Photosynthetically Active Radiation (PAR) Sensor Using an Array of Light Sensors with the Integration of Data Logging for Agricultural Application

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***Abstract*—The study focused on the creation of a sensor that measures natural light coming from the sun. There are different kinds of measuring light and these are the LUX meter, Quantum Meters, Electrical Light meter and other kinds of sensor that measures light. One of these is the Photosynthetic Active Radiation (PAR). Studies show that the light in forest canopies typically requires a huge quantity of light sensors. Some of these light sensors usually require huge amount of money, hence, detailed studies for this agricultural used are very expensive. This study shows the creation and testing of a practical and inexpensive sensor for measuring photo-synthetic photon flux density or PAR. Detailed instructions are provided for assembly and calibration. The sensor was made from a blue enhanced silicon photodiode held within an 8mm substrate protective casing coated with IR blocking filter. The Apogee SQ-520 Quantum Sensor was used as a standard for comparison. The stability of the VTB8440BH sensor compared favourably to Apogee SQ-420 Quantum Sensor. Based on the data gathered, the group was able to obtain the linearity of the proposed and commercially PAR sensors which has a correlation coefficient of 0.99. This means that it is close to +1, thus, it has a positive correlation coefficient. The group was able to meet and satisfy all of the required objectives stated in the paper for the creation of Photosynthetically Active Radiation Sensor using an Array of Light Sensors with the Integration of Data Logging for Agricultural Application.**

Keywords-Photosynthetically Active Radiation, Data logging, Correlation, Quantum Sensor

I. INTRODUCTION

Light is probably the most important part in environmental sector affecting water use of in most plants and irrigation system. There are devices which can measure light or solar radiation one of which is called PAR sensors. Photosynthetically active radiation (PAR) is a segment of solar radiation, which has a range of wavelength of 400nm-700nm. This is the same wavelength that a human eye can see. It serves as an energy for the process of photosynthesis. Each plant species has a different response to the measurement of PAR [1]. For example, in the direct exposure of the sun a 37% threshold increase in apple fruit production while in the same PAR amount and exposure a 23% threshold increase in peach production [2]. Besides from agriculture, monitoring PAR can also be helpful in issues regarding weather forecast and global climate change [3].

One way of measuring PAR is by using a quantum sensor. The sensor is made up of a silicon photodiode, diffuser screen, and an optical filter for intercepting light that is not within the 400nm-700nm [4]. There are also other ways of estimating PAR. An example of it is to relate PAR to global solar radiation by using linear regression, but the relationship between the two depends on the weather conditions [5]. Another is by using atmospheric factors to estimate Photosynthetically Active Radiation [6].

PAR sensor measurements have high spatial variability in which measurements differ across different location. A multipoint sensor system is necessary to produce a reliable system for precise agriculture and environmental monitoring [7]. PAR data measurements are used as a model validation to analyse the effects of climate change, atmospheric chemistry and usage of land on net primary production and biogeochemical cycles [8]. With high end commercial PAR sensors and data loggers, it offers accuracy, reliability and durability that would fit in a multipoint sensor system. There are companies that offer different types of PAR sensor in which they offer a great measurement of sunlight [9]. However, these commercial sensors are not advisable for a small-scale agricultural operation because the commercial system is not flexible in terms of scalability and functionality resulting to expensive implementation of the system. This means that the number of sensors required can be prohibitive for many research in terms of the budget. Hence, the main problem that the study needs to address is that there is much to gain from building an alternative PAR sensor from off-the-shelf components.

The main objective is to present an alternative photosynthetic active radiation sensor with an integration of data logging system with the following specific objectives: (1) design a PAR sensor using an array of photodiodes together with a filter material that only allows 400-700 nm wavelength to pass through; (2) design a module that will store the measured value of the PAR sensor in a storage medium; (3) test and calibrate the proposed system for measuring and storing PAR measurements; and (4) compare the proposed system with a commercially available PAR sensor.

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This study focused on the design of Photosynthetic Active Radiation (PAR) sensor using readily available photodiodes, filters and custom data logger. The PAR sensor would focus on measuring the Photosynthetic Photon Flux Density (PPFD) which is in the form of micromoles of photons per meter squared per second (µmol m-2 s-1) with no specific plant species [10]. The sensor would be used in different agriculture applications for investigating photosynthesis and plant productivity. Monitoring the effects of the PAR value to the plants was part of this paper. The PAR sensor is only used during daytime where it would record the gathered data. In testing, there should be no obstruction between the sensor and the sunlight [11].

