Designing a Wireless Sensors Network for Monitoring and Predicting Droughts

A Gaddam, M Al-Hrooby, W F Esmael,
Center for Engineering & Industrial Design
Waikato Institute of Technology
Hamilton, New Zealand
Anuroop.Gaddam@wintec.ac.nz

Abstract— **Global warming and lack of rain were the main problems that caused increased drought around the world. In New Zealand, according to National Institute of Water and Atmospheric Research (NIWA) the drought in 2012 and 2013 was the worst drought in the last 70 years. Therefore, there is a need for technological intervention to monitor basic information about the weather and soil condition in order to identify and predict drought conditions. Initial experiments have shown that the proposed wireless sensor drought monitoring system is capable of remote real-time monitoring for extended periods. This monitoring can also help identify drought in the early stages and thereby indicate promptly when to take corrective measures. Intelligent sensors in a wireless network monitor the soil condition. These sensors collect various environmental; parameters and then send the pre-processed data wirelessly to a base station. From the base station this data uploads every two seconds to the cloud (internet) for further analysis. If a drought condition is identified by the monitoring system then an alert message is sent to the user via text message or email.**

Keywords-wireless sensor network, drought monitoring, Internet of things digital signal processing, internet of things, zigbee, raspberry pi, remote sensing

I. Introduction

The climate is getting hotter for several reasons, such as greenhouse gas emissions, population growth. Thus, the environmental problems will increase and affect soil condition. Global temperatures have increased by about 0.75°C in the past 100 years as shown in Figure 1 [1].

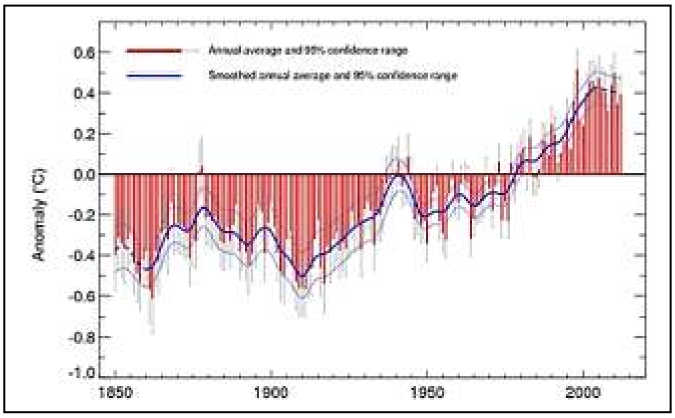


Figure 1. Change in temperatures around the world in the last 100 years [3]

Drought refers to a lasting water shortage due to water consumption or water demand higher than water supply [2]. This leads to unbalanced water cycling. For example, insufficient rainfall and strong vaporization result in continued loss of soil water for subsequent drought. Generally, there are three concepts of drought, meteorological, hydrological, and agronomic/agricultural. Global warming is one of the primary causes of drought around the world. Scientific studies have shown that despite all the strong measures to reduce global warming it is still happening [3]. Therefore, there is need for technological intervention to monitor the basic information about the weather and soil condition in order to identify and predict drought conditions.

It is well known fact that environmental monitoring is remote and widely distributed. The traditional approach to analyzing soil parameters is doing an on-the-spot evaluation, which is always a very inconvenient procedure and require additional labor. Several soil monitoring systems were developed to [4] make use of the technology. However, these systems are mainly connected by cables to transmit and collect soil data and require a power supply distributed across vast remote farms. Data and power lines make the whole system very hard to deploy, difficult to expand, and costly to invest in.

In order to circumvent these problems, we designed a wireless drought monitoring system based on wireless sensor network. The proposed system can be a transition from traditional agriculture to modern agriculture, by monitoring various parameters in a farm, this system can facilitate the end-user with real-time information of the farm. This information can be accessed from anywhere around the work over the internet. This approach will play a greater role in the gathering of environmental information, and will help in the development of agricultural information resources [5]. By integrating Wireless Sensor Network (WSN) and Internet of things (IOT), we aim to develop a system that can report drought condition promptly and to help achieve smart, precision agriculture.

