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Soil Urea Estimation using Embedded Systems

Sulaxana R.Vernekar, Jivan S. Parab

Abstract.With the advancements in technology constant efforts are being made towards making agriculture sustainable. Green Revolution made extensive use of chemical fertilizers to increase the crop yield, which gave the desired outputs, but high usage of fertilizers led to soil degradability, ground water contamination etc. Precision farming techniques are currently being used to make agriculture sustainable and profitable. Lot of automation is involved in the techniques used for irrigation, harvesting, soil testing etc. Soil testing is an important aspect in agriculture as it decides the crops that can be grown in a particular type of soil and also todecide how much external inputs can be applied to give a good crop yield. Precision farming involves techniques which are real time based. The paper discusses the design and development of a novel soft core embedded platform on Altera FPGA for estimation of urea in soil. RF spectra of five different constituents found in soil are recorded using a scalar network analyzer consisting of Signal Hound tracking generator TG44A and Signal Hound spectrum analyzerUSB-SA124B and a dielectric cell. The samples for recording the RF spectra are prepared in the laboratory by mixing five different constituents namely urea, potash, phoshate, salt and lime taken in the study in distilled water in different proportions. The spectra obtained are then passed through a multivariate system ported on FPGA for the estimation of an unknown concentration of urea in a sample. The multivariate analysis is done using Partial Least Square Regression (PLSR) technique and is implemented using SIMPLS algorithm developed in C. The results obtained show that the estimated values of urea have percentage error of around 5% which is acceptable. Even if the sample concentrations lie outside the confidence interval i.e CI, the estimated results are still satisfactory.

Keywords: Multivariate, FPGA, PLSR, RF Spectroscopy, Urea.

I. INTRODUCTİON

With growing population and shortage of land resources available for agricultural use, there is a need to make agriculture sustainable. Fertility of soil plays an important role in agriculture. The complexity of the soil system is exhibited in terms of spatial and temporal variability. These variability in soil needs to be studied properly to understand the type of crops that can be grown with minimum use of external resources. Laboratory soil testing methods make extensive use of apparatus and procedures making it very costly, time consuming and labor oriented. Further these methods do not take into consideration the spatial variability exhibited by the soil in a particular area.

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Thus the soil nutrient status provided using the above method gives an average report of the soil leading to over and under application of fertilizers. This gives rise to problems such as degradation in soil fertility, ground water contamination etc.

[1] Hence there is a need to manage the limited natural resources available for agriculture in a planned and sustainable manner. Lot of research work is being undertaken to provide solutions to various agricultural problems. Precision farming also called as site specific management is a modern agricultural technique used for sustainable agriculture. The benefits of precision farming are increased crop productivity and profits along with the conservation of natural resources [2]. Precision farming uses various technologies for site specific management of farms and soil sensing is one of the important tools used, in order to manage the external inputs required for crop growth. The application of fertilizers to the soil is done based on the soil nutrient test report. The use of precision farming requires rapid, accurate and real time soil nutrient testing techniques. Some of the currently used techniques in soil nutrient testing are electrochemical sensing that makes use of an ISE (Ion Sensitive Electrode) or ISFET (Ion Selective Field Effect Transistor) for measuring the potential developed between a sensing and a reference electrode. The potential measured is proportional to the activity of the specific ion concentration. The other method is based on optical sensing which makes use of IR, NIR and vis regions for the spectral measurement [3].

The paper discusses a novel technique wherein RF spectra of the various constituents in difeerent proportions taken in the study were recorded using an instrumentation consisting of a dielectric cell and a scalar network analyzer. The spectra obtained were then fed to a PLSR multivariate system desigined using soft core FPGA platform for the estimation of an unknown concentration of a constituent in a sample.

II. METHODOLOGY

The instrumentation for obtaining the RF spectra of soil composition was designed using dielectric cell having a capacity of 15ml in which the sample was placed. A Signal Hound tracking generator TG44A was used to transmit RF signals into the cell and a Signal Hound spectrum analyzer USB-SA124B was used at the receiving end for recording the RF spectra of the sample under test placed inside the cell. The cell was designed using acrylic sheets and to insulate the sample under study from electromagnetic interferences it was covered with a copper foil on the outside and a gold foil on the inside of the cell. The signal was transmitted into the cell through a gold wire running through the centre of the cell from one end to the other.

The tracking generator and the spectrum analyzer were connected in such a way so as to form a scalar network analyzer. The soil constituents that were taken in the study were urea, potash, phosphate, lime and salt. Samples were prepared by mixing these constituents in different proportions and the spectrum for each sample was recorded.

