Sensor Array Networking and Data Telemetering System

George Mavros
Kathleen McKearney
Bomi Park
YoungBeom Ryu
Department of Electrical and Computer Engineering
University of Arizona, Tucson, AZ

ABSTRACT

The Remote Sensing Group (RSG) at the University of Arizona is currently using a data collection system that requires transfer of data with the use of wire connections. To improve the system, wireless technology is utilized to collect and transmit data larger distances to a storage computer. The main goal of this project is to aide RSG in determining if wireless communication is an acceptable and useful means of transferring collected data. In order to fulfill this goal, a wireless system was selected that met specifications defined by RSG. Tests conducted on the system provided significant results of the project, which are a communication distance of 150 feet, download distance of 40 feet, and successfully storing the transmitted data within 3% accuracy.

INTRODUCTION

The RSG has concentrated on radiometric calibration using satellites, such as NASA's Landsat TM, since the mid 1980's. The RSG has radiometric calibration facilities that use an energy surface-reflectance based method to record time-series measurements of sunlight reflecting off of the ground surface in order to calibrate a satellite sensor. The RSG measures the surface reflectance of four test sites as part of their research: White Sands Missile Range near Alamogordo, New Mexico; Lunar Lake Playa, near Ely, Nevada; Railroad Valley Playa, near Ely, Nevada; and Playa, located on the California-Nevada border southwest of Las Vegas.

The RSG desires to improve current data collection system at the Rail Road Valley test site in Nevada in order to calibrate a satellite sensor that will monitor weather conditions and climate changes of this area. Currently in the area only one ground cluster of four radiometers is in use, which collects weather information and then transmits it to a local storage device located 30 meters away via a hard-wired connection. The present system has two main flaws: the transmission of data via wires and the incapability of centrally storing it. There are several qualities of this system which are limited by the use of wires. First, the RSG desires a greater area of investigation, therefore the use of wires to transmit information is no longer practical. Also, the quality of data received from the radiometers to the storage device is compromised due to noise-error present in the transmission wires. The lack of a central storage device causes the RSG an inconvenience since data currently needs to be downloaded manually. It is also the source of information loss since previously acquired data is overwritten by new data if it is not downloaded in a timely manner. The manual download causes the data collection rate to be limited to 1 sample per 6 hours while the RSG requires a faster rate of collection. The task of improving this communication system will demonstrate to the RSG how to apply this solution to a larger scale of data collection.

OVERVIEW OF DESIGN

A system with the ability to communicate through a private wireless network was desired to overcome the limitations occurring from the hard-wired system presently used. The new system needed to fulfill all the specifications identified below:

- wireless transmission of data
- use of a central storage location for data
- 4 channel analog input on A/D converter
- minimum of 12 bit digitization
- minimum of 6/hour data sampling rate
- low current consumption system
- withstand temperature range of -20C – 50C

The collected data was chosen to be transferred using digital communication because it is more reliable than analog for data transmission. The main objective of design was to use a device connected to a cluster of three radiometers to receive, digitize and, if possible, store the analog data received by each radiometer before transmitting it to a central storage station. The focus of the research was then turned to data-logger transceivers that have these abilities and could be purchased based on the project's budget.

SELECTED EQUIPMENT

The equipment was selected based on extensive research of available products. The first observation was that the commercial market related to wireless transmitting data-loggers is currently limited and no one device was identified to satisfy all of the project's specifications. The V-Link-SK was chosen above other options because it satisfies the majority of the project's requirements. The V-Link-SK kit contains two V-Link data-loggers, one base-station, antennas, and all of the necessary software and cables. The following is a description of the important features of the V-Link:

- Wireless communication distance between transceiver and Base-station is 200 feet max
- 2 Mbytes flash memory built-in transceivers, ability to store approximately 1 million data points
- 2 KHz sweep rate, programmable from 32 to 2048 sweeps/second
- -40 to +70 deg Celsius operating temperature
- 12 bits resolution analog to digital (A/D) converter that is built-into transceivers
- Base-station able to connect to up to 2000 stations simultaneously
- Seven programmable channels, 1 reserved for temperature, 3 for analog input