II. Drought Condition in New Zealand

In general, a drought is a rainfall decrease that may cause problems for farming and crop growth [6]. Soil is affected by the drought by losing water, humidity and nitrogen which is will reduce the soil productivity. For that reason this section will compare 2010, 2011, and 2012 for the soil moisture, the amount of drought and the climate change impact [6, 7].
After a three month period of extremely low rainfall, drought in the Waikato region of New Zealand was announced in January

2010. The soil moisture deficits continued until the end of May 2010, by which time there was an extreme drought in Auckland and the Waikato [8].

In 2011, the soil moisture deficits were short, especially in January. However, there was a huge drought in February 2011, so that significant soil moisture deficit was experienced by the end of February 2011 in most of New Zealand's cities. However, this drought considered somewhat in to August and September 2011, although there was little rain, there was a soil moisture flaws in end of the year in some of the South Island.

In 2012, soil moisture deficits were unusually prevalent in most of New Zealand by the end of January. In March, 2012, the drought was reducing and the soil become more productive but by the start of September the drought was back, and prevalent throughout New Zealand. In November, 2012 the drought was continuous for a long period of time in the North Island, which was unusual. According to the records held by NIWA, the drought in New Zealand continued until 2013, which meant that New Zealand recorded the highest drought for 70 years [8].

III. RELATED WORK

Several solutions are presented in the literature or available in the market, but they provide limited functionality, high cost, and constant maintenance issues. In Murcia, Spain an ecological horticultural enterprise [9, 14] has been established to wirelessly monitor the drought condition. The area selected is a semi-arid region, which makes drought a frequent concern. The project consists of two types of networks sensors and one wireless sensor network. The first sensor network is called 'Soil Mote'. It has ten nodes connected by a cable. This sensor monitors soil temperature, moisture content and salinity. The second sensor network is called 'Environmental Mote'. It also has ten nodes, which measure the ambient temperature and humidity in the field.

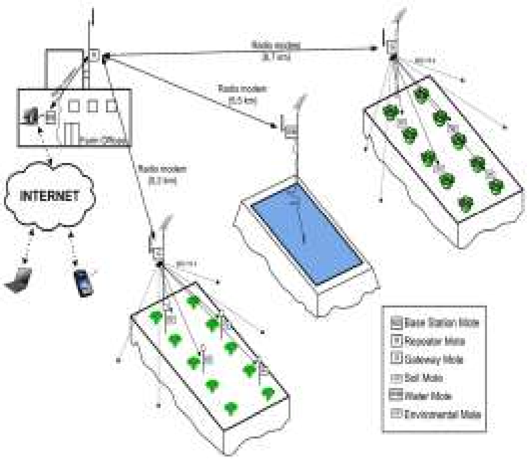


Figure 2. Functional block diagram of drought monitoring system[8]

The third wireless sensor is called 'Water Mote'. It is located in one of the ponds used to irrigate the crops on the farm. The 'Water Mote' monitors salinity and temperature to determine the water quality [12]. All the recorded data is sent to the central computer in the farm offices through a wired gateway as shown schematically in Figure 2. The drawbacks for this kind of system is the high cost of each sensor and wired installation [15]. Also, the data captured from this kind of system is on a local database which cannot be accessed by the users from a remote site [12, 13].

By considering all these issues, we have designed and developed a low-cost drought monitoring system that can be easily deployed and the captured data can be accessed from any computer or mobile device.

IV. SYSTEM ARCHITECTURE

The developed wireless system consists of five wireless sensor modules that are distributed over a farm, each sensor module monitors an area of about 1.8 km radius (Figure 3). These modules continuously collect key environmental parameters such as relative humidity, soil moisture content, sun light (luminance levels), and ambient temperature. The data collected by each individual sensor will be sent wirelessly to the base station through a Zig Bee radio. The recorded data is displayed on Google® Apps via Raspberry pi which is connected to the internet.

