An In-Situ Precision Agriculture Framework for Sri Lanka based on Reflectance Spectroscopy

A.S. Maxworth, J.A.K.S Jayasinghe

Department of Electronic and Telecommunication Engineering, University of Moratuwa

Abstract- Precision Agriculture is completely new to the Sri Lankan agricultural community. The objective of this paper is to identify the methods and implementations that can be applied to the agricultural sector of Sri Lanka. While composing the framework with identified implementations the cost, scientific and technological knowledge of the farmers were taken into consideration.

Index Terms- In-Situ, NIR, Precision Agriculture, Reflectance Spectroscopy

I. Introduction

Agriculture can be considered as the most important field for the existence of mankind and all living beings. In most of the countries in the world the staple food of their population should be produced through cultivation. In Sri Lanka the staple food is rice, which should be harvested from paddy. With the population growth, the demand for food also rises. Therefore in order to maintain a continuous food supply, there are various steps to be taken.

Sri Lanka is an agriculture dependent country from the ancient history. The magnificent reservoirs which were built to store water and large flat and sloped lands reserved for paddy cultivation can be given as examples for an immortal history.

But today the productivity of the agricultural sector is considerably decaying when compared to the earlier days. Out of the total land only 28% is allocated for agriculture. And the contribution to the Gross Domestic Production (GDP) from the agricultural sector is only 5% in 2007 [27]. The percentages of imports of agricultural produce were increased during the past ten years. Due to the reduced food production the self-dependency of the country has been diminished.

There are various reasons for this low productivity of the agricultural sector in Sri Lanka. One reason is the lack of labor force. In earlier days the main occupation was farming. Therefore almost all the people were involved in farming in order satisfy the food requirement of their own family but now that culture has been changed. The young generation is reluctant to move into the agricultural sector. The main reason for that is the low productivity of the agricultural fields. The fertilizers, the weedicides and pesticides are very expensive. Also the prices of all the agricultural products are controlled by the government. Therefore the profit that can be obtained from a plantation is insignificant when compared to the expenses. Due to those reasons the young generation is not involved in the agricultural sector, and they move into various other industries instead. It is the main reason for the reduction in labor force involved in the agricultural sector [26].

The other reason is that the lack of technological usage in the field of agriculture. Although the countries like United States and Japan use various technological devices in the agricultural sector, Sri Lanka is still practicing primitive techniques in most of the stages in the agricultural produce processing. Although some high-en equipment are used in post harvest practices such as sorting and packaging , all the in-field steps such as spreading of seeds, application of water, application of fertilizer and crop harvesting are done manually without any technological interaction. Because of the heavy manual interaction there are lots of human errors introduced in the all those steps since when everything is done manually, the measurements vary depending on the person and his or her experience [28].

Due to the lack of technological usage in the agricultural industry, a considerable amount of harvest is wasted. One reason for this wastage is the improper water and fertilizer management. As mentioned above in this paper, application of water and fertilizer is done manually based on the person's experience. There the person may not consider about the moisture content of soil and the fertilizer requirement of the plant. Applying water and fertilizer excessively or insufficiently will degrade the plant life and hence reduce the productivity of the plant. Also at the stage of harvesting and post harvest processing some percentage of harvest is being wasted.

Quality of the seeds is an essential factor when it comes to productivity. Due to the lack of scientific and technological involvement currently there is no method of measuring, the quality of seeds. Therefore the harvest that can be taken from a land is quite low.

In order to solve the above mentioned issues, the main step can be given as introducing precision agriculture to the Sri Lanka agricultural sector. There are various researches which were carried out throughout the world regarding precision agriculture. In simple terms precision agriculture is about applying the correct amount at the correct time. With the introduction of the precision agriculture, technology will be introduced into the agricultural sector therefore human interaction can be minimized. When introducing precision agricultural practices into the Sri Lankan agricultural industry there are various factors to be considered, for an example the instruments that are to be introduced to the fields should be low in cost and less complex in technology. The farm lands in Sri Lanka are not large as the farm lands in developed countries. Therefore the instruments such as GreenSeeker® [30] will not be applicable here. One concern here is that the device which is used to get the in-situ measurements should be a portable device.