- Ability to be powered by an external battery, 3.1V to 9V

V-Link data-loggers transceivers

The V-Link data-loggers are the collectors of the system. The data-loggers are responsible for collecting data from the radiometers, then to digitize before storing these data and finally to transmit the data to the computer when asked. The data-loggers have three channels, specifically channels 5, 6 and 7, available for analog inputs. Each radiometer is directly wire connected to a channel of the data-logger. The data transmitted from the radiometers arrive at the data-logger's channels in analog form. Thus the first function that the data-logger performs is the digitization of the data before it stores the data in its memory. Channel 8 is reserved by the manufacturer for the internal temperature measurement.
The figure below is a representation of the data-logger's functionality

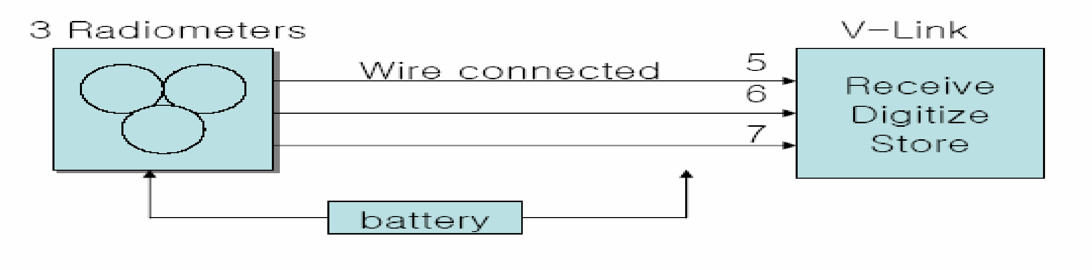

Figure 1. There are three input channels from the radiometer which are connected to the V-Link transceiver.

Base-station receiver

The base-station is responsible for the wireless communication between the data-loggers and the software that commands the data-loggers. It functions as the link between the computer and the data-loggers. The base-station operates only when communication with the transceivers is desired. In all other cases, the base station can remain turned off.

Figure 2. The base station functions as a link between the computer and the V-Link transceivers.

The WDL software

The software is simple to use in order to operate the transceivers. To command the data-loggers for a specific operation, the base station functions as the link between the computer and the transceivers. To test communication between the base station and transceivers, the specific address of the transceiver desired to be reached is entered and the system will check for established communication.

The sweep rate and the number of collected data points can be chosen. There are 5 different sweep rate options starting at 32 sweeps/second up to 2048 sweeps/second. The sweep rate is the rate of samples the data-logger will collect from the input per second. If the amount of desired data is known or the period of time desired to trigger is known, setting one of the two will update the other, according to the sweep rate entered.

If there are no more adjustments to be made, the transceivers can be now triggered to begin storing data. If two or more transceivers are desired to be triggered simultaneously, after setting up each transceiver individually, the universal address should be entered and data collection will begin. After this operation the software can be turned off. When the storing period is over, the transceivers are accessed individually in order to transmit the data stored in their memory to the computer by downloading the data. After receiving the data, the software offers the option to graph the data received on a ‘bits Vs sweeps/second’ chart. The downloaded file can also be opened with an Excel file to observe the values at specific times. To convert the output bits of the graph to measured voltage, the formula is used:

$$\text{Voltage} = \text{Output Bits} * (3 / 4096) \qquad (1).$$

OPERATION OF THE FINAL SYSTEM

An overview of the operation of the system as a whole is as follows. Each transceiver is given an analog input from a cluster of radiometers. Within the transceiver unit, the collected analog data is digitized by the A/D converter, stored in its internal memory and then can transmitted when desired through the base station to the hard drive of the computer. It is at this point the data can be analyzed for results.

