A WiFi based Smart Wireless Sensor Network for an Agricultural Environment

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***Abstract*— The main objective of the present work is to develop a smart wireless sensor network (WSN) for an agricultural environment. Monitoring of environmental factors have increased in importance over the last decade. In particular monitoring agricultural environments for various factors such as temperature and humidity along with other factors can be of significance. A traditional approach to measuring these factors in an agricultural environment meant individuals manually taking measurements and checking them at various times. The ability to document and detail changes in parameters of interest have become increasingly valuable, to such an extent that unattended monitoring systems have been investigated for this function. This study investigates a remote monitoring system using WiFi, where the wireless sensor nodes are based on WSN802G modules. These nodes send data wirelessly to a central server, which collects the data, stores it and will allow it to be analyzed then displayed as needed.**

Keywords-component; WiFi; 802.11g; wireless sensor network; WSN802G modules; smart sensing; agricultural monitoring; temperature measurment; humidity measurment; atmospheric pressure measurement; soil moisture; water level; light detection;

I. Introduction

Within an agricultural environment, awareness has increased about implementing technology into the industry [1]. Manual collection of data for desired factors can be sporadic, not continuous and produce variations from incorrect measurement taking. This can cause difficulty in controlling these important factors [1][2][3]. Wireless distinct sensor nodes can reduce time and effort required for monitoring an environment. The logging of data allows for reduction of data being lost or misplaced. Also it would allow placement in critical locations without the need to put personnel in hazardous situations. Monitoring systems can ensures quicker response times to adverse factors and conditions, better quality control of the produce and a lower labor cost. The utilization of technology would allow for remote measurement of factors such as temperature, humidity, atmospheric pressure, soil moisture; water level and light detection. There appears to be increased development aimed towards wireless solutions compared to wired-based systems [1][4][5]. One particular reason is that the sensor location can often require being repositioned and a traditional wire layout could cost a substantial deal of time and energy in order to address such wiring problems[5][6]. The system aims to reduce the cost and effort of incorporating wiring and to enhance the flexibility and mobility of the selected sensing points.

The wireless sensor network looks at being a comparatively self-organizing system [6]. It allows sensor nodes to connect to the network and have their data logged to the allocated sensor server selected. The present paper describes the development of a wireless agricultural environment measuring temperature, humidity, atmospheric pressure, soil moisture; water level and light detection. Where the wireless connection is implemented to acquire data from the various sensors, in addition to allow set up difficulty to be as reduced.

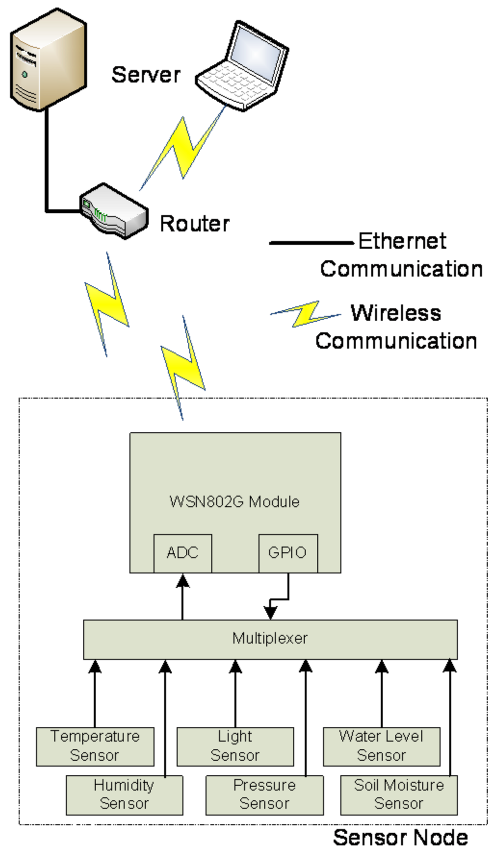

Figure 1. Block diagram of System being developed.

