DEVELOPMENT OF INTELLIGENT LOGGER CONTROLLER FOR COTTON PHENOTYPING

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Abstract

A typical cotton breeding program evaluates thousands of small field plots each year. Although cotton breeders make extensive field notes in an effort to collect data, the process is subjective and prone to a large degree of error. The efficiency of cotton breeding could be increased significantly, while minimizing cost, with the availability of more accurate methods of collecting information. High-throughput phenotyping paved the development of large mapping populations but the current electronic data loggers/monitors used are not intended for these purposes. For example, the current data loggers, General Purpose Input/Output ports are mostly Analog to Digital Converter (ADC), the number of serial ports is limited, and they do not have the capability to connect new sensors' communication protocol thereby minimizing the use of newer sensors available on the market. The main goal of this work is to design and develop a new data logger specifically to be used for cotton phenotyping, which incorporates multiple ADC lines, digital input/output lines, serial ports, I2C, CAN bus and SPI connections. This paper will present the design and development of the new data logger which makes use of Controller Area Network (CAN) Bus technology in connecting different sensors. The newly developed data logger provides seamless integration of all sensors used, expandability in terms of sensor connectivity with different communication protocol availability, and minimized wires that connect sensors and controllers. All this will pave the way for minimizing the work of breeders and instead help them focus more on processing their data.

Introduction

The cotton breeding program evaluates many small field plots yearly. In an effort to collect data, breeders create extensive notes but this process is very subjective and prone to errors (Maja et al. 2016). Crop production, in general, has steadily increased over time due to the advances in managing crop and breeding program (Duvick 2005; Lopes et al. 2012). However, changes in climatic patterns, land, and water issue, provide additional challenges to geneticists and breeders in ensuring yield stability in varying environmental conditions (Brummer et al. 2011).

The efficiency of cotton breeding could be increased significantly while minimizing cost with the availability of more accurate methods of collecting information (Furbank and Tester 2011). Cotton researchers/breeders utilized the latest technologies to study the plants on its growing season in the field and determined which breeds respond well to disease or lack of water. This can be accomplished by examining the genetic makeup of certain cotton breeds and utilizing technologies which allow the breeder to study with a greater number of trial lines (Barker et al. 2016).

High-throughput phenotyping paved the development of large mapping populations (Philips 2010 and Pingali 2012) but the current electronic data loggers/monitors being used are not intended for these purposes. For example, the current data loggers, General Purpose Input/Output ports are mostly Analog to Digital Converters (ADC), the number of serial ports are limited, and they do not have the capability to connect new sensors' communication protocol such as Inter-Integrated Circuit (I2C), Controller Area Network (CAN) Bus or Serial Peripheral interface (SPI), thereby minimizing the use of newer sensors available on the market (Barker et al. 2016). J. Barker et al. (2016) developed their own data logging software using National Instrument LabVIEW to collect, georeferenced and logging sensor data.

Other drawbacks include using multiple loggers to collect additional sensor data which cannot be accommodated on one logger (Barker et al. 2016). With this setup, combining the data from one logger to the other is another hurdle that researchers need to work out and it must be done in a way where all the data lines up. Otherwise, the processed data will not provide the correct results or provide inaccurate results, if there is an offset of data between loggers (Cobb et al. 2013 and Haghighattalab et al. 2016).

Developing a new data logger for phenotyping; which provides seamless integration of all sensors used, expandability in terms of sensor connectivity with different communication protocol availability, and minimized wires that connect sensors and controllers, will pave the way for minimizing the work of breeders and instead focus more on processing their data (Cobb et al. 2013 and Barker et al. 2016).

The objective of this work is to develop a new data logger specifically to be used for cotton phenotyping, which incorporates multiple technology interfaces (ADC, I^2C, SPI, CAN, and UART) and used CAN bus as the base communication protocol for adding different sensors.

Materials and Methods

System Background

The requirements for the data logger system include the following main functionalities; sensor type addressing mode, sensor type counter mode, microSD card capability, CAN Bus interface and direct RTK-GPS connection. Aside from these main functionalities, all of the standard sensor connections are also available such as the ADC, universal asynchronous receiver/transmitter (UART), inter-integrated circuit (i2c), and serial peripheral interface (SPI). Both the sensor type addressing and counter modes only applies to sensors connected to the Sensor boards. Sensors connected to a dedicated CAN Bus board will have the option to define the type of sensor data being transmitted to the CAN Bus line and how many (counter) of the same sensors are in the line. The main purpose for these is the provide modularity in terms of the number of the same sensors that can be added to the data logger. This will make it easier for the user to add a group of sensors or sets of sensors for simultaneous data collection from multiple plant plots. The design framework depicted in Figure 1 will allow multiple sensors to be attached to the main controller using the CAN Bus protocol as the interface for sensors to the data logger. The main idea of using one interface is to provide seamless integration of other sensors to the data logger and provide simple connectivity.