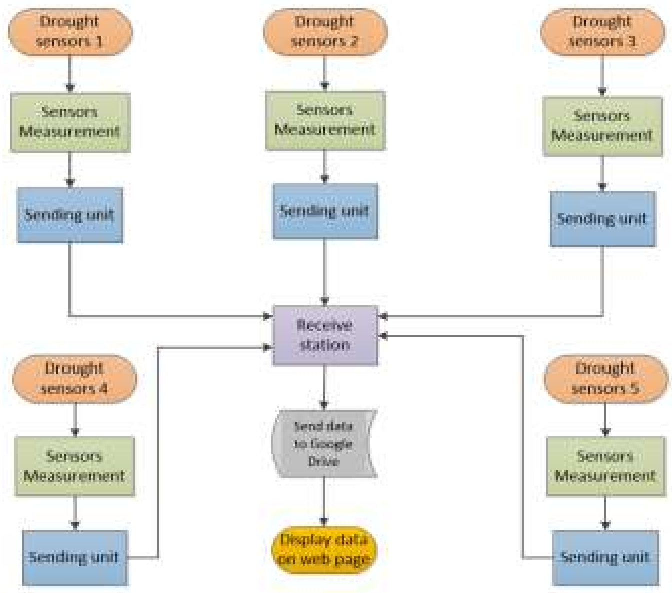


Figure 3. Functional block diagram of wireless drought monitoring system

This system pre-processes and sends the data wirelessly to Google® Apps to log and visualize captured data in the form of graphs in real time.

V. WIRELESS DROUGHT MONITORING SENSOR DESIGN

Three types of sensors and a Zig bee based wireless module were selected for the prototype monitoring system. To interface the sensors and, to process, wirelessly communicate the data from the sensors Arduino Uno which is equipped with ATmega 328 microcontroller chip was used.

A. Atmospheric Digital Temperature & Humidity Sensor

Relative humidity is a measure of the amount of water vapor contained within the air which is usually expressed as percentage humidity. Humidity is a very important environmental element that must be controlled for healthy plants. It controls the rate of transpiration and how the nutrients are received by the plant. The humidity levels works as a pressure cap on the plant, keeping the moisture in the plant, allowing it to have proper transpiration rates of the fluids. When humidity levels drop too low, the plants transpire at a rate much quicker than that of nutrient uptake. The nutrients or minerals do not transpire through the plant, only the water does. So this leaves behind a concentrated level of nutrients in the plant that will actually cause a nutrient overload, which is not desirable for plants. Conversely, when humidity levels get too high, moisture is building up on the plants and walls, forming whole colonies of molds, fungi, and mildews. Similarly the biochemical functions in plants that are required for growth and survival are temperature dependent. An optimal temperature range within which a particular plant species will be carrying out photosynthesis at its maximum rate (given that sufficient CO_2, water and light are also present) outside this range, photosynthesis and other plant processes begin to slow down, to the point where they stop and growth ceases.

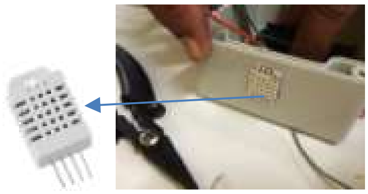


Figure 4. DHT22 Digital Temperature and Humidity Sensor

DHT22 sensor was chosen to monitor ambient temperature and humidity (Figure 4). This sensor proved to be reliable and stable. The output from DHT22 is a calibrated digital signal which can be interfaced directly to Arduino Uno port pin. It utilizes exclusive digital-signal-collecting-technique and humidity sensing technology that calibrates automatically. With its small size, low power consumption, and ability to function in all kinds of harsh application occasions, make the DHT22 suitable to use as a drought monitoring sensor. The output from this sensor is shown in the graph in Figure 5.