The objective of this paper is to identify the methods and propose a framework which is suitable for the Sri Lankan agricultural community. When developing the precision agricultural framework the following areas are taken as main focus areas.

- In-Situ soil moisture content measurement and analysis
- In-situ soil nutrient content measurement and analysis
- Remote sensing information storage and sharing

For soil moisture content measuring there are various methods exist [1], [2]. In Sri Lanka currently grid based soil sampling method is used to sample soil and soil testing is done under laboratory conditions with the oven drying method [4]. The oven drying method is considered as a very accurate method but it is very much time consuming. It needs at least 24 hours to get the complete measurement. Since the soil sample has to be removed from its original location in order to get measurements, this is considered as a destructive method. Also this method is not suitable for in-situ measurements.

Resistive and capacitive sensors are widely used to measure the moisture content due to their simplicity. In both of those methods, the electrical resistivity (ER) or electric conductivity (EC) is measured across two electrodes [3]. But the effects of salinity and soil texture introduce lots of side effects on the measurements [3], [8]. Also the readings are highly affected by the pH value of the soil. Therefore the precision of the resistive and capacitive sensors are considered to be low.

The nuclear methods such as neutron scattering and gamma attenuation can be taken as highly accurate soil moisture sensing methods [4]. But the high cost and the complexity of the arrangement make them less applicable for the Sri Lankan agricultural sector.

Satellite based remote sensing methods are not applicable for the Sri Lankan agricultural industry since the plantations span across only through hundreds of acres therefore the satellite images are not precise enough for the decision making process.

Near Infrared spectroscopy can be used to get real time in-situ measurements of a soil surface with a considerable accuracy. Also the implementation can be integrated into a portable device [3], [9] – [10].

Soil nutrient measurement and analysis can be categorized into two main sections. Direct soil analysis and plant analysis. In direct soil analysis a soil surface or a sample of soil is directly analyzed. In the plant analysis method plants are observed in order to detect the nutrient deficiencies [12]. Image processing techniques are used mainly for the plant analysis. Plant analysis can be considered as a remedy and direct soil analysis can be considered as a precaution. Because the deficiency symptoms of plants occur when the deficiency is severe, therefore direct soil analysis is better in that extent since it can predict the nutritional deficiencies.

Most of the direct soil nutrient analysis is done under laboratory conditions. Ion spectrometer, secondary ion mass spectrometer and ion mobility spectrometers are used in order to detect the nutrients. But that equipment is very much expensive therefore they are used at the research laboratories only. Also they are destructive methods since the soil sample has to be removed from the original location. Currently the farmers bring the soil samples into the laboratories that they have prepared based on the grid based sampling. Although the spectrometers provide a high accuracy, the ultimate result is not accurate because of the grid based sampling. Different parts of the land may have different nutritional requirements. But the final sample of the grid sampling method is a mix of samples from different parts of the field therefore it is an average and not accurate. The best way is to divide the land into finite management elements (FMEs) depending on the nutritional requirements. For that purpose in-situ measurement tool is required.

Ion-selective electrode (ISE) or the ion selective field effect transistor [5] are widely used method for the detection of nutrients present in a soil sample. ISE uses an ion selective membrane to separate the ions and gives an indication of the amount of nutrient present depending on the voltage developed across the ion selective electrode and the reference electrode. The main drawback of this method is it takes measurements while the sample is in its aqueous phase. Therefore this is more suitable for laboratories rather than for an in-situ measurement device. Another drawback is, to identify different ions, different ion selective membranes must be used and one membrane can detect only one type of ion in most of the cases.

Hyper spectral reflectance spectroscopy can be sued for the detection of nutrients on a soil surface [11]. Most widely used method is near infrared or NIR reflection spectroscopy [6], [9]. Also it can be used to implement a device which can be used to give real time in-situ measurements.