A. Sample preparation.

The samples were prepared in the laboratory by making molar solutions of each constituent taken in the study. Based on the calculations the amount of urea required to be added to 15ml of water was found to be 225mg, potash 280mg, phosphate 3.78gm, salt 220mg and lime 375mg. These values obtained are considered as the normal values in the study and are denoted as 1. The other concentrations which were taken in the study are as follows: 0.5 which is half of the normal concentration, 2 for double the normal concentration and so on. The concentrations of the various constituents taken in the study are as shown in Table 1.

Table I. Nomenclature used for different concentrations of the five constituents.

Concentrations denotation	Concentration(mg/15ml)				
	Urea	Potash	Phosphate	Lime	Salt
0.5	112.5	139.7	1890	187.5	109.87
1	225	279.5	3780	375	219.75
1.5	337.5	419.2	5670	562.5	329.63
2	450	548	7560	750	439.5
3	675	687.5	9450	1125	659.25

B. Building the PLSR model

In order to estimate the concentration of urea in an unknown sample, multivariate analysis technique was used. Multivariate analysis consists of various methods like discriminant analysis, principal component analysis, factor analysis, canonical analysis, Partial Least Square Regression Technique (PLSR) etc. The designed system makes use of Partial Least Square Regression Technique (PLSR) in the estimation of urea concentration in a sample since this technique is better suited for applications which are predictive in nature. In such cases the number of factors is much more than the number of observations. It also takes into account the relationship existing between the factors and the responses based on which a predictive model is built. The factors are extracted as linear combinations of the spectral amplitudes and the linear combination of these extracted factors are then used in the prediction of the responses [4]. The algorithm used in building the PLSR model is SIMPLS which is implemented in C and ported on Altera FPGA. The flowchart for the SIMPLS algorithm is as shown in figure 1.

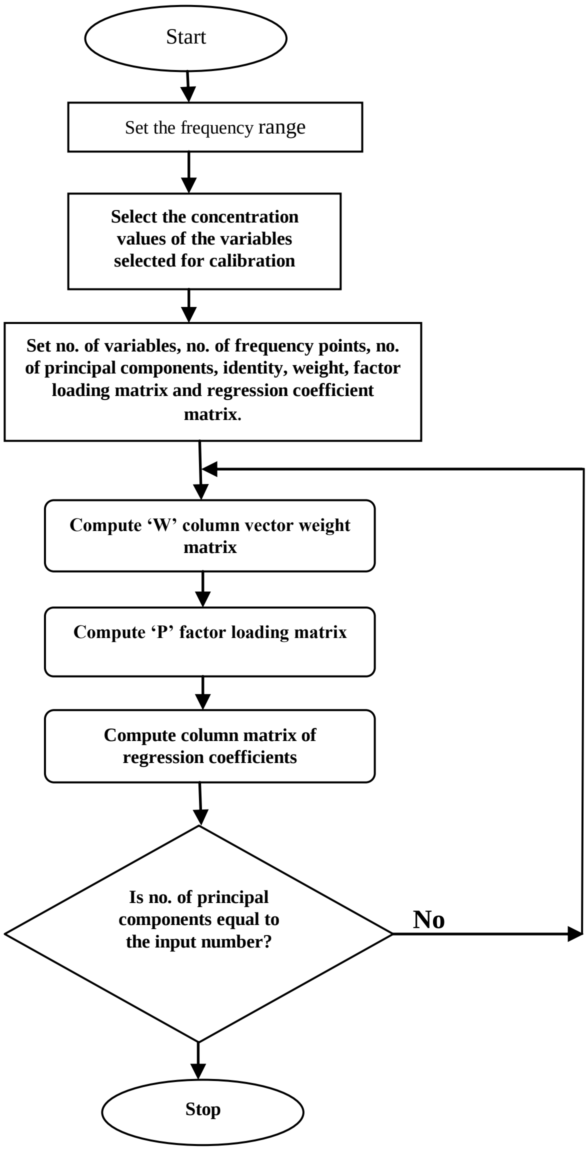

Fig. 1. Flowchart of SIMPLS algorithm

III. FPGA PLATFORM DESIGN FOR SOIL ANALYSIS

FPGA's are reconfigurable devices and provide the designers with flexibility and higher levels of abstraction. The advancements in FPGA technologies has led to improvements in power consumption, time delays in Configurable Logic Block (CLB), and cost per unit device [5]. This has enabled the use of FPGA's as reconfigurable embedded processors in many designs. FPGA use either a hard processor core or a soft core processor. Hard cores have a custom VLSI layout that is added to the FPGA and they are less configurable; however, they tend to have higher performance characteristics than the soft cores. Soft cores use existing programmable logic elements from the FPGA to implement the processor logic. A soft-core processor is a hardware description language (HDL) model of a specific processor (CPU) that can be customized for a given application and synthesized for an FPGA target [6].