II. Description of System being Developed

The system being developed is based on the WSN802G WiFi / 802.11 module in order to communicate data to a selected Server (Figure 1). The WSN802G module is connected to the various sensors with analogue outputs via a multiplexer used for signal gating. Where two particular signals can be selected based on the General Purpose Input/Output (GPIO) values from the WSN module. The signals are measured and converted to values that are then transferred to a selected server connected to same network via a standard Wireless-G router. The server can be connected to the network either Wireless itself or through a wired Ethernet connection. The server stores the received data into a comma-separated values (CSV) file format which can be straightforwardly imported into a database, excel file or other software in order to perform analysis and displaying of data.

III. Agricultural Factors Investigated for Measurement

A. Temperature

One vital measurement essential for monitoring in many agricultural environments is temperature. Dependent on the agricultural product being grown temperature can affect growth such as germination, sprouting, flowering and fruit development [7]. Particular agricultural products have suitable temperature ranges; accordingly the system investigates using the DS600 temperature sensor integrated circuit produced by Maxim- Dallas Semiconductor (Figure 2).

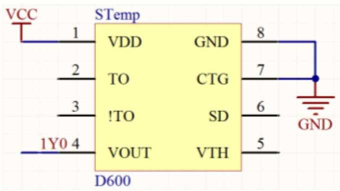

Figure 2. Configuration of DS600 Temperature Sensor.

The DS600 provides an analogue output that varies depending on the temperature being measured [8] (Figure 3). The voltage output is then connected to one of the multiplexer channels allowing for the desired signal to be selected and sent to the ADC on the WSN802G module allowing for measurement and transmission. The output of the DS600 is linear with regards to temperature and is proportional to degrees centigrade [9].

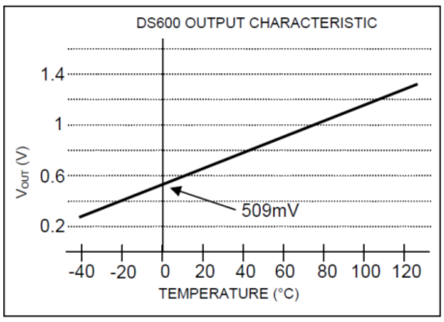

Figure 3. DS600 output characteristic from specification.

The output of the sensor is measured by the WSN802G module's ADC and then transmitted to the selected server IP address to be logged and analyzed. This value can then be used to calculate the value of temperature (T) where V_{OS} is equal to 509mV and $\Delta V/\Delta T$ is equal to 6.45mV/°C (2).

$$V_{OUT} = (\Delta V / \Delta T) \times T + V_{OS} \tag{1}$$

$$T = \frac{(V_{OUT} - V_{OS})}{\Delta V / \Delta T} \tag{2}$$

Measurements logged for temperature taken within an enclosed area can be seen over an approximately 12 hour period (Figure 4).

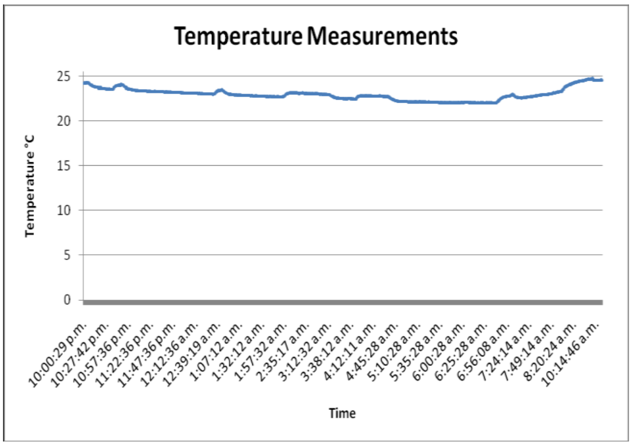

Figure 4. Logged Data for DS600 Temperature Sensor Output.