When a NIR beam with the spectral components of 900nm – 1700nm is used the following parameters can be measured for the correlation coefficients of 0.82, 0.87, 0.86 and 0.72 respectively [3]:

- Soil moisture
- Total Carbon concentration
- Total Nitrogen concentration
- pH

The information derived from the soil moisture sensing can be used to implement an automated irrigation system for the Sri Lankan agricultural fields. Automating irrigation systems can be considered as the main application of measuring soil moisture content [7]. Fertilizer application unit can be implemented separately or can be integrated with the irrigation system itself.

Global Positioning Systems (GPS) are heavily used in the modern world to obtain site specific data [3], [19]. With the use of GPS data the land can be divided into finite management elements (FMEs) in order to manage them properly [3]. The usage of GPS is not currently practicing in Sri Lanka. The reason is that the farm lands are quite small, therefore large devices with GPS are not necessary and the cost of operation is unbearable for the farmers. The ideal implementation would be a handheld device with a small size GPS.

It is important for the government institutions and research centers to keep a database regarding the farm lands. Such a system is called a Geographical Information System or a GIS [13]. Sri Lanka is a country in which there is a huge geographical variation within a few square kilometers. For an example in the Central Province of Sri Lanka, the area is hilly and the land is more are more subjected to soil erosion. And the Southern province of Sri Lanka is a flat land. Therefore the crops cultivated in those areas are different.

Although there are several researches currently on progress, there are no proper data bases to gather information. Therefore it is essential to develop a site specific database or a Geographical Information System (GIS) for the agricultural purposes [19].

The fig: 1 shows the main agro-ecological zones in Sri Lanka [29]. The categorization here has been done depending on the amount of rain received in those areas. A similar categorization can be done depending on the types of soil available in the areas. It is important to implement a distributed system which contains information about each cultivation area in a specific data base.

Agriculture related information gathering [22] and clustering [16], [24] have become major research areas in the modern world [13] - [15]. Based on the gathered information novel methods of farm management are being introduced [17] – [18].

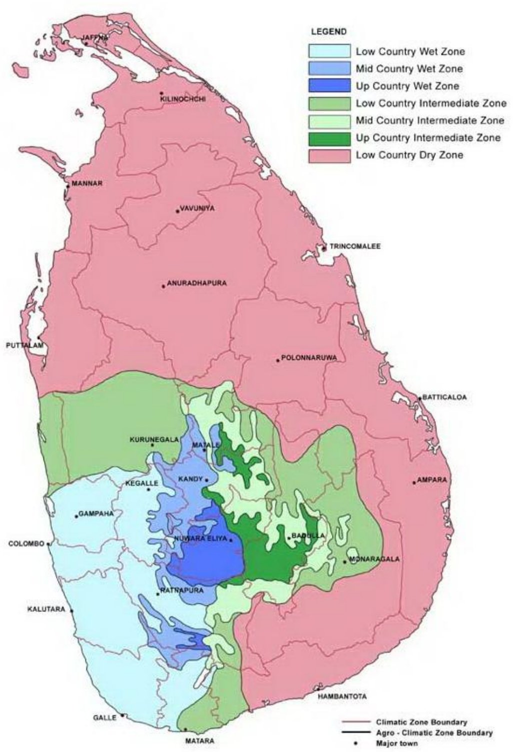

Figure 1: Main Agro-Ecological Zones in Sri Lanka. (This image originally appeared in [29].)

Agricultural information storage and sharing has been done with the use of different wireless networks [21] such as Zigbee [20], and Ultra-Wide-band (UWB) [23]. The information which is required for a researcher is not available about Sri Lanka in a reliable manner.

As mentioned earlier different geographical locations of Sri Lanka are suitable for the cultivation of different crops. There are three main export crops in Sri Lanka, namely tea, rubber and coconut. And the staple food in Sri Lanka is rice. And the rice or paddy cultivation is done in areas where there is a clay soil. The fig: 2 below shows the main paddy cultivation areas in Sri Lanka [25].