The ALTERA DE2 development board having Cyclone II target which support the 32 bit NIOS – II soft core processor is used in the design of PLSR block.

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The entire soft core system developed for PLSR analysis is as shown in figure 2.

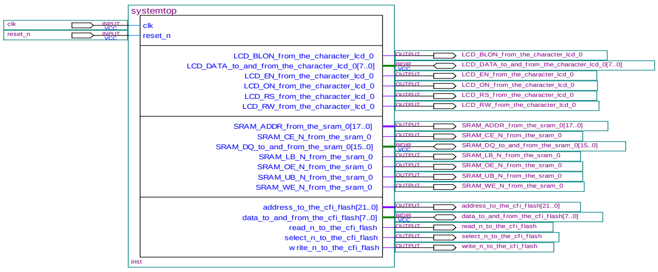


Fig. 2. Block Design File for Urea Prediction

Figure 3 shows the SOPC components selected for PLSR analysis of soil constituents such as NIOS II CPU on which the PLSR algorithm is running,4 MB Flash Memory to store the soil calibration and prediction spectral data sets, SRAM to store the C code and LCD panel to display the result.

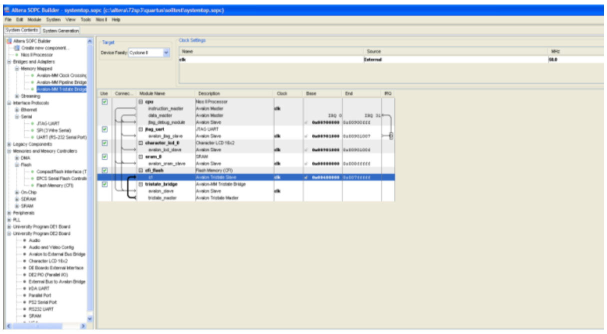
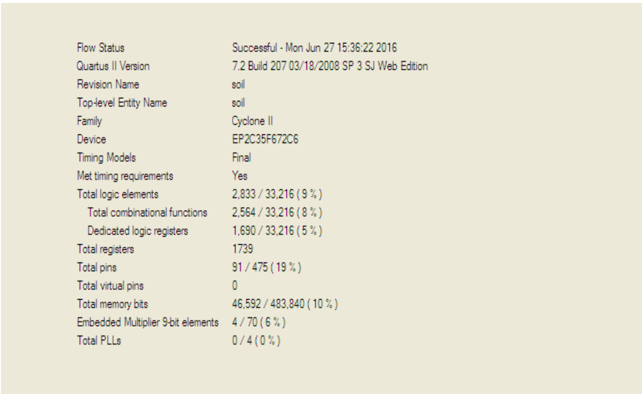


Fig. 3. SOPC Components for PLSR Analysis

The entire system is then compiled in quartusII and the compilation report of the full system is given in Figure 4.



Flow Status	Successful - Mon Jun 27 15:36:22 2016
Quartus II Version	7.2 Build 207 03/18/2008 SP 3 SJ Web Edition
Revision Name	soil
Top-level Entity Name	soil
Family	Cyclone II
Device	EP2C35F672C6
Timing Models	Final
Met timing requirements	Yes
Total logic elements	2,833 / 33,216 (9 %)
Total combinational functions	2,564 / 33,216 (8 %)
Dedicated logic registers	1,690 / 33,216 (5 %)
Total registers	1739
Total pins	91 / 475 (19 %)
Total virtual pins	0
Total memory bits	46,592 / 483,840 (10 %)
Embedded Multiplier 9-bit elements	4 / 70 (6 %)
Total PLLs	0 / 4 (0 %)

Fig . 4. Compilation Report

The spectra recorded were divided into two sets: the calibration set and the prediction set. 16 spectra were taken in the calibration set to build the PLSR model and the remaining spectra were used as unknown spectra for the estimation of urea concentration. figure 5 shows the spectra recorded for 10 samples out of the 16 samples taken in the calibration set.

