IJCAT - International Journal of Computing and Technology, Volume 6, Issue 9, September 2019
ISSN (Online) : 2348-6090
www.IJCAT.org
Impact Factor: 0.835

Front-Interface of Smart Agricultural Irrigation Monitor to Aid Crop Production in Trinidad and Tobago

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Abstract - In agriculture, irrigation is a crucial component of crop production. Trinidad and Tobago faces two seasons: "dry" and “rainy” seasons. In the dry season rainfall is scarce and irrigation must take place in order to provide plants with the necessary moisture required for successful growth. In the rainy season there is excessive rainfall which may result in waterlogging of soil. Many farmers however apply irrigation without measure of the actual amount of water applied and the optimum requirements for plant growth. This may lead to over-irrigation or under-irrigation. Over-irrigation and under-irrigation introduce many negative consequences to the farming practice, all resulting in financial loss to the farmers and their livelihoods. This paper entails the actual development of a front-interface of a Smart Agricultural Irrigation Monitor to aid crop production in Trinidad and Tobago. In the rainy season excessive rainfall may result in too much moisture being applied to land so this system will also be capable of indicating to administrator the status of soil moisture during rainfall.

Keywords - FPGAs in Agriculture, Agricultural Systems, Smart Agricultural Systems, Intelligent Agricultural Systems, Crop Production, Intelligent Crop Production, Agricultural Technology Adoption, Smart Irrigation, Precision Agriculture

1. Introduction

Climate change is one of the most serious challenges faced in agriculture while at the same time agriculture is blamed for contributing to climate change because of the use of pesticides, land use practices and fertilizers [10]. Climate change may result in droughts, adverse weather conditions, changing rainfall patterns, etc. This results in reduced production and productivity. This ultimately affects the food security of billions of people around the world, particularly in Trinidad and Tobago where the livelihoods of a large portion of the population is dependent on agriculture [10].

In the past six decades the upgrading of agriculture policies in Trinidad and Tobago was geared toward an increase in food production. This policy upgrade resulted in an increase in use of pesticides, inorganic fertilizer, machinery etc. The methods used for weed, pest and diseases control have changed from the safe use of natural, cultural and biological control to the use of pesticides, weedicides, etc [17]. The use of natural sources of nutrition such as compost, manures from livestock and even the strategic use of nitrogen fixing crops such as pigeon peas has been replaced by the excessive use of inorganic fertilizers [17]. There is also an increase in the use of technology in agriculture. The use of technology in agriculture can not only significantly increase agricultural sustainability and production but also reduce wastage of available agricultural resources such as access to water, fertilization, all in the long run resulting in a cost saving.

The use of technology can also reduce the cost associated with human labour. One major area of crop production which can benefit from technology is that of irrigation. Currently in Trinidad and Tobago a variety of methods are used for irrigation, however none of them include the element of soil moisture monitoring to avoid over-irrigation and under-irrigation. This paper serves to propose an intelligent agricultural maintenance system capable of aiding farmers of Trinidad and Tobago using smart and precision irrigation of their crops. This system should not only significantly reduce wastage of water but also significantly minimize the use of human resources in the actual process of irrigation. It makes it very possible for these same human resources to focus more time on strategic planning for their agricultural business.

2. Review of Existing Agricultural Maintenance Systems

[4] evaluated the performance of export of agricultural produce during the period 1980-2004 for Caribbean countries which have borrowed from the Caribbean Development Bank, excluding territories dependent on the United Nations. [4] also assessed the issue of food security and dependency. [4] concluded that there is an urgent need for the transformation of agriculture in the Caribbean region with the use of technological advancements to guarantee diversification in high value, dynamic and processed export markets. This will result in a substantial earning of foreign exchange for the sustainable development of countries in the Caribbean region [4].

[7] reviewed the use of precision agriculture technology in cotton farming. In precision agriculture the variability of certain aspects of soil and crops is assessed and information is gathered for use in site-specific management practices for optimization crop production. [7] assessed the effects of various regional characteristics on the intensity of precision agriculture technologies utilized by cotton farmers. At the end [7] reaffirmed the importance of technology in agriculture and the need to keep innovating to sustain agriculture, specifically the cotton industry.

[9] presented benefits of agricultural innovation to peasant farmers in rural areas in China. Peasant farmers in rural areas must afford to adopt agricultural innovation in order to increase the production and revenue in agriculture [9]. [9] indicates that technology innovation in agriculture is a great consideration for avoiding potential food crisis in China. [9] reported that with the involvement of technology innovation and advancements such as the use of hybrid seeds, fertilizers and pesticides the annual grain output in China increased from 446 million tons in 1990 to 570 million tonnes by 2011. Although technological and scientific advancements benefit China at large, peasant farmers in poor rural area have not as yet adequately benefitted from them because technological and scientific adoption is expensive [9]. As such [9] suggest that movement policy should be geared towards assisting these peasant farmers adapting to technological and scientific advancements. This will further increase the agricultural output of the nation. [9] recommended an investment by governments towards research and development in agricultural technology for the development of the sector.