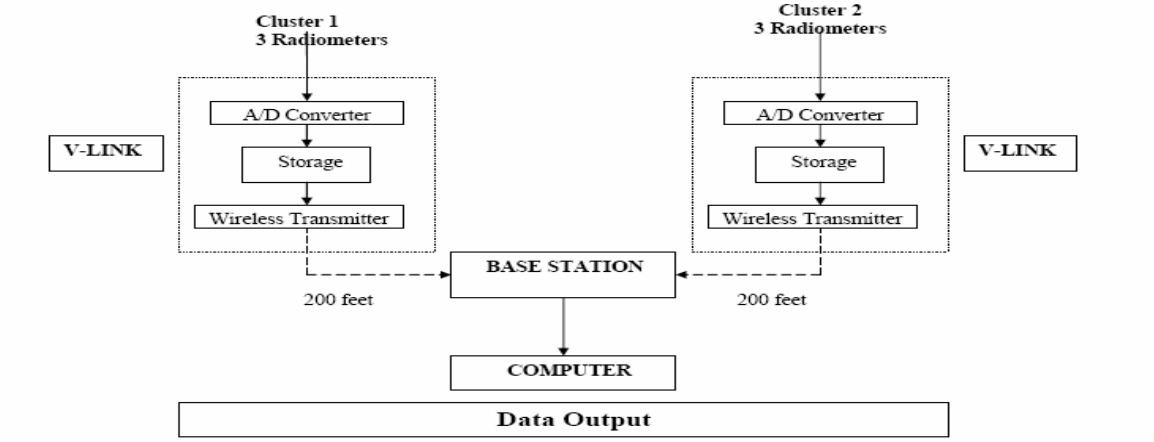

Figure 3. Block diagram of entire system configuration.

TESTING

A testing regiment was created beginning with some basic procedures to provide a full understanding of the equipment. The focus of the tests was to understand:

- how the data-loggers are configured using the WDL software

- the purpose of the initializing data collection parameters
- how to operate the data-loggers using the software command
- how to read and analyze the graphs of the downloaded data
- the communication between data-loggers, base-station, and computer

Each data-logger was tested individually by applying an analog input using a 1.5V battery to one of its channels. This process was repeated while changing the parameters of the data-logger every time. With this process the basic functionality of the devices was tested.

The subsequent tests occurred in the RSG lab where the focus was placed on the accuracy of the collected data. Using a DC voltage calibrator, each data-logger was tested individually for various constant voltages. This process was repeated using the same voltages as before, for testing one to three channels of each transceiver storing data simultaneously. Finally, a test of both data-loggers with all six channels triggering simultaneously was conducted. The purpose of this testing was to observe the behavior of the channels when storing data individually and simultaneously with other channels. The output graph of each test produced by the WDL software was compared to the voltage values recorded using a DMM.

A simple resistor circuit was utilized for the next procedure. The circuit, powered up by the DC voltage calibrator, was able to send a different voltage to every channel. All channels were tested simultaneously for various voltages and the data was verified again using the DMM.

With this procedure, a complete picture of the system operation was formed, thus the system was ready to be tested at an outdoor location. The above procedure using the same resistor circuit was repeated at the outdoor location. The circuit and the data-loggers were powered by a 9V battery. The outcome of this process would indicate any differences between the data received at the two locations, indoor and outdoor. Another factor that was tested at this stage was the communication distance between the devices. All devices were positioned apart at a range of distances in order to examine any variation in the speed and quality of communication.

The final test procedure situated the system under real conditions. An actual radiometer was used, which has three output channels that transmit different analog voltages while recording wavelengths of the sun. The output voltages of this radiometer vary every second since the earth is in constant movement and the measurements of the sun’s wavelengths change. This procedure was the most comprehensive because it would determine if the system was able to complete the project’s goal. It was during this stage in the testing that one of the data loggers, Address 2 in specific, was malfunctioning and had to be sent to the manufacturer for repair. The testing schedule continued with only one data-logger. The output channels of the radiometer were directly connected to the three analog input channels of the data-logger. The data-logger was triggered for a number of different conditions to exhaustively observe all possible outcomes. The data-logger was tested for various periods of time, for different initialization parameters and for different distances between the devices. A second data-logger, the Hydra, that the RSG group has been using, was deployed along with a DMM for data verification. This test created a clear and complete picture for the V-Link system. The results of the testing procedures and analysis follow along with observations and conclusions about the system.