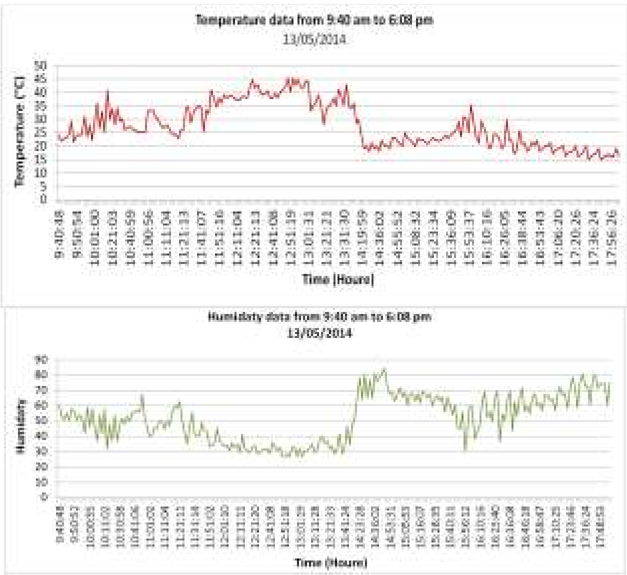


Figure 5. Data from DHT22 Digital Temperature and Humidity Sensor

B. Soil Moisture Sensor

Despite the importance of soil moisture information, widespread and/or continuous measurement of soil moisture is all but non-existent. "The lack of a convincing approach of measurement of soil moisture is a serious problem" [9]. Clearly, a need exists for continuous measurements of surface soil moisture. Also, remote soil moisture sensing increases the efficiencies of irrigation systems by preventing over watering and leaching of fertilizers and other chemicals offsite.

Soil Moisture sensor FC-28 comes with a pair of tech probes that can be inserted in the soil. A small current flow through the probes and the level of resistance will be measured. The resistance increases if the soil is dryer. The output from the sensor is an analogue output that can be connected to one of the analogue to digital port (ADC) available on the microcontroller board.

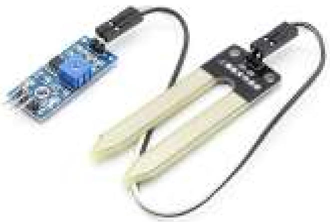


Figure 6. FC-28 Soil Moisture Sensor

FC-28 soil moisture sensor module has been calibrated in order to verify accurate operation of the device. A pot with potting soil was taken and the moisture levels are changed regularly. The pot was exposed to hot sun in order to get rid of the moisture. This allowed us to simulate a dry, arid soil environment. Similarly, the pot was watered to various levels, and the output from the sensor was recorded in Table I and is plotted as shown in Figure 7.

TABLE I. CALIBRATION RESULTS FOR (FC-28) SOIL MOISTURE SENSOR

Sensor reading (ADC value)	**Soil Condition**
0 ~300	Dry soil
300~700	Humid soil
700~950	Saturated with water

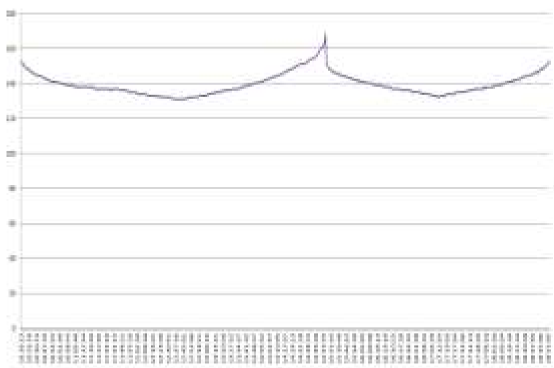


Figure 7. Data from Soil Moisture Sensor

C. *Light Intensity Sensor*

The cloudless skies associated with drought not only imply below-average rainfall, but also an increase in the amount of direct sunlight hitting the ground, which leads to higher evaporation rates. Intense heat and direct sunlight caused faster evapotranspiration rates. Without water, the plants go under stress and becomes dormant. BH1750FVI light intensity sensor was used to monitor the sun light as shown in Figure 8.

Figure 8. BH1750FVI Light Intensity Sensor

This module with a built-in 16 bit Analogue to digital converter generates a digital signal output. The data from this module is light intensity in lx (lux) with a resolution of 1 lx and a range of 1~ 65535 lx (Figure 9).

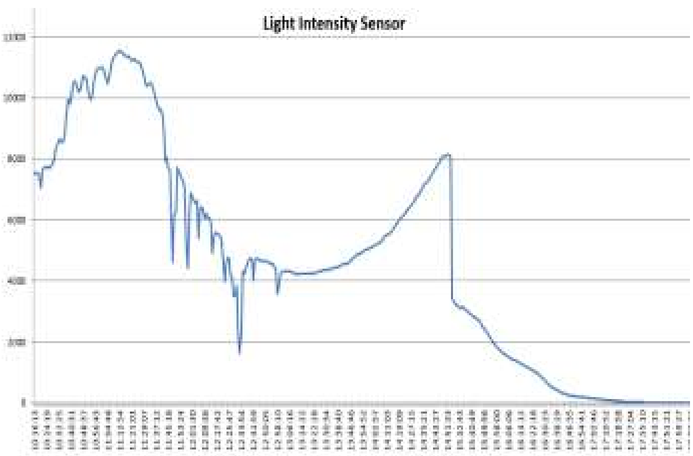


Figure 9. Data from light intensity sensor

D. *Interfacing Sensors*

Five drought sensing units were built for the drought monitoring system (Figure 11). Each sensor unit consists of three sensor modules that can monitor four different parameters. These sensors are DHT22 Temperature/Humidity sensor, FC-28 Soil Moisture sensor and Digital Light sensor.