B. Humidity

Humidity is of importance as when levels are too low or high agricultural products can suffer. If humidity is held below 50 percent for extended periods of time, growth can suffer as lose of water from leaves might be faster than replacement. Similarly if Humidity is above 80 percent for extended period's risk of disease can increase [7]. The system uses the HIH-4010 Humidity sensor produced by Honeywell. The HIH-4010 provides an analogue output [8] that is connected to a voltage buffer followed by a voltage divider configuration (Figure 5). This is in order for the voltage value to be within the WSN802G ADC's voltage range. The voltage output is then connected to one of the multiplexer channels.

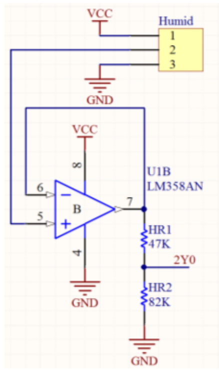

Figure 5. Configuration of HIH-4010 Humidity Sensor.

Various calculations are needed in order to get the humidity value from the analogue output [10]. There is a need to calculate the Sensor's Relative Humidity (RH) value dependent upon Voltage Supply (V_{SUPPLY}) (3). For a system that would run of battery power it is important to know Voltage Supply over different periods, as both the Humidity sensor and WSN802G module are running on the same power supply the regular voltage readings by the WSN802G can be used for calculation. There also requires some compensation for temperature (T) (4) which will be acquired from the DS600 temperature sensor [8]. The voltage divider configuration implemented also needs to be considered when performing the calculation of the result (5).

$$V_{SensorOut} = V_{Supply}\left[0.0062(SensorRH) + 0.16\right] \quad (3)$$

$$RH_{TempCom} = \frac{SensorRH}{1.0546 - 0.00216T} \quad (4)$$

$$V_{OutDiv} = \frac{HR2}{HR1 + HR2} V_{SENSOROUT} \quad (5)$$

Measurements logged for Humidity taken within an enclosed area can be seen over a 24 hour period (Figure 6).

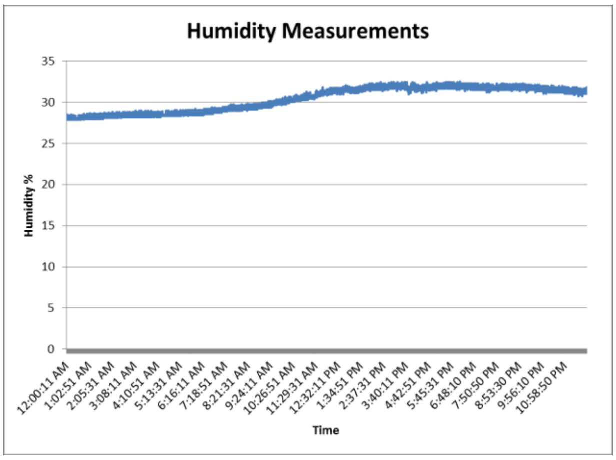

Figure 6. Logged Data for HIH-4010 Humidity Sensor.

C. Light

The measurement of light intensity and duration can be of significance as in certain cases it has an effect on growth processes of farm and plants in an agricultural environment. Monitoring light for control and management of light sources can play a role with flowering, blooming and ripening of produce [7][8]. It could be of use in a system that utilizes or implements supplemental lighting options. The system investigates the use of an APDS-9002 ambient light photo sensor. The analogue output of the sensor connects to a load resistor and filtering capacitor (Figure 7). There after it's then connected to a multiplexer channel allowing for selection to one of the WSN802G ADCs.

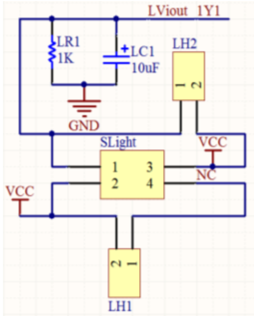

Figure 7. Configuration of ADPS-9002 Light Sensor.

The ADPS-9002 produces a current output that can be converted to a voltage using an external resistor LR1 [11]. The value of the resistor determines the current-to-voltage conversion (Figure 8) [11]. The capacitor in parallel with the resistor acts as a low pass filter to deal with certain noise present.