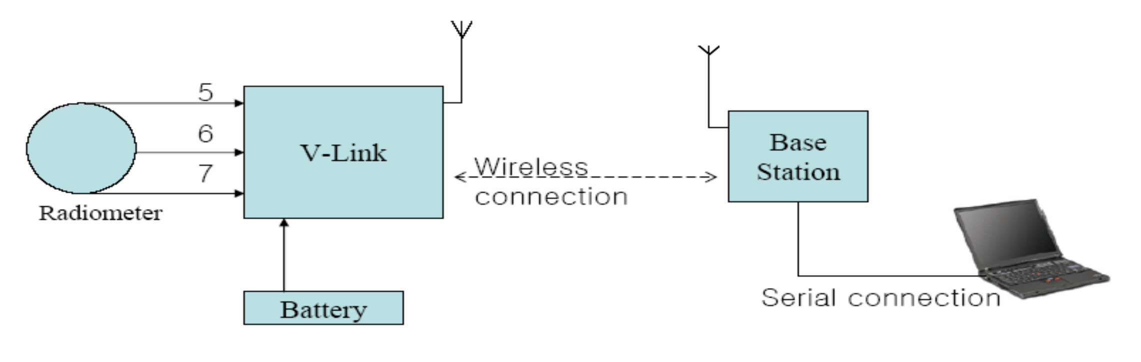

Figure 4. A detailed look at the connections between the input (radiometer), V-Link transceiver, base station and computer.

RESULTS AND OBSERVATIONS

The outcomes of the most significant testing procedures are presented and analyzed in this section.

Testing using the DC voltage calibrator

Completing the testing procedure using the DC voltage calibrator, a number of observations were extracted related to the accuracy of data received and the behavior of the input channels when triggered individually and simultaneously. For all the testing, a DMM was used to verify the data given by the graphs. First, each channel was triggered individually for various voltage values in the range of 0.01V to 3V. A constant voltage graph was given for each case by WDL. Using formula (1) the exact result for each test of the data-logger was calculated. Comparing this result to the DMM measurement, an error of less than 1-3% was noticeable. Microsoft Excel software was utilized to create tables in order to compare the two measurements, DMM Vs V-Link.

Observations:

Triggering two and then three channels simultaneously, by applying the same voltage to each channel, for all the voltage values as before, created the observation that the data error increases for each case. When two channels are triggered simultaneously the data error reaches 4% per channel, and for all three channels the error in data increases to 5%. Since the voltages do not exceed 3V, the error in data is barely noticeable and negligible. Another noticeable observation is that the data measured by all channels of the two data-loggers are very similar, so the conclusion that the two V-Link data-loggers behave similarly can be extracted.

Channel 5			Channel 6			Channel 7		
meas.volt (v)	*exp.volt(v)*	*error rate(%)*	*meas.volt (v)*	*exp.volt(v)*	*error rate(%)*	*meas.volt (v)*	*exp.volt(v)*	*error rate(%)*
0.01	0.010	0.000	0.010	0.010	0.000	0.010	0.010	0.000
0.0985	0.100	1.500	0.098	0.100	1.600	0.098	0.100	2.500
0.489	0.500	2.200	0.487	0.500	2.600	0.488	0.500	2.400
1.173	1.200	2.250	1.172	1.200	2.333	1.170	1.200	2.500

1.957	2.000	2.150	1.957	2.000	2.150	1.955	2.000	2.250
2.879	2.900	0.724	2.877	2.900	0.793	2.876	2.900	0.828

Table 1. Values obtained when each channel was triggered individually

Channel 5			Channel 6			Channel 7		
meas.volt (v)	*exp.volt(v)*	*error rate(%)*	*meas.volt (v)*	*exp.volt(v)*	*error rate(%)*	*meas.volt (v)*	*exp.volt(v)*	*error rate(%)*
0.01	0.010	0.000	0.010	0.010	0.000	0.010	0.010	0.000
0.098	0.100	2.000	0.097	0.100	3.000	0.097	0.100	3.000
0.488	0.500	2.400	0.487	0.500	2.600	0.485	0.500	3.000
1.171	1.200	2.417	1.167	1.200	2.750	1.165	1.200	2.917
1.956	2.000	2.200	1.955	2.000	2.250	1.950	2.000	2.500
2.878	2.900	0.759	2.877	2.900	0.793	2.875	2.900	0.862

Table 2. Values obtained when all three channels were triggered simultaneously.