Zig Bee wireless is an RF chip powered by 2.7 to 3.3V and can be connected to the microcontroller without any additional power-supply circuit. The XBee series-2 modules are configured as Coordinator AT and Router AT, which can transmit data up to 1.6 kilometers line of sight. . The three sensor modules are connected to the Arduino UNO as shown in Figure 10.

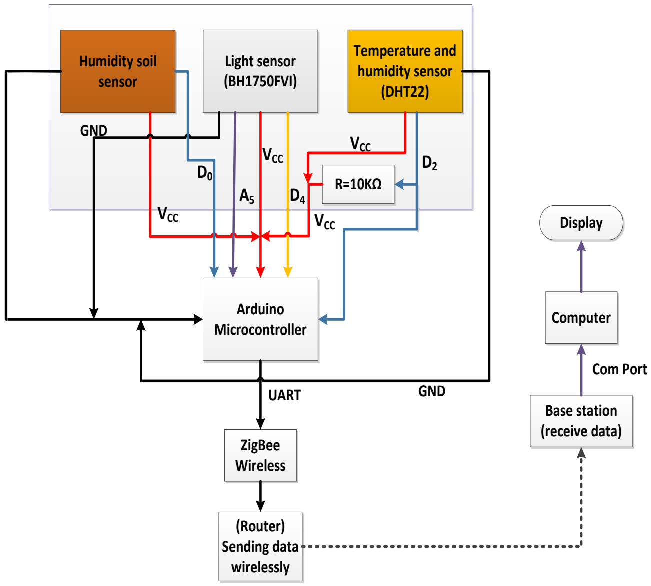


Figure 10. Circuit Block Diagram of Sensor Module

Figure 11. Wireless Drought Moinitoring Sensor Module

E. *System Setup*

When the sensing unit is set-up the coordinator is able to make an automatic connection to the routers and creates a wireless mesh network. Broadcast commands are sent by the coordinator to the routers and the routers can send information back to the coordinator. The received data is checked for correctness. The sensor units are programed to send a unique identifier for each type of sensor. This enables the software program to identify the type sensor it is communicating with. The Table II below shows the data packet sensors send to the coordinator.

TABLE II. DATA PACKET FROM SENSORS SEND TO THE COORDINATOR

Sensor ID	**Luminance** (lux)	**Relative Humidity** (%)	**Ambient Temp** (^oC)	**Soil Moisture** (ADC value)
S1	4955	23.8	37.4	721
S2	7538	24.3	37.3	681
S3	4310	29.4	31.9	665
S4	4255	29.9	31.9	159
S5	7526	51.8	22.2	154

The setup of the drought monitoring system requires the installation of the serial port monitoring software. The program for Serial Data Acquisition in real-time was written using “Processing programming language”, Figure 12 shows the interface window.

Figure 12. Software interface to collect data from sensors

Once the developed software is installed and running, the Zig Bee coordinator is connected to the Raspberry Pi’s USB port. The corresponding port numbers are then selected on the software program. The Zig Bee module acting as the coordinator is associated with WSN to collect the data and monitor the sensors.

F. System Deployment

Five drought monitoring wireless units were deployed around a farm (Figures 13 and 14). These units continuously monitor the soil and send data to the coordinator, which is inside the building as shown in Figure 15.