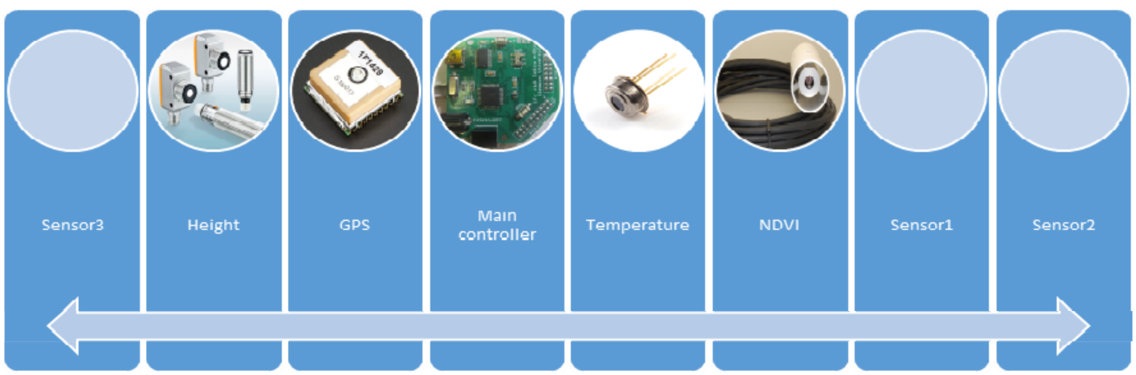
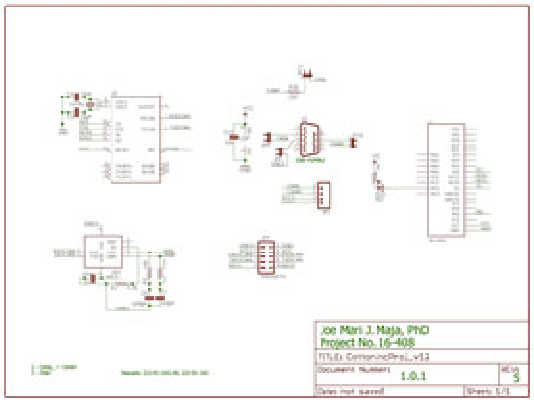


Figure 1. A design framework for using a unified communication protocol for all devices.

Schematic and Board Design

The first prototype was created into two modules; main controller and CAN Bus controller. The main controller handles the intercommunication between different sensors while the CAN Bus controller handles the CAN protocol which includes speed, timing, ID allocation, data transmission and etc. The first prototype of the CAN Bus Controller schematic and board layout is shown in Figure 2. The CAN Bus Controller used a microchip (MCP2510, Microchip, USA) to handle all CAN protocol management while the main controller (Atmega644P, ATMEL, USA) consists of a microSD for data storage, CAN Bus interface, ADC lines, and UART connectivity. Figure 3 is the printed circuit board for both the CAN Bus and main controller with its components already soldered.

The main controller was a derivative of the Intelligent Farm Controller (iFc) of Clemson Sensor and Automation Lab. (www.iad4sc.com) as shown in Figure 3. The iFc was created as the main controller for the different projects of the Sensor and Automation Laboratory such as the penetrometer, 4spray, intelligent sprayer, ramp applicator, and etc.