Testing using the resistor circuit, indoor

The completion of this test procedure enabled additional conclusions regarding the behavior of the channels when triggered simultaneously and also regarding the accuracy of the data when each channel is measuring a different voltage. The resistor circuit was manipulated in many ways so that different voltages could be obtained for each test. All voltage values were in the range of 0.01V and 3.0V.

Observations:
Channels with input voltage close to 0V or to 3V, the end points, face a smaller data error from channels measuring values between 1V and 2V. The error identified in these measurements did not exceed the error observed when testing using the DC constant voltage calibrator.
The channels face a greater error when triggered simultaneously than when triggered individually.

	Channel 5			Channel 6			Channel 7		
time (sec)	*meas.volt (v)*	*exp.volt (v)*	*error rate (%)*	*meas.volt (v)*	*exp.volt (v)*	*error rate (%)*	*meas.volt (v)*	*exp.volt (v)*	*error rate (%)*
0	1.952	2	2.405	1.313	1.3	-0.962	0.663	0.667	0.623
10	1.952	2	2.405	1.31	1.3	-0.793	0.659	0.667	1.227
20	1.951	2	2.441	1.311	1.3	-0.849	0.66	0.667	1.049
30	1.951	2	2.441	1.31	1.3	-0.793	0.659	0.667	1.227
40	1.95	2	2.478	1.31	1.3	-0.793	0.659	0.667	1.199
50	1.95	2	2.478	1.31	1.3	-0.793	0.659	0.667	1.199
60	1.95	2	2.478	1.31	1.3	-0.736	0.66	0.667	1.049

Table 3. The values obtained when a different voltage was applied to each channel and all channels

were triggered simultaneously.

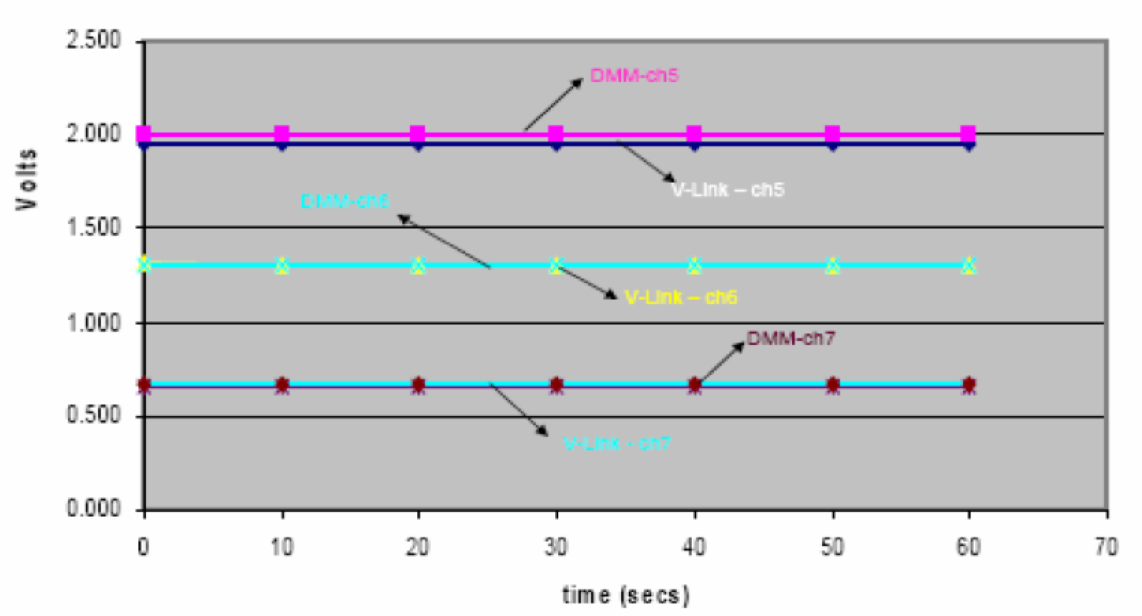

Figure 5. The graph for testing the system using the resistor circuit. Notice the constant voltages and the minimal difference between measured and expected value.