Figure 13. Drought Monitoring sensors locations on a farm

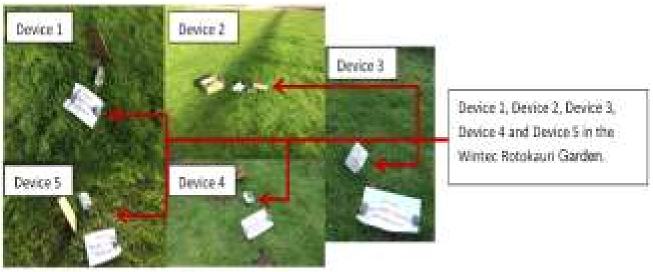
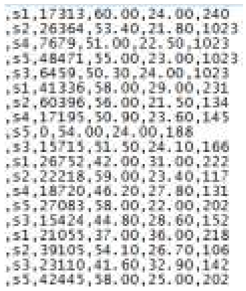


Figure 14. Drought Monitoring Units on a farm

Figure 15. Coordinator locations inside a building collecting data from sensor units

Once all the system hardware is connected, the serial port is opened on the software program. The program initially records and displays the number of sensors in the network as shown in Figure 16. This feature enables us to verify whether all the sensor nodes are communicating with the coordinator and working properly. Any sensor node failure can be detected and rectified at this stage.



```
,s1,17313,60.00,24.00,240
,s2,26364,53.40,21.80,1023
,s4,7679,51.00,22.50,1023
,s5,48471,55.00,23.00,1023
,s3,6459,50.30,24.00,1023
,s1,41336,58.00,29.00,231
,s2,60396,56.00,21.50,134
,s4,17195,50.90,23.60,145
,s5,0,54.00,24.00,188
,s3,15715,51.50,24.10,166
,s1,26752,42.00,31.00,222
,s2,22218,59.00,23.40,117
,s4,18720,46.20,27.80,131
,s5,27083,58.00,22.00,202
,s3,15424,44.80,28.60,152
,s1,21055,37.00,36.00,218
,s2,39105,54.10,26.70,106
,s3,23110,41.60,32.90,142
,s5,42445,58.00,25.00,202
```

Figure 16. Data packets from sensor units

G. Initial Results

We successfully deployed and tested our drought monitoring wireless system that is capable of providing spatially distributed soil/atmospheric data relevant for plant growth. The coordinator software records, displays the data in real time and simultaneously uploads on to Google® Apps as shown in Figure 17.

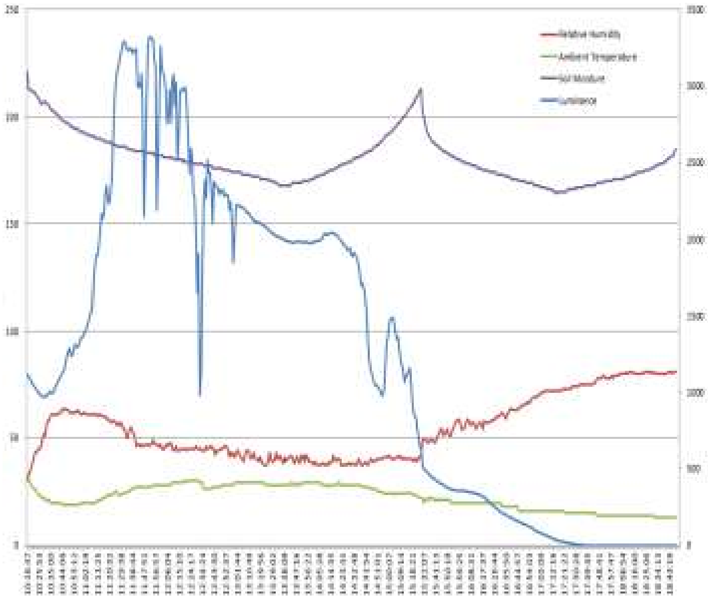


Figure 17. Data from sensor-1 being plotted on Google® Apps

Figure 17 shows the real time data consisting of temperature and humidity of atmosphere, soil moisture and illumination. This snapshot shows the data collected during eight hours and twenty eight minutes in a day. In order to monitor the drought in different sites, we focused on upgrading our system with more wireless drought sensor units.

By connecting the system to the internet, we can login to the system and get real time soil/atmospheric data remotely on any mobile device with internet connection as shown in Figure 18.