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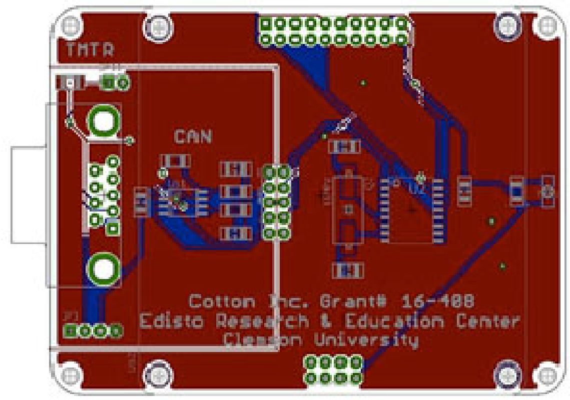
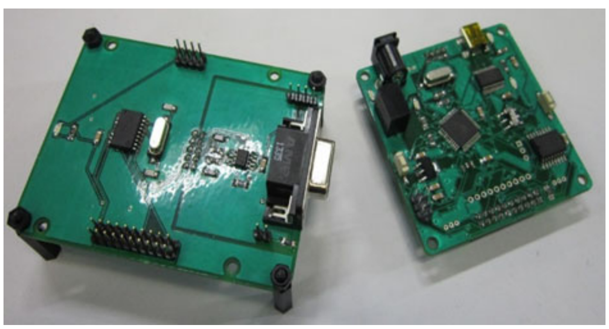


(b)

Figure 2. (a) Schematic and (b) board layout model of the CAN Bus Controller



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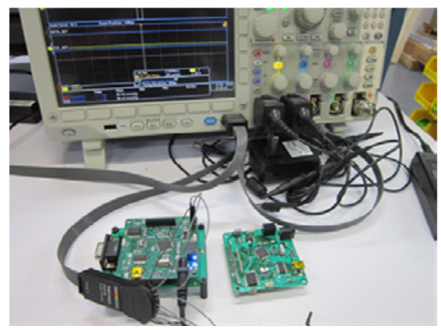
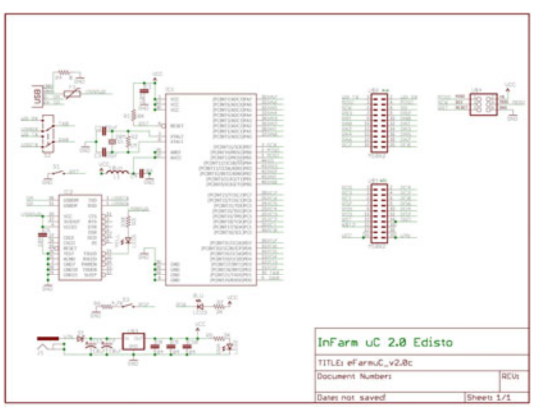


(b)

Figure 3. Fabricated board for both the CAN Bus Controller and Main Controller.



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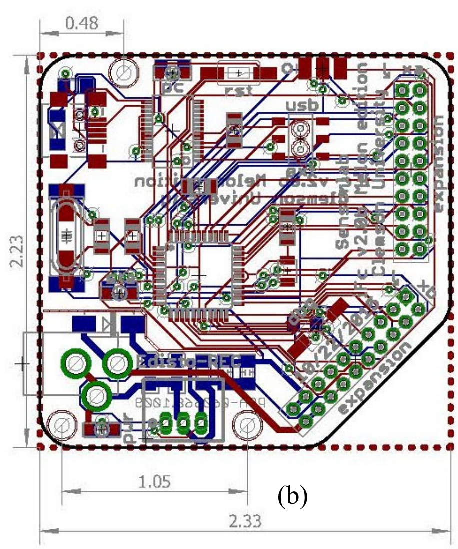


(b)

Figure 4. (a) Schematic and (b) board layout model of the Main Controller

The second and third prototypes were created to address some of the problems with the first prototype, using a different CAN Controller chip (MCP2515) and testing the speed of the CAN Bus to transfer data from one end point to the data logger without overloading the line.

The final prototype consists of three independent boards; the data logger board, Normalized Difference Vegetation Index (NDVI) sensor board, and General purpose sensor board. Each of the boards has its own CAN Bus controller (MCP2515) and microcontroller (Atmega644P). The data logger board as depicted in Fig. 5a has two Ethernet/RJ45 connectors on the left side of the board. The two connectors are the same pin configuration and are intended for sensors which uses the Can Bus protocol. Figure 5b is the RJ45 pin configuration. Note on the pin configuration, the raw voltage (VRAW) from the data logger which is normally the power derived from the self-propelled vehicle can be used to power multiple boards and sensors.