Testing using the 4-channel radiometer outdoors

The three different output voltages sent by the three channels of the radiometer vary every second as explained above. Thus to verify the data received by the V-Link data-logger, a second data-logger, and the Hydra that the RSG provided, was utilized along with a DMM. Measurements were taken on cloudy and sunny days, at different hours of the day and for various periods of time to thoroughly test all possibilities. In addition, the distance factor was tested again.

Observations:
The data recorded by the V-Link data-logger agree by 97% with the measurements recorded by the DMM and the Hydra data-logger. The difference between sunny and cloudy days is very obvious from the data. For cloudy days the highest voltage calculated did not exceed 0.435V while for sunny days calculations of voltage up to 1.6V were recorded.

Unfortunately, there was no further success in communication distance. Communication between the data-logger and the base-station/computer never exceeded 150 feet and when downloading, the devices could not be further apart than 40 feet. The following is a table of data recorded from the three devices, V-Link, DMM, and Hydra, at specific times and a graph verifying the accuracy of data received by the V-Link.

	Channel 5			Channel 6			Channel 7		
time (sec)	*V-LINK*	*DMM*	*HYDRA*	*V-LINK*	*DMM*	*HYDRA*	*V-LINK*	*DMM*	*HYDRA*

0	1.113	1.137	1.121	0.439	0.469	0.447	0.000	0.000	0.000
20	1.121	1.142	1.134	0.439	0.470	0.448	0.000	0.000	0.000
40	1.182	1.204	1.192	0.441	0.471	0.449	0.660	0.000	0.000
60	1.187	1.206	1.195	0.442	0.473	0.451	0.000	0.000	0.000
80	1.189	1.210	1.196	0.443	0.472	0.451	0.000	0.000	0.000
100	1.077	1.103	1.088	0.422	0.457	0.432	0.000	0.000	0.000
120	0.993	1.028	1.006	0.346	0.370	0.355	0.000	0.000	0.000
140	0.959	1.001	0.970	0.322	0.341	0.332	0.000	0.000	0.000
160	0.946	0.998	0.957	0.245	0.259	0.254	0.000	0.000	0.000
180	0.650	0.672	0.661	0.221	0.234	0.230	0.000	0.000	0.000
200	0.597	0.613	0.604	0.213	0.225	0.221	0.000	0.000	0.000
220	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4. A table with the values recorded by the DMM, the Hydra and the V-Link for a testing using the three channel radiometer.