[10] indicates that one of the major environmental challenges faced in agriculture is that of inconsistency of rainfall. This is immediately linked to relatively low rainfall or frequent drought spells or in worst case scenario high levels of soil erosion. All instances may either result in over-irrigation or under-irrigation. In light of this [10] stresses on the need to adopt good production practices and sustainable production systems to uplift agriculture.

[15] evaluated the impact of improving farming techniques in the Gaza of rural Mozambique on agriculture in the area. The impact of a group-based approach towards the adoption of technology in agriculture was evaluated. [15] indicated that the intervention of improved farming techniques including the adoption of technology was successful in increasing the number of households in rural Mozambique in participating sustainable farming practices. According to [15], the region is vulnerable to drought. Since water for crop production is completely sourced from the rain, drought is the most common factor adversely affecting food security and revenue from agriculture. Heavy rainfall can result in floods which can wash away top-soil, hence affecting agricultural revenue generation [15].

[16] presented a qualitative analysis on the adoption of innovations in agriculture. The agricultural sector is faced with a need to increase production of food reserves to support the nutritional needs of an expanding population. [16] stresses the need to adopt approaches to carrying out operations inherent in the agricultural sector. To do this the sector must invest in research and development to enable technology adoption. Agricultural technological innovations will provide limitless possibilities to help challenges faced in labour, market fluctuations, food supplies for the population etc. [16] presented a list of drivers for the adoption of technology innovations in agriculture including the use of information and communication technologies (ICTs).

[17] discussed the importance, usage and role of modern technology adoption in agricultural improvement. [17] implied that driverless tractors and a variety of other agriculture machinery containing GPS and electronic sensors may prevail in that in the future of agriculture. [17] also discussed the use of crop sensors in aiding farmers in the application of fertilizers in a very effective way in order to maximize nutrient take-up by plants. [17] also presented the monitoring and controlling of irrigation system via mobile technology and cameras. Smartphones gave the farmers the ability to control the switching on and off of irrigation systems using electronic devices to avoid human intervention in this respect. [17] claims that use of modern technology has

resulted in a significant increase in the agricultural outputs of the top 15 countries that utilize such technology and has contributed substantially to the GDPs of these countries.

[18] encouraged intensifying sustainable crop production via modern farming practices and the use of technology to guarantee resilient crop production. To do this institutional environmental and social principles must be taken into consideration. [18] encourages agricultural management strategies like conservation agriculture where disturbance to the soil is minimized. [18] also provides support to farmers in progressing with integrated pest management systems which depends on natural pest control and more effective use of fertilizer and water resources for ensuring soil is healthy and adequate for crop growth.

3. Contribution of Research

The general trend recognized in the review of existing agricultural systems is that many researchers have recognized the need for technology adoption in sustainable development in the agriculture sector. There is a need to automate all processes in agriculture which originally were executed by human elements. This paper contributes to the agricultural sector by development of a front-interface of a Smart Agricultural Irrigation Monitor capable of aiding the solution of issues faced in crop production in Trinidad and Tobago. One major issue identified in the review of literature is that or adequacy of water for irrigation of crops. Droughts many times result in under-irrigation, while excessive rainfall and stormy weather may result in over-irrigation and in worst case scenarios, flooding which affects the topsoil. Both scenarios adversely affect crop production. This front-interface of a Smart Agricultural Irrigation Monitor will have the following features:

(a) Measures soil moisture and transmits real-time information about soil moisture using GSM modem from a variety of locations within the portion of land to administrator for analysis.
(b) Capable of allowing setting of optimum moisture level for different crops.
(c) If moisture level falls below the minimum threshold required, then an irrigation system is turned on for that portion of land and kept on until optimum moisture level restored.
(d) If moisture level above max allowable then warning messages to be send to administrator using GSM modem for intervention for removal of excess moisture.

Other features which must exist but will be included in future development of this system are:

(a) Must possess a graphical user interface on the administrative side for displaying all messages, warning and information sent by agricultural maintenance terminals in the field for manual control of switches, actuators which resolve moisture issues if there is need for manual intervention
(b) System is portable and capable of being powered via batteries or the 12V outlet of a vehicle (Cigarette lighter)
(c) Must be scalable, hence allowing addition of more terminals depending on the size of parcel of land under crop production.

The proposed intelligent agricultural maintenance system consists of several segments. A parcel of land under cultivation may be divided into several sectors or segments depending on the irrigation requirement of the crop to be cultivated. One (1) Slave Terminal (ST) will be placed on each sector of land. As such if the parcel of land is divided into 20 sectors then 20 slave terminals would be required. The system also consists of one (1) Master Control Terminal (MCT) and one (1) Central Administrative Terminal (CAT).