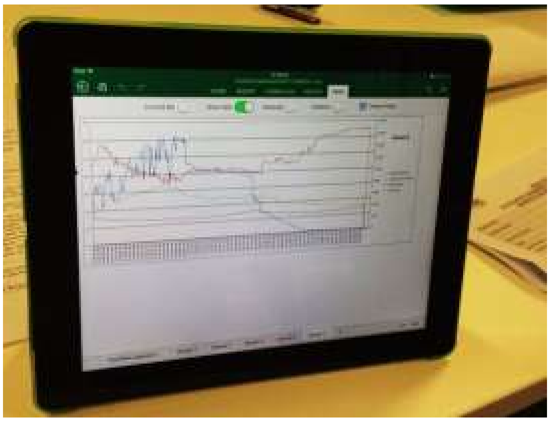


Figure 18. Data Being Displayed on a Mobile Device

H. Conclusion & Future Work

This paper reports that a wireless sensor network based drought monitoring system was developed and was successfully tested. It can monitor four different soil/atmospheric parameters. Once the data is captured it is recorded and displayed on Google Apps to be accessed by the user from anywhere.

Further research could include looking at integrating a GPS sensor and a sensor to detect soil salinity in each wireless sensor unit. By gathering the data over time, a pattern can be formulated, which can help us to not only to identify drought but also predict future droughts.

REFERENCES

[1] World-health, "World Health Organization," 2008, website (http://www.who.int/world-health-day/toolkit/report_web.pdf) accessed on 2/11/2013.

[2] Lindquist, Rosanna T. "Review of the National Oceanic and Atmospheric Administration (NOAA), website (http://www. noaa. gov/)." Journal of Agricultural & Food Information 15, no. 2 (2014), pp: 149-150.

[3] An, Xiaofei, Minzan Li, Lihua Zheng, Yumeng Liu, and Hong Sun. "A portable soil nitrogen detector based on NIRS." Precision Agriculture 15, no. 1 (2014), pp: 3-16.

[4] Zhang, Qin. "Precision Agriculture for Grain Production Systems, Brett Whelan, James Taylor, CSIRO Publishing." (2014), pp: 159.

[5] Tait, Andrew, Troy Baisden, David Wratt, B. Mullan, and A. Stroombergen. "An initial assessment of the potential effects of climate change on New Zealand agriculture." New Zealand Science Review 65, no. 3 (2008), pp: 50-56.

[6] Cameron, Michael Patrick. "The demographic implications of climate change for Aotearoa New Zealand: A review." (2013).

[7] Tait, Andrew, James Sturman, and Martyn Clark. "An assessment of the accuracy of interpolated daily rainfall for New Zealand." Journal of Hydrology, no. 1 (2012), pp: 51.

[8] López, Juan A., Antonio-Javier Garcia-Sanchez, F. Soto, A. Iborra, Felipe Garcia-Sanchez, and Joan Garcia-Haro. "Design and validation of a wireless sensor network architecture for precision horticulture applications." Precision agriculture 12, no. 2 (2011), pp: 280-295.

[9] Martin, Jonathan G., Claire L. Phillips, Andres Schmidt, James Irvine, and Beverly E. Law. "High-frequency analysis of the complex linkage between soil CO2 fluxes, photosynthesis and environmental variables." Tree physiology 32, no. 1 (2012), pp: 49-64.

[10] V. Mhatre and C. Rosenberg, "Design guidelines for wireless sensor networks: communication, clustering and aggregation," Ad Hoc Networks, vol. 2, no. 1, pp. 45-63, Jan. 2004.

[11] W.-S. Jang, W. M. Healy, and M. J. Skibniewski, "Wireless sensor networks as part of a web-based building environmental monitoring system," Automation in Construction, vol. 17, no. 6, pp. 729-736, Aug. 2008.

[12] R. Mittal and M. P. S. Bhatia, "Wireless Sensor Networks for Monitoring the Environmental Activities," Analysis, 2010.

[13] N. S. Shamsuddin, "Development Of Sensor Nodes In Wireless Sensor Network for Environmental Monitoring (WisNEM)," 2008.

[14] R. Kays et al., "Tracking Animal Location and Activity with an Automated Radio Telemetry System in a Tropical Rainforest," The Computer Journal, vol. 54, no. 12, pp. 1931-1948, Aug. 2011.

[15] S. E. Díaz, J. C. Pérez, A. C. Mateos, M.-C. Marinescu, and B. B. Guerra, "A novel methodology for the monitoring of the agricultural production process based on wireless sensor networks," Computers and Electronics in Agriculture, vol. 76, no. 2, pp. 252-265, May 2011.