From the above details it is clear that since that even though the same crop is cultivated, the geographical areas are different. Therefore it is essential to maintain a site-specific database for agricultural related information. Due to the lack of a properly maintained database in Sri Lanka, the researches have to do the surveys prior to the researches by consuming a lot of time and effort.

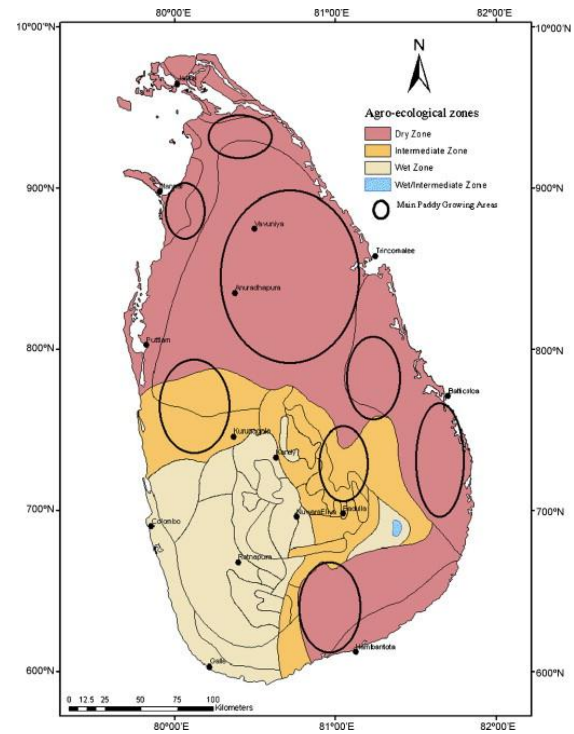

Figure 2: Main Paddy cultivation areas in Sri Lanka. (This image originally appeared in [25].)

II. METHODOLOGY

The proposed framework is developed according to two approaches. The two approaches are selected based on whether the farm is a small/medium scale or a large scale farm.

The first approach is suitable for a small or a medium scale plantation. The second approach is suitable for large scale cultivations and there the process is fully automated.

In both of the approaches, hyper-spectral near infrared (NIR) sensors are used to measure the moisture content and the nutrition content.

i. Approach I: Map-Based

In the first approach, the soil moisture content and the nutritional content will be measured in real time with the use of a handheld device. The values are recorded together with the GPS coordinates. Later the stored data will be analyzed and the moisture/fertilizer availability map will be produced as the output. This approach requires the following two devices:

1. Handheld measurement device
2. PC based analyzer

In this method a person has to carry the handheld device through the field while taking the readings. The readings will be automatically stored in the internal memory of the handheld device. The analysis report will be produced separately and the

water/fertilizer application should be done under the manual controlling. This method is suitable for small and medium scale farms, since the initial cost is low.
Within the handheld measurement device the following units exits. The functionality of each will be followed.

(i). Hyper spectral NIR reflectrometer to measure the soil moisture and nutrient content.
(ii). GPS unit which will detect the location
(iii). Internal storage/ data logger
(iv). Timer unit

The following figure will show the internal components of the handheld device.

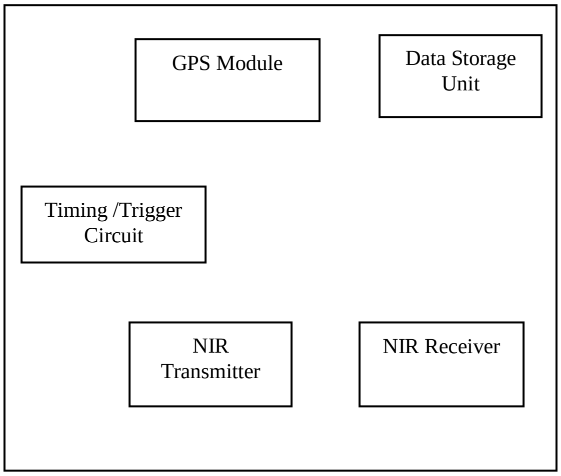

Figure 3: Internal modules of the handheld device

The person who is carrying the device will be walking through the field. If the field is comparatively large, the person can cover a part of the land on one particular day and the other parts on a separate day. There is no need to cover the total area on the same day. Also if a tractor is driven across the land, some plants may get damaged and it is the main reason for the selection of a man walking across the land.