II. Methodology

A correlational research process was used to tackle 2 or more variables and assesses the statistical relationship between the two PAR sensors [12]. The research used to determine the linearity of both sensors and from there concluded the linearity of the proposed sensor vs the commercially sensors [13]. The study aimed to create a solution that can be an alternative to the existing PAR sensor.

A. *Hardware Development of the Proposed PAR Sensor System.*

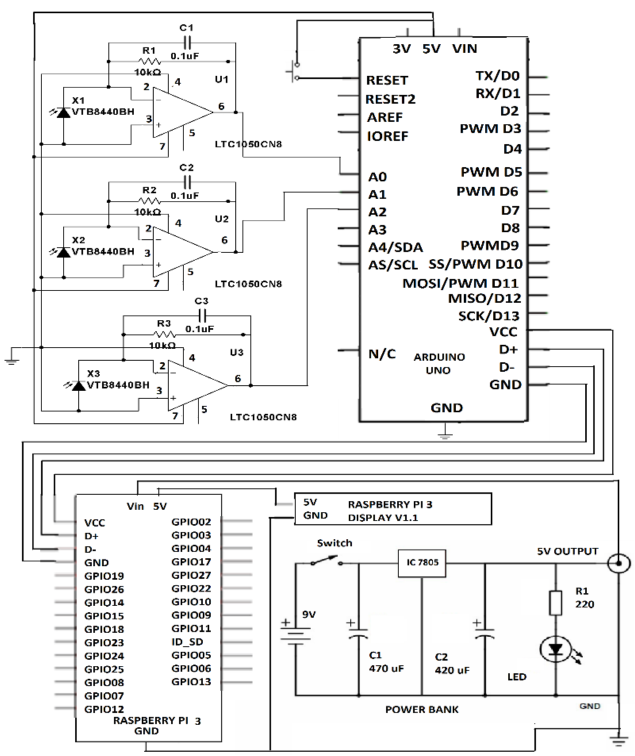

Figure 1. Schematic diagram of the par sensor array with the readout circuit

The proposed system would have three modules. The first module is an array of PAR sensor using filters and photodiodes that is on a flat surface [14]. Arranging the PAR sensor in an array provides multiple reading that were used to determine the PAR values. The PAR sensor measures the photosynthetic light emitted by the sun which passes through the optical filter that only allows 400-700nm and then to the array of silicon photodiode producing an analog signal and it is connected to a readout circuit which would condition the signal for the microcontroller module. The second module is the Arduino microcontroller. The analog signal coming from the readout circuit is converted to digital signal using the Arduino's analog-to-digital converter. After that the Arduino is programmed to transfer the results to the third module which is the Raspberry Pi. The Raspberry Pi as a microcontroller/mini pc,serve as the storage medium for the results. An LCD connected to the Raspberry Pi is programmed to display the results in the LCD display.

Fig. 1 A readout circuit would be used to amplify the analog signal for analog-to-digital conversion. As shown in figure 3 the proposed system connects the Si photodiode's positive (+) pin into the noninverting (+) pin 3 of the op amp and connects the Si photodiode's negative (-) pin into the inverting (-) pin 2 of the op amp. In addition to this a +5V supply is connected to the pin 7 and the ground is connected to the pin 4 of the op amp. A resistor and capacitor is connected as feedback of the circuit using op amps output pin 6 and the Si photodiode in pin 2. Connecting the Si photodiode this way results to amplifying the diode in a photovoltaic mode. This mode gives a higher sensitivity operation than the photoconductive mode which focuses on faster response than precision.