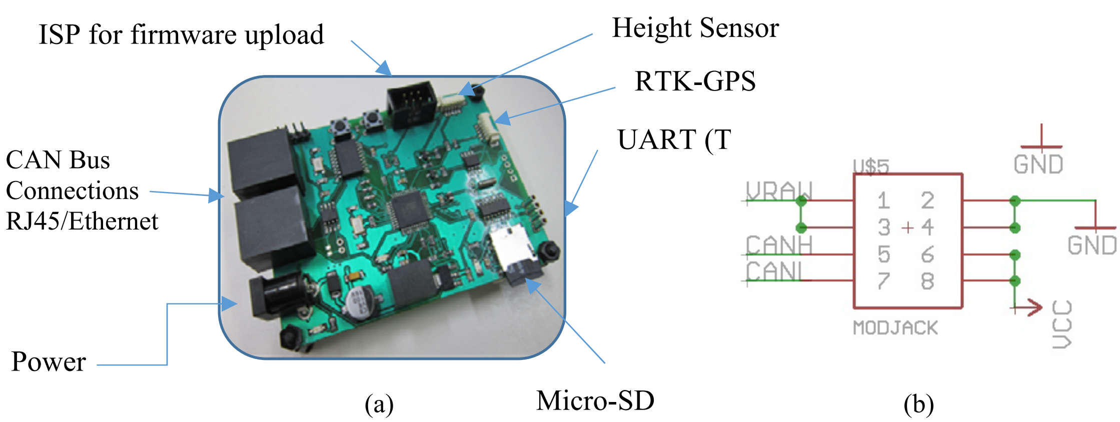


Figure 5. The (a) Final data logger board and its (b) RJ45 connector configuration.

A real time clock (RTC) module was also added in the data logger board for accurate date and time information. The RTC module includes a coin cell battery to preserve the configured date and time even when the board is not powered. The RTK-GPS can be directly connected to the main board using a picoblade connectors and the height sensor.

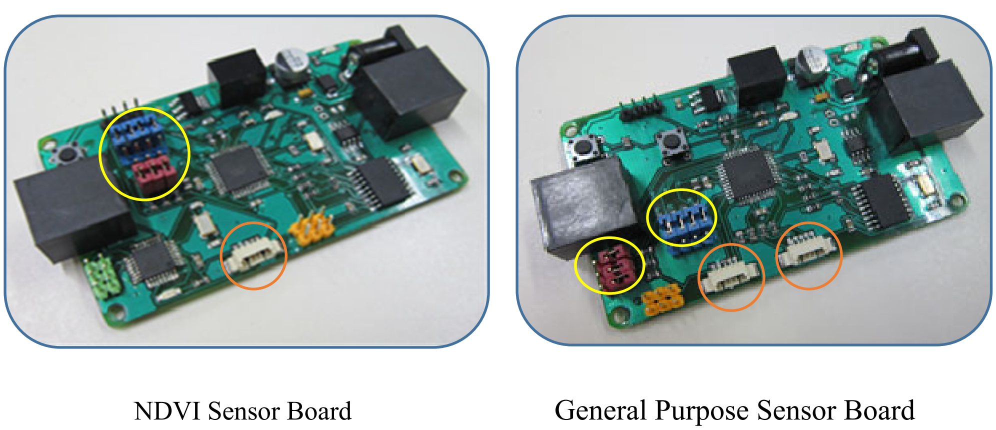


Figure 6. The NDVI and General Purpose Sensor Board.

The two sensor boards NDVI and General purpose is shown in Fig. 6. The NDVI sensor board was created as the interface for the sensor currently being use for NDVI is SDI-12, thus to accommodate the sensor from decagon the

NDVI Sensor board translate the SDI-12 data from the NDVI sensor to CAN-Bus. The SRS NDVI of Decagon devices has two of these modules, an upward pointing (SRS-Ni) and downward (SRS-Nr), can be connected directly to this board. A driver (firmware) was created to communicate with these two decagon sensors and translate the data into CAN Bus which is then transmitted to the data logger.

The General Purpose Sensor board will be used for temperature measurement and can also be used for other analog sensors in the future.

Both boards can be powered directly from the RJ45 connections as shown on the two RJ45 connectors on each end. Sensors that will be attached to these boards will use the picoblade connectors (shown by the orange circle in Fig. 6).

The sensor boards have address settings (red and blue jumper cap [yellow circle]) which can be used to configure each board. These two colored settings will be used for the sensor type address (red) and the number (blue) of the sensor type connected to the data logger. The red jumper cap has a three bit setting which means 8 different sensor type can be defined. The blue jumper cap has 4 bit settings for the number of boards that can be attached to the CAN Bus line or network. The 4-bit address will provide 16 setups of the same boards in the network. The current 4-bit address are shown in Table 1.