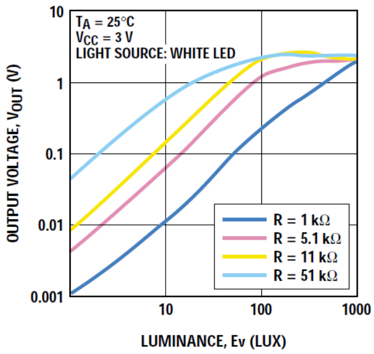

Figure 8. ADPS-9002 Specification for Output Voltage vs. Luminance at Different Load Resistor.

D. Pressure

Air pressure measurement is a feature that is of interest, as it has relationship to other weather factors that might be used for prediction of upcoming changes in the environment. Low pressure is often associated with poor weather, with a rapid change in pressure occurring meaning possible radical weather changes [8]. The system investigates using a NPP-301 NovaSensor Pressure Sensor (Figure 9) produced by GE Industrial, Sensing which has the voltage output linearly proportional to input pressure [12].

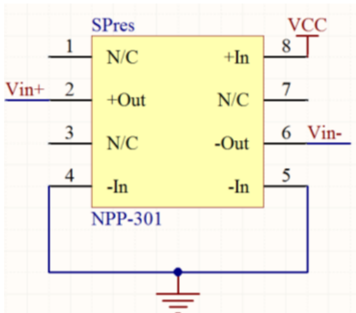

Figure 9. Configuration of NPP-301 Pressure Sensor.

The system implements an instrumentation amplifier in order to amplify the differential signals from the NPP-301 bridge sensor (Figure 10). The NPP-301 parameters have a Full Scale Output of 60mV, linearity of ±0.20%FSO and offset of ±10mV/V.

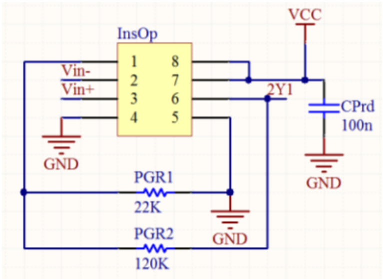

Figure 10. Configuration of Instrumentation Amplifier.

As the Full Scale Output was only 60mV the small differential voltage was amplified for better use with the WSN802G ADC. The Gain of the instrumentation amplifier was set by the external resistors PGR1 and PGR2 to obtain the desired gain value (6).

$$G = 5 + 5\left(\frac{PGR2}{PGR1}\right) \tag{6}$$

E. *Water Level and Soil Moisture*

The measurement of water level or soil moisture can be of significance with regards to agricultural products for their survival and growth. The utilization of the VG400-LV probes produced by Vegetronix are used for the measurement of water level and soil moisture. They are insensitive to water salinity and are designed to have low power consumption [13]. The Vegetronix VG400-LV Specification illustrates measurement of voltage output volumetric water content (VWC) in a particle type of soil (Figure 11) [14]. Similarly there is a distinct relationship with water level adjacent to measuring probe.

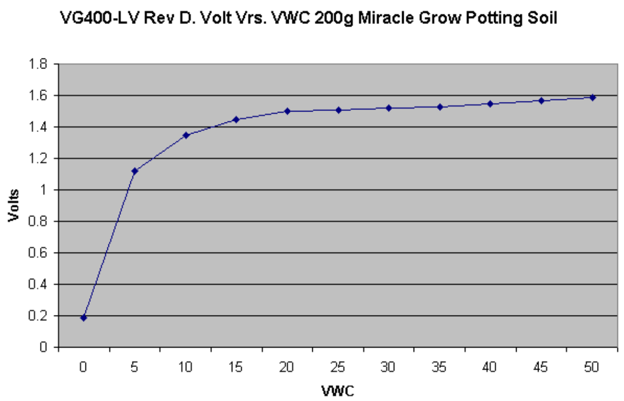

Figure 11. Vegetronix VG400-LV Specification measurement of voltage output volumetric in Potting Soil.