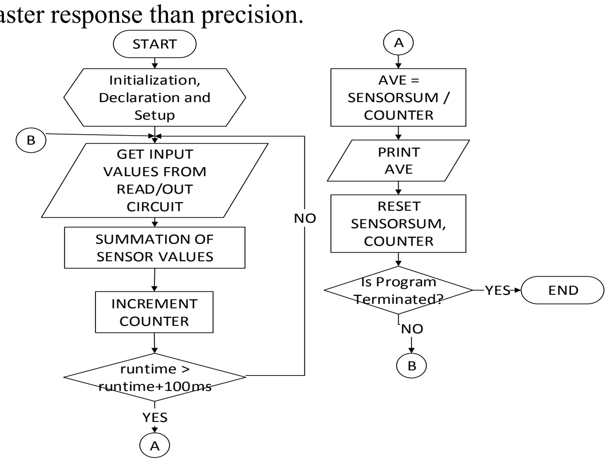

Figure 2. Proposed PAR sensor system arduino flowchart

B. *Software Development of the Proposed PAR Sensor System*

Fig. 2 shows the flowchart of the proposed PAR Sensor software. Before the main code started, the code would started to initialized the necessary variables which includes the analog pin assignments and calibration factors. After that the sensor would send the raw values to the Arduino Microcontroller. It should then be converted to its voltage value in millivolts (mV) and multiplied by a calibration factor that would give its PAR value. To reduce the noise from sensors values, a moving average filter algorithm is applied. It would add the measurements gathered within 1 second then divide it by the number of readings within that duration. The data from the sensors should be printed in serial output every second including its average.

Fig. 3 shows the flowchart of the proposed PAR sensor data logging system. Before the data logging system is started, the serial communication between the Arduino and RPI should be connected for it to start. After that initialization for necessary parameters which includes the creation of log files and GUI components. After that the main user interface for the data logging system should appear. If the start button is clicked, the values in the listbox would be cleared and the main_data function should be called.

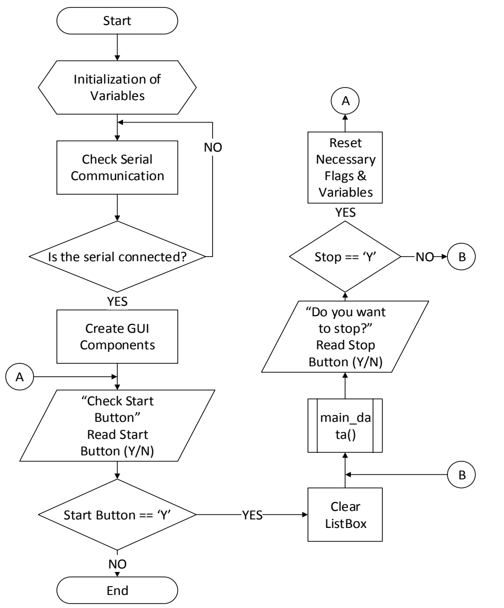

Figure 3. Proposed PAR sensor system raspberry pi flowchart

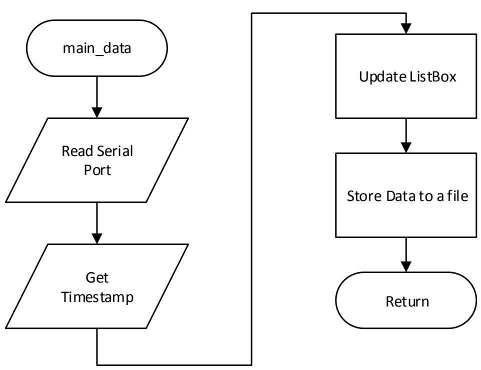

Figure 4. Main_data Flow chart

Fig. 4 shows the main_data function. This is where all the handling of data processing, formatting, and parsing that will be used for saving data and display. If the main_data function was called, the data from the serial port will be read and it would be parsed and formatted for display. The timestamp would also be generated. The data that are processed from the serial port and the timestamp generated is updated in the listbox and the labels. Then, the data is stored into a file, it should have two sets of log files; the data gathered per second and the average output of the sensor within 5 minute interval. The log files created is in CSV Format. The main_data function will continuously run every second until the Stop button is clicked.

C. System Calibration and Testing

The proposed sensor will undergo series of testing to avoid measurement errors which may result to erroneous results., the light sensors was tested first individually to verify that each sensor are giving the expected results when they are integrated as an array.