Table 1. 3-bit address setting for the sensor type.

Address	*Sensor Type*
0x00-0x04	Not used (reserved)
0x05	GPIO/ADC/Distance
0x06	NDVI
0x07	GPIO/I^2C/Temperature
0x07~0x0F	Not used(reserved)

Sensors and RTK-GPS

The different sensors including the RTK Rover were mounted on an aluminum extrusion as shown in Fig. 7. The following sensors are currently used for this work (See Table 2).

Table 2. Sensor specifications.

Sensor Type	*Model*	*Specifications*
Ultrasonic	UGT250	Distance: 200~2200 mm
IRT*	MLX90614	Temperature: -40C ~ 382.2C FPV: 10^O
Spectral Reflectance	Decagon SRS-Ni/Nr	Spectral Band: 650 nm and 810 nm

The current IRT sensor being tested is an infrared thermometer (MLX90614, Melexis, BE). It has a circular field of view (fov) of 10 degrees with a small diameter of about 20 mm at a distance of 150 mm from the object of interest. The measured temperature is the average of the object inside the fov area. The main advantage of this sensor is its price but the disadvantage is the effective distance which can be address via a Fresnel lens.

The decagon SRS-Ni/Nr (Fig. 7 [The two white module in the middle]) was used for measuring spectral reflectance from the crop canopy. The SRS-Ni (Hemispherical) is an upward looking sensors which has a fov of 180^o while the SRS-Nr (Field stop) has a fov of 36^o. Both sensors used two wavelengths (650 and 810 nm) where both can be used to calculate the NDVI.

The ultrasonic sensor (UGT520, ifm, DE) was used to measure the distance between the sensor and the object. There were two ultrasonic sensors used to determine the height of the plant. The sensor can measure distance from 200 to 2200 mm. The minimum effective area of the reflective object is 200 x 200 mm. One of the sensors will be used as a calibration sensor which is pointed directly to the ground while the other sensor will be pointed to the crop. The calibration data will be used to capture the true height of the crop by taking the difference between the two distances thereby minimizing the error caused by perturbations or vibration of the sensor while the machine is in motion.

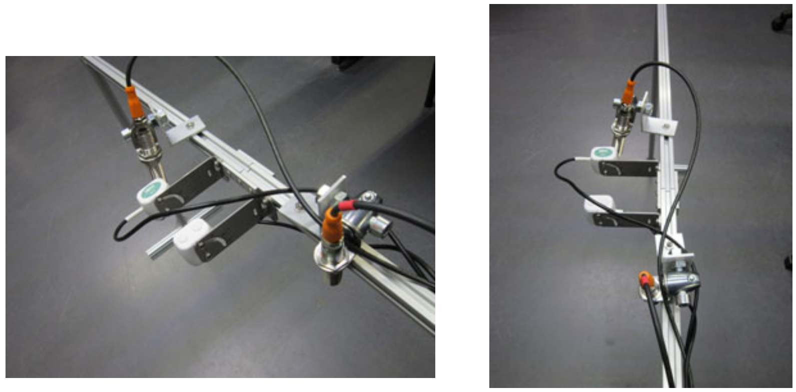


Figure 7. The sensors setup attached to the aluminum extrusion.

In addition to the sensor, an RTK-GPS antenna will be mounted on the top of the aluminum extrusion to geo-reference the data collected from the different sensors. The antenna is connected to a GPS controller (piksi, swiftnav, USA) which automatically process the GPS signals and RTK correction from another piksi controller which serves as a base station.

Firmware Development

The firmware for both the data logger and sensor boards were all written in C. The programming was written in a modular design where each of the important functions were written in a separate file for easy debugging. The following were categorized as important functions or drivers; CAN Bus, microSD, UART, Addressing and counter mode, ADC, SPI, I^2C and SDI conversion. The main firmware of the data logger at start up performs the following; check all the connected sensors availability at startup, RTC date and time if it is current, SD Card presence and a short diagnostic by transmitting a 4-byte data ("EREC") and wait for the same message to be sent back to the main controller by one of the sensor boards. If no error is found the main controller will start logging all the data to the microSD received from all the sensor boards connected including the GPS. The saved data is formatted into a text delimited file and filename is automatically created based on the date and time stamp.