Global Positioning System will be having an accuracy of 1-30m. The average walking speed of an individual is about 5km/h. If the land to be critically analyzed the device should be triggered for every 15m, hence the device activation time is 11s. And if the land to be analyzed every 30m, the activation time should be 22s.

The signal flow chart of the handheld device can be expressed according to the Fig 4.

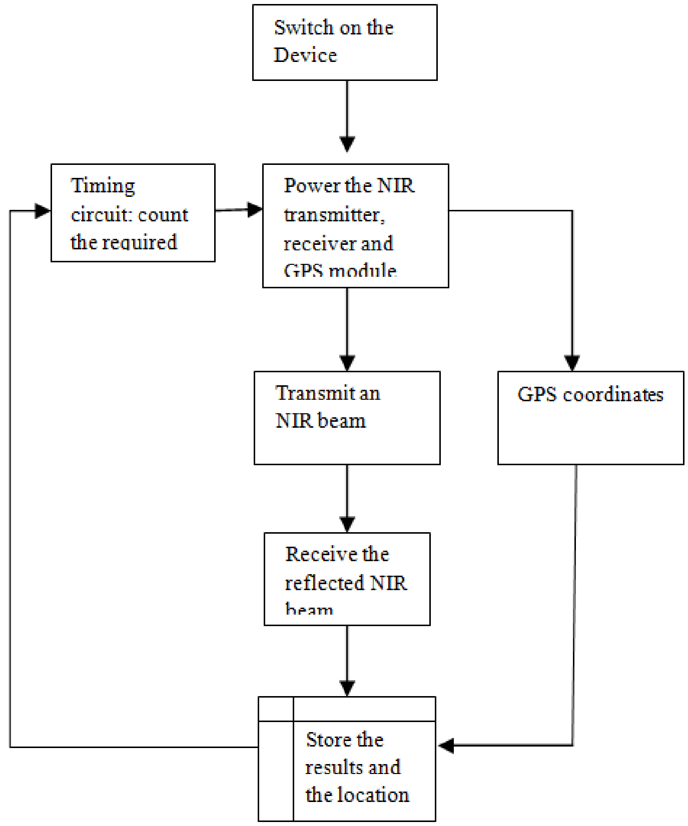

Figure 4: Signal path of the handheld device

The internal storage if the handheld device will record each GPS location and the NIR reflectance for the two wavelengths which correspond to moisture and nutrient content. The output of the handheld device is a chart of the format in fig: 5

Longitude	Latitude	Transmission energy	Reflected energy

Figure 5: Format of the information

For the purpose of analysis a tool which is based on MATLAB® from MathWorks Inc. MATLAB is a very powerful analyzer tool that can be used in three different ways for the analysis purposes.

1. MATLAB centric: where the data will be copied onto the MATLAB workspace and the moisture and nutritional availability surface of the land will be plotted with respect to the GPS coordinates.
2. Excel centric: the MATLAB software will be running underneath for the analysis purposes. The MATLAB functions will be called from the Excel interface.
3. Stand-alone analyzer tool: In this approach MATLAB is not needed in the user's computer. The developer can insert the MATLAB functions into the Excel workspace and afterwards those functions will work as the inbuilt Excel functions.

Out of the three methods listed above the 3rd method is the most suitable one for the ordinary farms, where they may have accessibility to a normal desktop personal computer with an operating system, but not MATLAB. The following gives the steps involved in developing a standalone software tool for the analysis purposes.

The output of MATLAB will be a graph which shows the soil moisture and nutritional requirement. That graph can be taken into a paper and can be handover to the farmer his/her information.