IV. Module Connection

A. *Multiplexer Connection*

The WSN802G module and its ADCs are connected to the various sensors with analogue outputs via a multiplexer used for signal gating. The various sensors are connected to different channels of the multiplexer and the two ADCs; ADCX and ADCY of the WSN802G module are connected to the multiplexer's 1-COM and 2-COM ports respectively. The WSN802G has General Purpose Input/Output (GPIO) pins where the system uses the GPIO pins GPIO2 and GPIO3 as outputs to select multiplexer channels connected to the ADC at specific times (Figure 12). The GPIO0 and GPIO1 are used as inputs that are connected to GPIO2 and GPIO3 respectively in order to transmit their values to be logged.

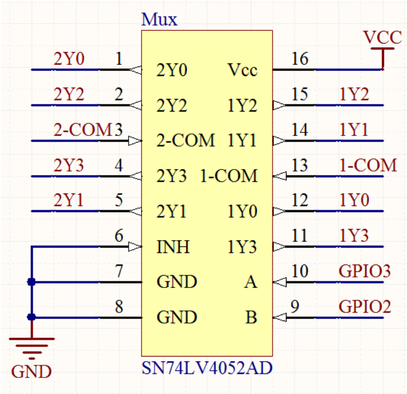

Figure 12. Configuration of Multiplexer with GPIOs as Inputs to A and B

B. *ADC Voltage Protection*

The WSN802G module and its ADCs have a maximum voltage range that the system utilizes, though the majority of sensors used should remain within the required range, a TLV431 three terminal adjustable shunt regulator was used to restrict the voltage maximum as a precaution (Figure 13).

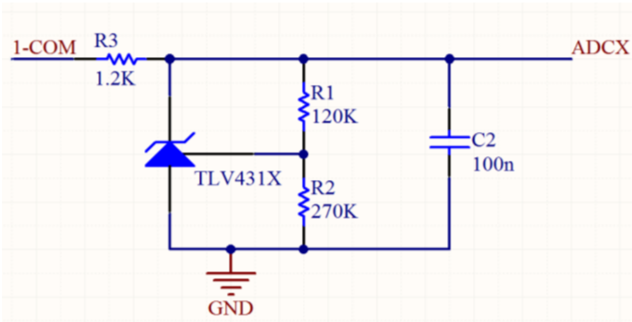

Figure 13. Configuration of TLV431 for ADC Voltage Protection.

The output voltage value of the TLV431 can be set between a range of 1.24 to 18V [15] where the values of R1 and R2 determine the value for output voltage (7).

$$V_{OUT} = V_{REF}\left(1 + \frac{R1}{R2}\right) \tag{7}$$

The system has the TLV431 configured to limit Vout to a maximum of 1.8V so to be within the WSN802G ADC voltage range. The ADC protection configuration suitably limits the maximum voltage output, while maintaining a suitable linear voltage for the other values that are within the acceptable range (Figure 14).

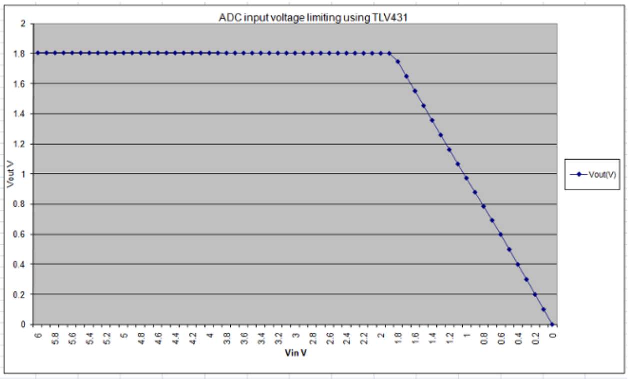

Figure 14. Voltage Output Maxiumum Limited by TLV431 over various Voltage Inputs.