1. ***Calibration Factor:*** The proposed PAR sensor system and the commercial PAR sensors run simultaneously It was tested in a clear-sky weather condition to measure its peak value to be used for computing the calibration factor.

$$Calibration\ Factor = \frac{Maximum\ Reference\ Sensor\ Ouput}{Maximum\ Proposed\ Sensor\ Voltage\ Output} \tag{1}$$

2. **System Testing:** the sample system reading that is used for calibrating the system. The system is modified to have a smaller percent difference between the two sensors to improve their relationship. Trial 1 and 2 has a maximum percent difference of 6.1236% compared to the modified version of the system in Trial 3 and 4 that has only a maximum percentage of 2.7527%. The difference between the percentages showed a significant improvement in the system.

TABLE I. SUMMARY OF SYSTEM CALIBRATION AND TESTING DATA

	Proposed Sensor	**Reference Sensor**
	(mV)	(μmol $m^{-2}s^{-1}$)
Mean	3888.9707	1598.5771
Standard Deviation	102.4453087	84.40669584

3. **Summary of System Calibration and Testing:** Table 1: shows the summary of the data gathered during the calibration stage of the study. The peak value during each trial was selected. Based on the voltage output from the proposed PAR sensor and the readings from the USB Smart Quantum Sensor (SQ-420,Apogee) was close to the ideal 5 volts and 2000 μmol m−2s−1 respectively. The mean of the proposed sensor and reference sensor was used for computing the calibration factor. The calibration factor that the researchers used for the system testing is 0.4143 μmol m−2s−1 / mV.

The data gathered in the system testing as shown in table 2 were the collected average of 1 second results within 5-minute intervals. Based on table 3 the average absolute difference that was obtain in the system testing was 40.6148 (μmol m−2s−1) with a standard deviation of 36.2106. The difference between the two sensors could be an error due to the different spectral response of both sensors. The average absolute percent difference is 4.74% with a standard deviation of 0.034061666. This can be lowered if all the trials of the system testing were done during clear-sky conditions. Even if the sensors were tested close to each other to minimize. The spatial error would increase during cloudy weather condition, which was the reason for the largest error recorded of 19.9%. Also, large errors were observed when PAR values are greater than 1000 μmol m−2s−1.