Based on the analysis report the fertilizer specifications can be made. If the moisture content and the nutritional requirement in a specific area are high the farmer can apply a small amount of water and fertilizer on to that area if the water/fertilizer application is done manually.

ii. Approach II : Site Specific

In order to develop a fully automated irrigation system a short range wireless transmission medium such as Bluetooth should be used. The short range communication medium will be used for the data transfer from the site-specific sensors to the water/fertilizer application unit. The steps involved in the automatic water/fertilizer application unit are as follows:

Step 1: the soil moisture content will be measured and recorded with the GPS coordinates

Step 2: the soil nutrient content will be measured and recorded with the GPS coordinates

Step 3: if the soil moisture content is less than a certain threshold, the irrigation system will be activated

Step 4: if the soil nutrient content is less than a certain threshold the fertilizer application system will be activated

Step 5: once the soil moisture content is up to the required limit, the automatic irrigation system will be deactivated

Step 6: once the soil nutrient content is up to the required limit, the automatic fertilizer application unit will be deactivated

Steps 1 and 2 will be done through the handheld device. From step 3 onwards, the controller circuit has to take over the process. The controlling function can be integrated in to the MATLAB analyzer environment.

To accomplish the above said environment only three units:

1. NIR sensors with a Bluetooth module
2. Personal computer with a Bluetooth transmitter and a receiver
3. Electrical controller

The signal flow chart of the complete system can be demonstrated according to fig: 6.

This fully automated system requires site-specific fix array of sensors for moisture and for nutrient detection. Also the infrastructure for irrigation should be implemented prior to the activation of the system. Unlike the first approach, here there is a considerable amount of initial cost should be applied for the infrastructure. This approach will be applicable for a large scale farm where there are number of finite management elements.

Here also, the sensors will be near infrared sensors to measure the soil moisture content and the nutritional content. A small Bluetooth module should be integrated into the sensors. Depending on the size of land, the number of sensors required varies. The number of sensors and the sensor locations must be decided after an initial survey.

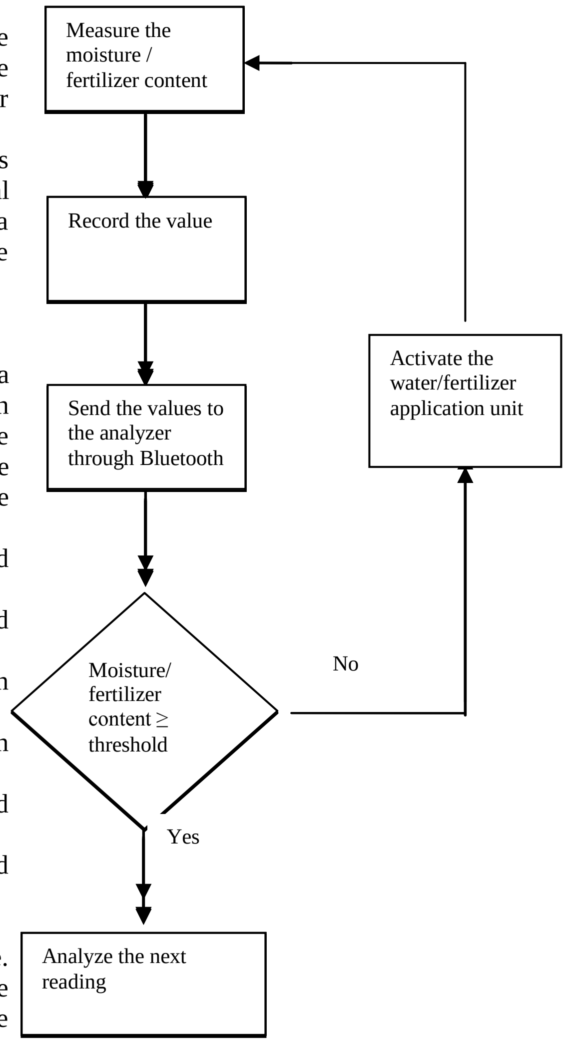

Figure 6: Signal flow of the automatic system

An initial survey should be done in order to partition the land into finite management elements. Depending on the site specific properties the land must be sub divided into FMEs and for each FME several sensors should be places.