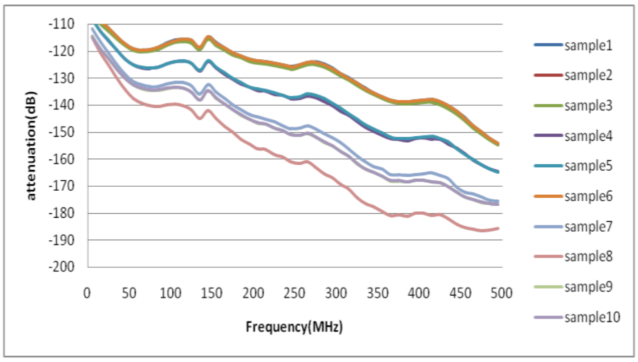


Fig. 5. RF Spectra of different samples

IV. RESULTS

FPGA platform designed around Altera DE2 board having target as CYCLONE II EP2C6 was used in the estimation of urea concentration in soil using RF spectroscopy in the frequency range of 10MHz-500MHz. The PLSR model based on SIMPLS algorithm was developed in C language and ported on NIOS II platform to estimate the urea concentration. The acquired data was processed using PLS algorithm in 'C language' for computing the unknown concentration of urea. The system for multivariate analysis has been tested by running the SIMPLS C algorithm to estimate the level of soil urea concentration. The spectral data was stored in the flash memory of the DE2 board in a zip format. The SIMPLS algorithm reads the data from the flash memory and processes it and computes the prediction result. Depending on the estimated value of urea, an output message gets displayed on the LCD display. The concentrations of urea were varied from 0.5 to 3 and the rest of the constituents in the sample were kept at their normal value i.e. 1. The results obtained are as shown in table II. Figure 6 shows the estimated result of urea in a sample.

Table II. Results of Urea Estimation

Sample No.	NaCl	Potash	Lime	Phosphate	Urea_Actual	Urea_Pred	%Error
1	1	1	1	1	112.5	111.25	0.88
2	1	1	1	1	168.75	167.91	0.49
3	1	1	1	1	225	225.04	0.017
4	1	1	1	1	281.25	281.51	0.09
5	1	1	1	1	337.5	338.18	0.2
6	1	1	1	1	450	451.77	0.39
7	1	1	1	1	562.5	540.9	3.84
8	1	1	1	1	675	630.03	6.66

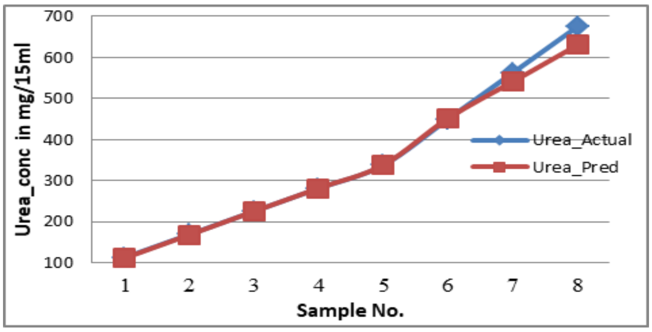


Fig. 6. Graph showing the actual and estimated values of urea

It was observed that by changing the concentration of urea in a sample and keeping rest of the constituents in the sample at their normal concentration value, the percentage error rate in the prediction varies. As the concentration of urea is varied below and above its normal value, it is observed that the percentage error rate in prediction increases. At sample no. 3 & 4 as shown in table 2, it is observed that error rate in the prediction is almost zero.

Depending upon the estimated value of urea concentration, the output displayed on the LCD display of the DE2 was “urea is normal”, “urea is above normal” or “urea is below normal”. Figure 7 shows the LCD display output.

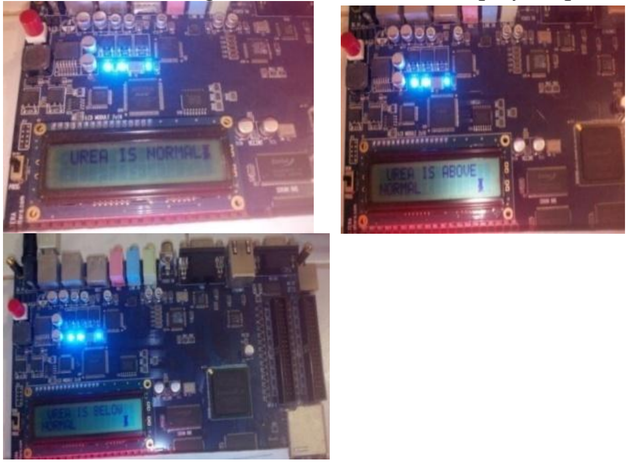


Fig. 7. Photos showing the LCD display

V. CONCLUSION

An RF cell was designed to obtain the spectra of samples consisting of mixture of various components taken under study. PLSR technique has been developed and ported on FPGA board to predict concentration of urea in a sample. Data lying between 10MHz and 500MHz has been used for calibration development and prediction. The system displays messages to indicate whether the concentration of urea in a sample is normal, above normal or below normal. The experimental results obtained indicate that the designed system can be used for the esrtimation of soil components as the results obtained in terms of percentage error rates are found to be within the required range for an instrumentation development. A further study can be made to find out the error rates in the prediction of other components in the sample taken in the study. We can also use different frequency ranges and find out which is the best possible frequency range suitable for the prediction of unknown components in a sample.

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