V. WSN802G MODULE

A. WSN Specification

The system being developed is based on the WSN802G WiFi / 802.11 module in order to communicate data to a selected server from various sensor nodes. The WSN802G module is compatible with standard 802.11b/g/n routers. The WSN802G module is able to go into sleep while still remaining part of a 802.11b/g/n network [16]. The system has applications running on a server or PC allowing for communication with one or more WSN802G sensor nodes. The sensor nodes can be used with routers that are also serving other applications.

The WSN802G radio modules can operate from an unregulated DC input in the range of 3.0V to 3.63V, it includes two 10-bit ADC inputs. The ADC measurements are triggered and added to the automatic I/O Reports that are communicated to the server. The WSN802G includes four primary GPIOs (Figure 15) which when programmed as inputs, are captured as part of the automatic I/O Report and also transmitted to server.

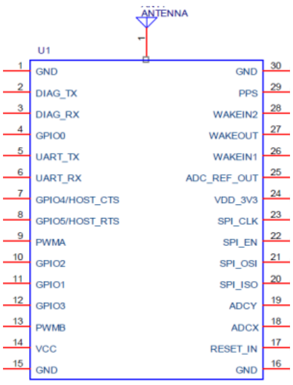

Figure 15. WSN802G Module Pin Configuration.

B. WSN802G Configuration

WSN802G modules will only accept wireless application commands from and send wireless application commands data/replies to the IP address of the server running their sensor application [16]. The server IP address can be configured in the SensorServerIP parameter in the WSNConfig application produced by RFM. WSNConfig provides users with their current IP address from the computer running the application (Figure 16). This allows relative ease for setting the SensorServerIP parameter, in particular for users inexperienced with acquiring network parameters like IP address. The WSNConfig application can be used to update the modules various elements, such as the GPIO states used for selection of multiplexer channels, changes to AutoReportInterval that determines how regular I/O Reports occur as well as other module configuration that are of use.

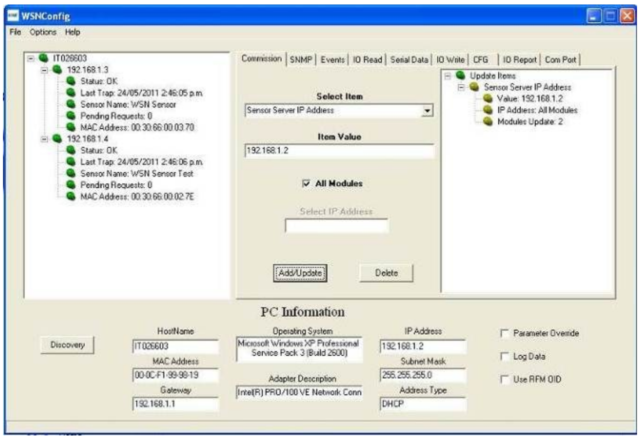

Figure 16. WSNConfig Application for setting SensorServerIP and other Module Parameters of System.

C. Data Logging

The system uses the WSNApp application (Figure 17) based on the original source code provided with the WSN802G development kit, where changes were made to the graph plotting and in order to log the data received into a comma-separated values (CSV) file for analysis.

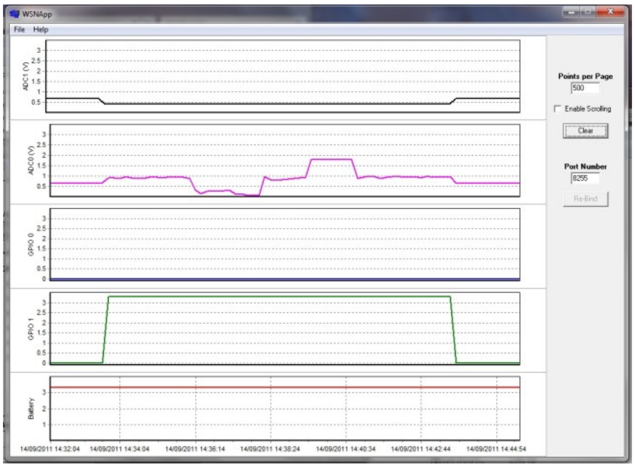

Figure 17. Modified WSNApp Application that Logs received Data when Run.