Though CAN Bus signal frequency can accommodate up to a maximum of 1Mbit/sec based on the chip used, the current configuration for this work was limited into 125 kbit/s as the maximum distance that this frequency can handle up 500 m.

Results and Discussion

Infrared Temperature

The current temperature sensor used has a short effective distance between the sensor and the object temperature being measured. Increasing the distance will also increase the area that will be calculated to get the average temperature. The only solution for this problem is to add a Fresnel lens in front of the sensors to maintain the fov and increase the distance of the sensor to the object. Results of the test did not produce an acceptable output and therefore a new sensor is currently being sourced out to replace the MLX90614.

Ultrasonic sensor

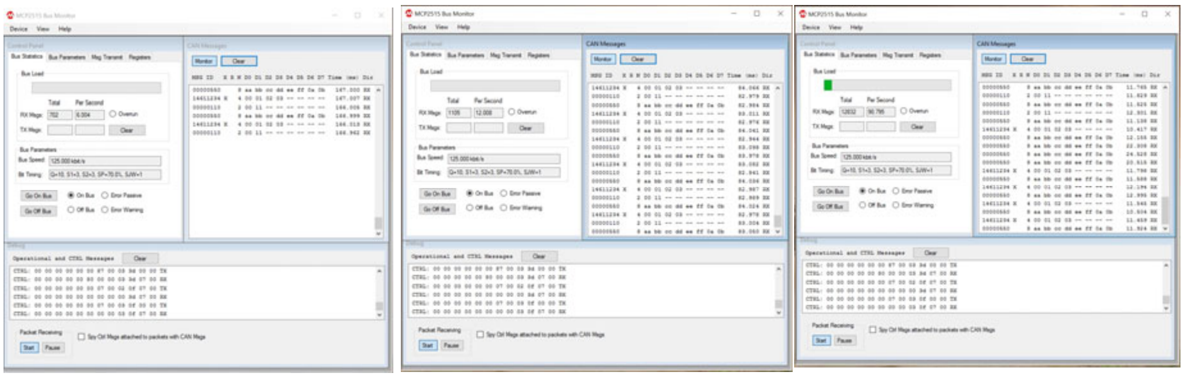
The data reported by the UGT250 is a numeric value that is highly correlated to the distance of the object of interest. The sensor boards have a voltage divider circuit for the UGT250 output pin that lowers the voltage output of the sensor to 5V. The maximum voltage of the output pin of the sensor is 10V. The controller has a 10-bit ADC where the maximum number generated by a distance of 2200 mm is 1023. To minimize the problem of erratic numbers, an average of 6 data readings were used as the final data for the distance. A linear regression analysis of distance measurement and the ADC readings was conducted and the results indicated that there is significant relation between the measured distance and the ADC readings.

Spectral sensor

The only test that was done for the spectral sensor was the SDI-12 to CAN Bus conversion. There was no test on the actual plant data reading due to the time spent in the development of the board. An extension of the proposal was submitted to field test the whole setup next year.

Data transmission

Transmission testing is a direct test of checking the ability of the CAN Bus line to transfer data from the two sensor boards to the data logger using the current configuration of 125kbits/s. A CAN Bus monitor was used to measure the amount of messages received by the data logger from the sensor boards. Messages were created at random with random data length (1-8) as well. The result showed that the data logger has been able to receive and process 90 messages per second with minimal load and with no errors detected.



6 messages/sec   12 messages/sec   90 messages/sec

Figure 2. Data transmission test reported by the CAN Bus Monitor in real time.

Summary

A new data logger and sensor boards for cotton high-throughput phenotyping were developed. The data logger has two Ethernet connectors which can be used to connect the sensor boards using CAN Bus technology. The two sensor boards that were currently developed were the NDVI sensor board and a General purpose sensor board. Firmware for each board were developed into modular design for easier debugging. Sensors such as NDVI, temperature and distance were tested for communication with the data logger and data transmission tests were also done to determine the maximum speed the CAN Bus can handle. Though the current CAN Bus configuration only utilized 125 kbit/s, a higher bandwidth is possible by updating the firmware for both the data logger and sensor board. Tests were conducted between data transmission from the sensor boards to the data logger and a maximum of 90 messages per second was achieved with minimal loading issue. The advantage of this work is minimal wire for sensors connectivity and does not need a PC/Laptop for data collection.

Acknowledgements

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