When it comes to irrigation, there are two main types of irrigation systems available, the drip irrigation systems and sprinkle irrigation systems. Drip irrigation systems are suitable for plantations where the plants are sparsely located and sprinkle irrigation is suitable for plantations where the plants are closely located. Depending on the type of crop the farmers can select the suitable irrigation system.

In the second approach the human interaction is minimal and all the processes are based on scientific inputs and automatic outputs.

iii. Implementation of the Geographical Information System

In both of the approaches mentioned above, some property either the soil moisture content or the soil nutrient content is recorded with respect to the GPS coordinate.

All those recorded values can be saved as a database. And that can be used as a site specific agricultural information database, which can be used for variety of purposes. To name a few applications of such a system, government organizations can use that database to collect agro-ecological data, agro-chemical companies can use the database for marketing purposes, and universities can use those data for various research purposes.

III. CONCLUSION

Methods and implementations which are suitable for the Sri Lankan agricultural community have been described in the body of the paper. The sensor medium is near infra red rays for all the approaches. Depending on the cost of implementations, land size of the cultivation and based on the scientific and technological knowledge, farmers can adapt the relevant system.

REFERENCES

[1] K.A. Sudduth et al, “Sensors for Site Specific Management”, The State of Site Specific Management for Agriculture, 1997, pp 110-183

[2] M.Edward et al, “ Remote and Ground based sensor Techniques to map Soil Properties”, Photogrammetric Engineering and Remote Sensing, Vol 69, No 6, June 2003, pp 619-630

[3] V.I Adamchuk et al, “On the go Soil Sensors for Precision Agriculture”, Elsevier Computers and Electronics in Agriculture, Volume 44, 2004, pp 71- 91

[4] G. Brian Leib et al, “Field Evaluation and Performance Comparison of Soil Moisture Sensors”, Soil Science, Volume 168, Issue 6, June 2003, pp 396-408

[5] J. Artigas et al, “Application of Ion Sensitive field Effect Transistor Based sensors to Soil Analysis”, Elsevier Computers and Electronics in Agriculture, Volume 31, Issue 3, May 2001, pp 281-293

[6] M.R. Ehsani et al, “A NIR technique for Rapid Determination of Soil Mineral Nitrogen”, Precision Agriculture, Vol 1, No 2, 1999, pp 219-236

[7] G.H. Snyder et al, “Moisture sensor- Controlled Irrigation for Reducing N leaching in Burmudagrass Turf”, Agronomy Journal, Vol 76, No 6, 1984, pp 964-969

[8] R.B Thompson et al, “Salinity Effects on Soil Moisture Measurement Made with a Capacitance Sensor”, Soil Science Society of America Journal, Vol 71, No 6, pp 1647-1657

[9] J.W. Hummel et al, “Soil Moisture and Organic Matter Prediction of Surface and Subsurface Soils using an NIR Soil Sensor”, Elsevier Computers and Electronics in Agriculture, Vol 32, 2001, pp 149- 165

[10] W.R. Raun, “Optical Sensor Based Algorithm for Crop Nitrogen Fertilization” Communication in Soil Science and Plant Analysis, Vol 36, 2005, pp 2759- 2781

[11] W.S. Lee et al, “Estimating Chemical Properties of Florida Soils Using Spectral Reflectance”, Trans. Of ASAE, Vol 46, Issue 5, pp 1443- 1453

[12] H. Al-Abbas et al, “ Spectra of Normal and Nutrient- Deficient Maize Leaves”, Purdue e-pubs, Purdue University

[13] Z. Zhu et al, “Research on GIS- based Agriculture Expert System”, WRI World Congress on Software Engineering, Xiamen, 2009, Vol 3, pp 252-255