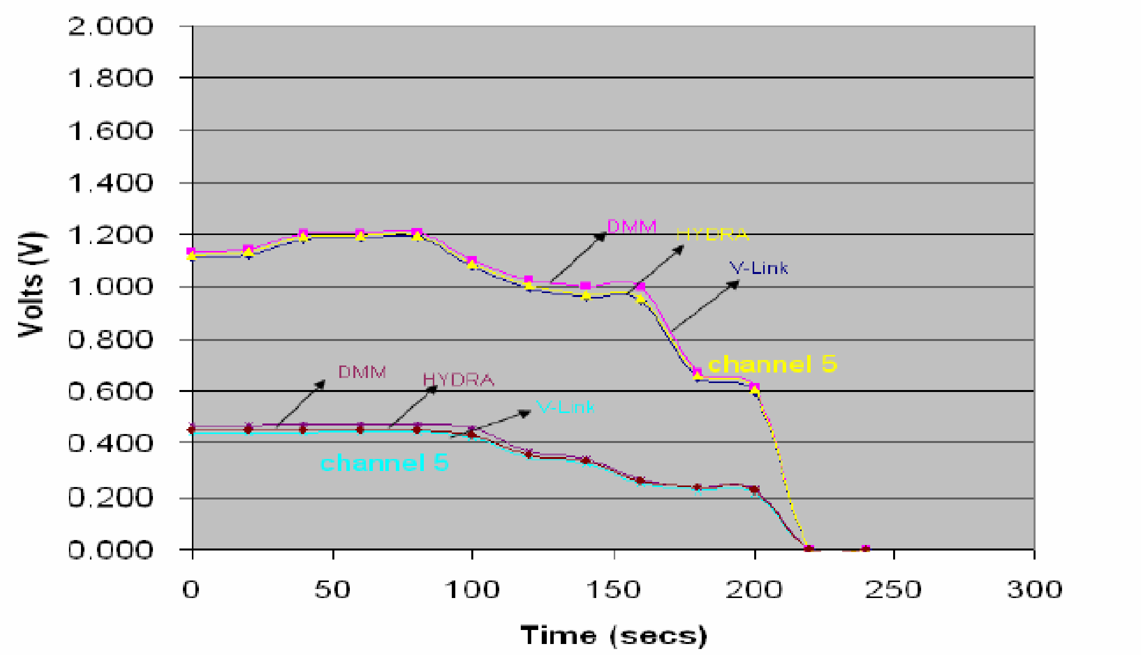

Figure 6. A graph that verifies the accuracy of the data received by the V-Link compared to the data recorded by the DMM and the Hydra.

RECOMMEDATION

There are two recommendations for this project which would have been completed given more time. These are suggestions that the RSG group may take to enhance the current working design.

The first recommendation is to sample data at regular time intervals. The manner in which the V-Links are configured now does not allow data to be sampled automatically at regular intervals. A solution to do this is to use an external timing device which generates a voltage. It could be applied to the sensor trigger function as an input to initiate sampling. For example, to sample every ten minutes for 20 seconds, the timing device would send a pulse of 3V for 20 seconds every 10 minutes. The V-Link would detect this applied voltage and trigger accordingly. When the 3V is not applied, the V-Link triggering will stop.

A second recommendation would be to expand the transmitting distance of the V-Link transceivers. Currently, the V-link system is operating with a monopole antenna similar to a cellular phone antenna. The system itself is operating in a line of sight functionality which indicates that the ability to visually see a transmitting antenna corresponds with the ability to receive a signal from it. A large amount of research has been performed on different types of antennas such as the monopole, dipole, Yagi-Uda and horn antenna. It is recommended to use a Yagi antenna based on the research performed. A longer antenna is desired because the length of an antenna is proportional to the directivity.

CONCLUSION

The distance of communication was an important factor to consider in determining the strength of the antenna of the current system. After the testing procedures it was concluded with the following values: for the outdoor testing in average, data-loggers can communicate at a distance of 150 feet but only 40 feet to download from them. Recall that in the specifications of the V-Link, the specified distance range for both functions is 200 feet. The reason for the large difference in the two distances lies on the number of commands the base station carries to the transceiver. To check the system for communication or to trigger the data-loggers, the base station carries one short command to the transceiver where as when downloading the data, the base station not only needs to deliver that short command to download but it also needs to verify the following two cases: the data are arriving in the same order in which they are measured and the data package that’s downloading is not being damaged. Transmitting range of 500 feet is what was initially desired. However, we have found that in order to expand these distances, it would require the utilization of additional directional antennas. A recommendation section regarding the antennas is has been provided for future improvement.

In conclusion, the design problem was the improvement of a currently operated system. The main problems with the system were the transfer of data with the use of a hard-wired connection and the lack of a central storage location. The basic design objective was to transmit the data using wireless communication and to store it centrally. The design work included choosing the hardware that would best fit the RSG’s needs. The project has been completed successfully. This project demonstrates that the wireless data network is an improved means of data transmission and storage, but the implementation studied in this project does not yet satisfy the needs of RSG.

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