosphere, 17: 19-29, 2007.

[16] *"http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en010242"*, accessed on 15 May 2014.

[17] *"https://www.sparkfun.com/datasheets/Components/DS1307.pdf"*, accessed on 15 May 2014.

[18] *http://www.engineersgarage.com/electronic-components/16x2-lcd- module-datasheet*, accessed on 15 May 2014.

[19] *"http://www.alldatasheet.com/datasheet-pdf/pdf/27251/TI/MAX232.html"*, accessed on 15 May 2014.

[20] X Wu and M Liu, *"In-situ soil moisture sensing: measurement scheduling and estimation using compressive sensing"*. In Proceedings of the 11th international conference on Information Processing in Sensor Networks (IPSN '12). ACM, New York, NY, USA, 1-12. DOI=10.1145/2185677.2185679 http://doi.acm.org/10.1145/2185677.2185679, 2012.

[21] Ramanathan, Nithya, T. Schoellhammer, E. Kohler, K. Whitehouse, T. Harmon, and D. Estrin, *"Suelo: Human-assisted Sensing for Exploratory Soil Monitoring Studies"*, 2009.

[22] *"http://www.specmeters.com/nutrient-management/nutrient-meters/"*, accessed on 2 November 2014.

[23] J. Drewry, M. Taylor, F. Curran-Cournane, C. Gray and R. McDowell, *"OLSEN P METHODS AND SOIL QUALITY MONITORING:ARE WE COMPARING APPLES WITH APPLES?"*.

[24] T. A. Le, C. S. Hong, M. A. Razzaque, S. Lee, H. Jung, *"ecMTCP: An energy-aware congestion control algorithm for multipath TCP"*. Journal of IEEE Communication letters, Volume 16, Issue 2, Paes 275–277.