[14] X. Wang et al, “Design and Realization of Precision Agriculture Information System based on 5S”, 19th International Conference on Geoinfomatics,Shanghai China, 2011, pp 1-4

[15] Q. Ma et al, “The Data Acquisition for Precision Agriculture based on Remote Sensing”, IEEE International Conference on Geoscience and Remote Sensing Symposium, Denver Colorado, 2006, pp 888-891

[16] D. Wang et al, “Research on Clustering for Agriculture Information”, The Sixth World Congress on Intelligent Control and Automation, Dalian, 2006, pp 2575-2579

[17] L. Li et al, “On Management of Technology and its Application in Agriculture of China”, 16th International Conference on Industrial Engineering and Industrial Management, Beijing China, 2009, pp 1779-1783

[18] M. Qingyuan et al, “Management Decision Making support system for of Precision Agriculture based on CNCS”, IEEE International Geoscience and Remote Sensing Symposium, Barcelona, 2007, pp 819-822

[19] Z. Weidong et al, “Development of agriculture machinery aided guidance system based on GPS and GIS”, Kobe, 2010, pp 313-317

[20] T. Kalaivani et al, “ A survey on Zigbee based Wireless Sensor Networks in Agriculture”, 3rd International Conference on Trendz in Information Science and Computing, Chennai, India, 2011, pp 85-89

[21] Y. Jiber et al, “Precision Agriculture Monitoring Framework based on WSN”, 17th International Wireless Communications and Mobile Computing Conference, Istanbul, 2011, pp 2015-2020

[22] R. Li et al, “Methods and Algorithms of Data Assimilation and its Application in Agriculture”, World Automation Congress, Kobe 2010, pp 29-34

[23] D. Wu et al, “Localization in UWB Sensor Networks for Agriculture Environment”, 4th International Conference on Wireless Communications, Networking and Mobile Computing, Dalian, 2008, pp 1-4

[24] Y. Duan et al, “Design of Agriculture information Integration and Sharing Platform based on Cloud Computing”, IEEE International Conference on Cyber technology and in Automation, Control and Intelligent Systems, Bangkok, Thailand, 2012, pp 353-358

[25] C.S. De Silva et al, “Predicting the Impacts of Climate Change – A case study of Paddy Irrigation water requirements in Sri Lanka”, Elsevier Agricultural Water Management, 2007, Vol 93 issue 1, pp 19-29

[26] K. Karunagoda, “Changes in the Labor Market and Domestic Agriculture”, Sri Lankan Journal of Agricultural Economics, 2004, vol 6, Issue 1, pp 82-97, Retrieved on 13th June 2011 from: http://www.slageconr.net/sjae/sjae61f/sjae06106.pdf

[27] “Sri Lanka, Overview of Economy”, Encyclopedia of the Nations, 2011, Retrieved on 13th June 2011 from: http://www.nationsencyclopedia.com

[28] N.F.C. Ranaweera et al, “Maize Production in Sri Lanka”, CGPRT, No 16, 2011, Retrieved on 13th June 2011 from: http://www.slideshare.net/Mahindadasa/maize-production-in-sri-lanka

[29] “Plantations in Sri Lanka”, Retrieved on 12th November 2012, from http://jayaneththi.blogspot.com/2011/03

[30] “GreenSeeker variable rata application and mapping system”, Retrived on 13th November 2012, from: http://www.ntechindustries.com/greenseeker-home.html

AUTHORS

First Author – A.S. Maxworth, Lecturer, Department of Electronic and Telecommunication Engineering, Faculty of Engineering, University of Moratuwa, Moratuwa 10400, Sri Lanka, Email: ashanthi_maxworth@yahoo.com, Alternate email: ashanthi86@gmail.com , Contact number: +94-38-2233149 (land phone) /+94-71-3628692(mobile)

Second Author – Prof. J.A.K.S. Jayasinghe, Senior Professor, Department of Electronic and Telecommunication Engineering, Faculty of Engineering, University of Moratuwa, Moratuwa 10400, Sri Lanka, Email: jaks@ent.mrt.ac.lk