TABLE II. PAR SENSOR SYSTEM DATA RECORDING

Date	Time	Proposed Sensor ($\mu mol\ m^{-2}s^{-1}$)	Reference Sensor ($\mu mol\ m^{-2}s^{-1}$)	Diff.	%Diff.
9/20/17	12:34 PM -1:04 PM	1076.0937	1187.4003	111.3067	9.83%
		1030.5921	1060.5506	29.9585	2.87%
		1010.673	1100.2745	89.6015	8.49%
		889.5893	992.6868	103.0974	10.95%
		1083.5932	1070.4546	-13.1386	-1.22%
		949.127	991.7782	42.6512	4.40%
10/10/2017	12:47 PM - 2:03 PM	1702.9433	1717.2127	14.2694	0.83%
		1187.5089	1264.8517	77.3427	6.31%
		612.3905	603.035	-9.3555	-1.54%
		528.4546	525.844	-2.6106	-0.50%
		436.1245	442.8257	6.7012	1.52%
		468.1206	482.3843	14.2637	3.00%
		703.0999	690.813	-12.2869	-1.76%
		434.623	442.7297	8.1067	1.85%
		375.2886	378.575	3.2864	0.87%
		426.8011	431.7887	4.9876	1.16%
		512.3024	509.1807	-3.1217	-0.61%
		522.7666	500.2113	-22.5552	-4.41%
		198.8047	196.04	-2.7647	-1.40%
		112.2717	116.304	4.0323	3.53%
		78.9088	78.916	0.0072	0.01%
		57.4931	70.224	12.7309	19.94%
10/11/2017	9:25 AM - 9:50 AM	1578.5516	1520.0907	-58.4609	-3.77%
		1243.6745	1280.7123	37.0378	2.93%
		1630.5771	1638.5127	7.9356	0.49%
		1363.313	1361.5727	-1.7404	-0.13%
		1726.8145	1756.0187	29.2041	1.68%
10/12/2017	1:32 PM -3:59 PM	1440.2847	1332.378	-107.9067	-7.78%
		1254.5924	1165.8427	-88.7497	-7.33%
		1209.0609	1127.8367	-81.2242	-6.95%
		1241.718	1153.371	-88.347	-7.38%
		1106.0798	1027.124	-78.9558	-7.40%
		1026.275	958.535	-67.74	-6.83%
		1011.8446	940.0993	-71.7453	-7.35%
		750.1876	710.936	-39.2516	-5.37%
		779.1261	740.3667	-38.7594	-5.10%
		789.7905	734.0157	-55.7748	-7.32%
		735.0165	715.1667	-19.8498	-2.74%
		822.229	779.5297	-42.6993	-5.33%
		783.0704	722.0487	-61.0218	-8.11%
		735.4242	702.8933	-32.5309	-4.52%
		694.5081	655.7957	-38.7124	-5.73%
		670.5472	632.9553	-37.5919	-5.77%
		593.9908	561.0527	-32.9381	-5.70%
		518.7594	493.801	-24.9584	-4.93%
		505.1254	493.884	-11.2414	-2.25%
		441.0675	410.634	-30.4335	-7.15%
		438.3359	446.0107	7.6748	1.74%
		400.3157	368.631	-31.6847	-8.24%
		365.6371	383.6773	18.0403	4.82%
		414.8833	421.9873	7.104	1.70%
		398.1292	376.766	-21.3632	-5.51%
		341.6282	324.8403	-16.7879	-5.04%
		268.4641	251.141	-17.3231	-6.67%
		228.3787	217.2917	-11.087	-4.98%
10/13/17	10:57 AM - 12:24 PM	1641.2643	1507.367	-133.8973	-8.51%
		1643.434	1621.7727	-21.6613	-1.33%
		1354.0675	1288.45	-65.6175	-4.97%
		1208.1737	1102.3653	-105.8083	-9.16%
		1028.5424	1117.8703	89.3279	8.32%
		1536.8107	1479.6357	-57.1751	-3.79%
		1642.7824	1642.6473	-0.135	-0.01%
		1679.2013	1549.717	-129.4843	-8.02%
		1503.5651	1457.4277	-46.1375	-3.12%
		1539.0996	1399.1223	-139.9772	-9.53%
		1209.0407	1204.789	-4.2517	-0.35%
		1263.8399	1178.6237	-85.2162	-6.98%
		1060.2479	1040.1977	-20.0502	-1.91%
		1089.6818	1049.585	-40.0968	-3.75%
		890.8992	855.9293	-34.9699	-4.00%
		754.7945	740.5543	-14.2402	-1.90%
		634.2373	634.4583	0.221	0.03%
		521.5069	498.498	-23.0089	-4.51%

TABLE III. PAR SENSOR SYSTEM DATA RECORDING

	Difference	%Difference
Mean	40.6148	4.74%
Standard Deviation	36.2106	0.034061666
Maximum	139.9772	19.94%
Minimum	0.0072	0.01%

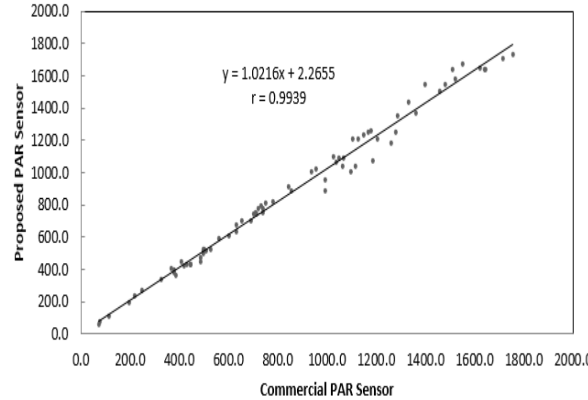

Figure 5. Proposed PAR sensor vs commercial PAR sensor

Fig. 5 Linear Regression was applied to the data gathered as illustrated in figure 1. Based on this figure, when the proposed PAR system increased its value the commercially available PAR sensor also increased. The value of r which is the correlation of coefficient is between -1 and +1 and is closer to +1. These result shows that there is a strong positive relationship between the proposed PAR sensor and the commercially available PAR sensor.

III. CONCLUSIONS

The proposed system containing an array of sensors with a data logger was built using the integration of Raspberry Pi, Arduino, and a read/out circuit. The read/out circuit contained the 3 Si photodiodes sensor with a built in infrared filter which intercepts wavelengths outside the range of visible light.

Data gathered were saved in the raspberry pi for detailed review process as data log was included in the proposed system. Aside from being a storage medium, the raspberry pi is connected to the LCD screen displaying the systems data gathering information including the time, date, reading from the three Si photodiodes and the average of the three Si photodiodes.