The data values logged are obtained from the I/O Report. The I/O Report datagram [16] demonstrates various objects of interest (Figure 18). The I/O Report contains values for source MAC address, ADC values, module voltage supply, Received Signal Strength Indicator (RSSI) and the GPIO states defined as inputs. The information is generated depending on the defined time between reports called the AutoReportInterval and in response to a user initiated IO_READ_REQUEST.

Byte 0	Byte 1	Byte 2	Byte 3
WSN802G Protocol Identifier = 0x52464D49			
Opcode = 0x0001		Transaction ID = varies	
Timestamp [7..4]			
Timestamp [3..0]			
MAC Address Bytes [5..2]			
MAC Address Bytes [1..0] (sender)		ADC0	
ADC1		VOLT	
RSSI		GPIO	

Figure 18. Datagram of I/O Report used for reporting of I/O values

When the modified WSNApp application is run it creates a CSV file in the same directory as the WSNApp application being executed. A CSV file with a filename of the current date is created in the form of “DD-MM-YYYY.csv”, for example a new log file created for the 14th of September 2011 would be "14-09-2011.csv". If a file already exists for logging of data for that date it will carry on adding entries to that file. The data logged per I/O Report entry is Timestamp, Source IP Address, Source MAC Address, ADC0 value, ADC1 value, Battery/Supply Voltage, GPIO0 and GPIO1 values and RSSI (Figure 19). This current configuration creates relatively small file sizes with 7500 sets of readings logged in an approximately 520KB file size. The MAC address is logged as well as IP address as data can be sent unsolicited and the MAC address being quite unique is provided to identify the sender. It is particularly helpful in situations where DHCP is used and the IP address is initially unknown or if the sender’s IP address has been exchanged for Network Address Translation NAT [16].

TIMESTAMP	SOURCE_IP_ADDRESS	SOURCE_MAC_ADDRESS	ADC0	ADC1	BATTERY	GPIO0	GPIO1	RSSI
14/09/2011 14:11:21	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-53
14/09/2011 14:11:24	192.168.1.4	00:30:66:00:02:7E	0.659824	0.689736	3.332	0	0	-38
14/09/2011 14:11:31	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-56
14/09/2011 14:11:34	192.168.1.4	00:30:66:00:02:7E	0.665103	0.695015	3.332	0	0	-42
14/09/2011 14:11:41	192.168.1.3	00:30:66:00:03:70	1.39179	0.939589	3.625	3.3	3.3	-53
14/09/2011 14:11:44	192.168.1.4	00:30:66:00:02:7E	0.906158	0.41173	3.332	0	3.3	-42
14/09/2011 14:11:51	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-54
14/09/2011 14:11:54	192.168.1.4	00:30:66:00:02:7E	0.855132	0.41349	3.332	0	3.3	-42
14/09/2011 14:12:01	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-53
14/09/2011 14:12:04	192.168.1.4	00:30:66:00:02:7E	0.659824	0.695015	3.332	0	0	-42

Figure 19. Logged data from CSV file displayed in Microsoft Excel where each node has the AutoReportInterval set for 10 seconds.

VI. CONCLUSIONS AND FURTHER INVESTIGATION

The current system still in the early stages of development performs well for transferring and logging of values from the various sensor nodes. It allows for relatively easy connection to nodes and communication. Further work is required with regards to battery and self-powering from solar panels or other renewable sources. The system will allow for additional or interchangeable sensors to be connected as the need occurs in the future. Further investigation is planned for integrating the measurement of nitrates in water sources near agricultural environments [17]. This is of interest due to the health concerns connected with nitrates for example Methemoglobinemiaas. There is a wish to create and have an application to perform analysis of the data sent and received, where the calculation of the corresponding ADC values are converted to sensor measurement values with minimal user intervention. The analysis application should account for sensor value correction, such as pressure might require adjustment with height above or below sea-level in order to be comparable over various areas. The system allows for relatively easy use and can be operated with standard commercial products that are widely in use allowing users to utilize equipment already in use.

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