The comparison of the commercially available PAR sensor and the proposed PAR sensor during the system testing resulted to an absolute difference error ranging from +4.7% to -4.7%. Using the linear regression and the analysis of the correlation of the data showed a close relationship in the reading from the proposed PAR sensor and the commercially available PAR sensor and based on the data gathered, the group was able to obtain the linearity of the proposed and commercially PAR sensors which has a correlation coefficient of 0.99 it means that it is close to +1 which means it has a positive correlation coefficient. The results of statistical testing applied to the regression coefficients show that there is a strong relationship between the Proposed PAR Sensor system and the reference sensor.

REFERENCES

[1] Zervoudakis, G.,Salahas, G.,Kaspiris, G.,Konstantopoulou, E. (2012). Influence of Light Intensity on Growth and Physiological Characteristics of Common Sage (Salvia officinalis L.). *Brazilian Archives of Biology And Technology, Volume 55*, 89-95.

[2] C-Hoffmann, S. U.,Hall, A. J., Rousseaux, M. C. (2012). Fruit, yield, and vegetative growth responses to photosynthetically active radiation during oil synthesis in olive trees. *Scientia Horticulturae, Volume 150*, 110-116.

[3] Cruse, M., Kucharik, C., Norman, J. (2015). Using a Simple Apparatus to Measure Direct and Diffuse Photosynthetically Active Radiation at Remote Locations. PLoS ONE.

[4] Mizoguchi, Y., Aoshima, T., Ohtani, Y., Nakai, Y. (2010). Comparison of the characteristics of five quantum sensors. *Bulletin of FFPRI, Volume 9*, 113-120.

[5] Mizoguchi, Y., Yasuda, Y., Ohtani, Y., Kominami, Y.,Watanabe, T. (2014). A practical model to estimate photosynthetically active radiation using general meteorological elements in a temperate humid area and comparison among models. *Theoretical and Applied Climatology, Volume 115*, 583-589.

[6] Pankaew, P.,Pattarapanitchai, S.,Buntoung, S. (2014). Estimating Photosynthetically Active Radiation using an Artificial Neural Network. *International Conference and Utility Exhibition 2014 on Green Energy for Sustainable Development*, 1-4.

[7] Aguilar, C., Herrero, J., & Polo, M. (2010). Topographic effects on solar radiation distribution in mountainous watersheds and their influence on reference evapotranspiration estimates at watershed scale. *Hydro Earth Syst. Sci Volume 14*, 2479-2494.

[8] Long, M. H.,Rheuban, J. E.,Berg, P.,Zieman, J. C. (2012). A comparison and correction of light intensity loggers to photosynthetically active radiation sensors. *Limnology and Oceanography: Methods. Volume 10*, 416-424.

[9] Tamasi, M.J.L.,Martinez Bogado, M.G. (2013). A theoretical approach to photosynthetically active radiation silicon sensor. *Thin Solid Films, Volume 534*, 497-502.

[10] Sudhakar, K.,Srivastava, T.,Satpathy, G.,Premalatha, M. (2013). Modelling and estimation of photosynthetically active incident radiation based on global irradiance in Indian latitudes. *International Journal of Energy and Environmental Engineering 2013*, 4-21.

[11] Galindo, P.,Zayer, R. (2014). Distortion Driven Variational Multi-view Reconstruction. *3D Vision (3DV), 2014 2nd International Conference, Volume 1*.

[12] Lin, P-Y.,Soriano, A.N.,Leron, R.B.,Li, M-H. (2010). Electrolytic conductivity and molar heat capacity of two aqueous solutions of ionic liquids at room-temperature: Measurements and correlations. *The Journal of Chemical Thermodynamics, Volume 42,* 994–998.

[13] Camposano, M.A., et al. (2015). Measurement of Skin Impedance, Skin Temperature, and Akin Optics and Correlative with Blood Glucose. *Undergraduate Thesis Mapua Institute of Technology, 2015*.

[14] Poullain, E.,Garestier, F.,Bretel, P.,Levoy, F. (2012). Modeling of ALS Intensity Behavior as A Function of Incidence Angle for Coastal Zone Surface Study. *Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International.*