The slave terminal represents the sector of land which it is assigned to. The purpose of a slave terminal is to monitor soil parameters such as soil moisture, pH, nutritional content for the sector of land its assigned to and report any deficiencies and other issues to the master control terminal via communication using a long-range XBee wireless communication network. The MCT in turn analyses the issues experienced on the STs and determines the best corrective action to resolve the issues faced. The MCT then sends commends back to the ST which will utilize electronic and mechanical devices existing at each ST for correcting the issues. In all events the MCT reports the issues faced at the STs to the CAT for recording purposes only. If any situation arises that the MCT cannot resolve and needs human intervention, then the MCT sends a request for resolution (RFR) request to the CAT which will then attract human intervention in that respect.

The MCT communicates with the CAT via a GSM mobile network which means that it is very possible for automatic text messages or even calls to be made to the CAT from the MCT. Fig 1 below gives the concept diagram for the Intelligent Agricultural Maintenance System.

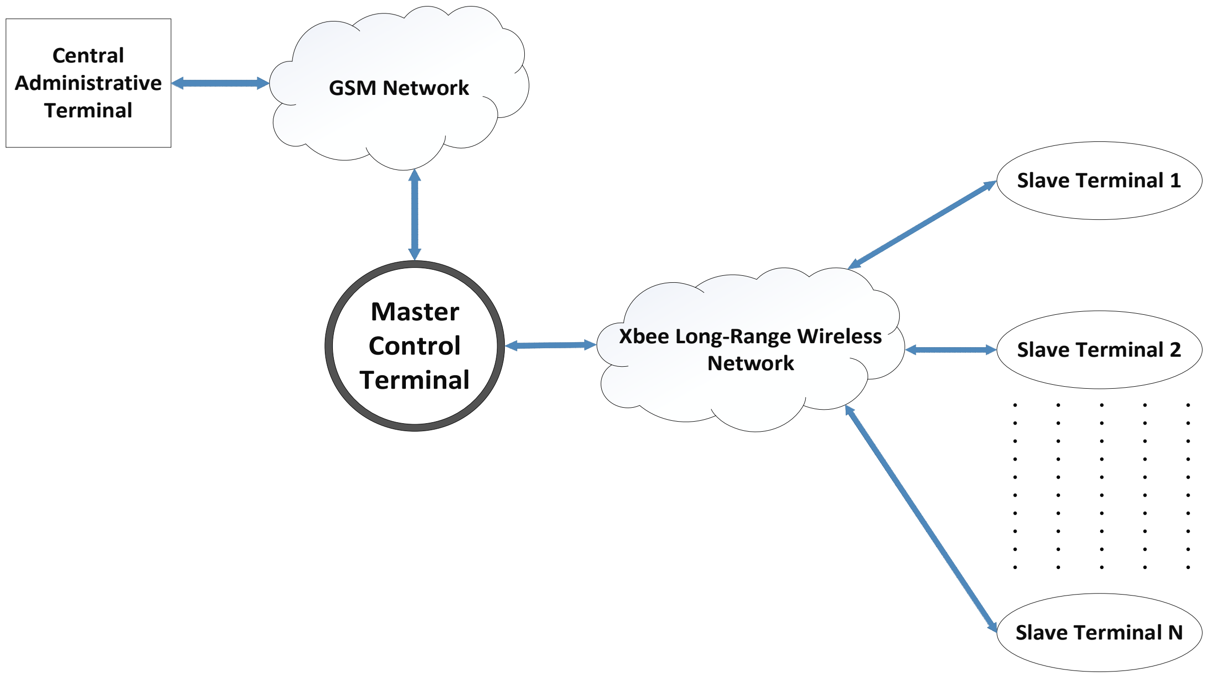

Fig 1: Concept Diagram of The Front-Interface of Smart Agricultural Irrigation Monitor

4. Design & Implementation of Front-Interface of Smart Agricultural Irrigation Monitor

The soil moisture sensor measures the soil moisture level and transmits to FPGA via Analog/Digital Converter (ADC). The FPGA will then interpret the data and assert the actuation signal high or low to correct a low soil moisture level. It would also send the appropriate warning messages to a cellular phone through the GSM modem. Fig 2 gives and overview of the required system. Fig 3 gives the FSM-D model for the agricultural maintenance system.

This section describes how the digital aspect of the system was designed to achieve project objectives. The system was designed following the FSM-D structured approach [20]. The general flow of the system is as follows:

1. On system startup initialize all signals and reset configuration.
2. Enable keypad entry.
3. Store input from keypad into appropriate signals based on which parameter switch the user has selected.
4. When configuration is complete start ADC sample.
5. When ADC sample is done, check the sample against the set threshold levels.
6. If the sample value is below the lower threshold, set an actuation signal high and transmit a warning message to the farmer.
7. If the sample value is above threshold, send a warning message to the farmer.
8. Return to step 4.

The digital component of the project was implemented in VHDL using Xilinx ISE IDE v14.7 and according to [19] and [20]. Each entity is identified by its name and whether or not it belongs to the AT, MT, data-path or control path.

a. Administrative Terminal- Frequency Divider

This component takes the reference clock (50MHz) and produces lower frequency signals required by the system. anyinteger frequency that is lower than its base clock. Six (6) clock frequencies were required for the system: 1Hz, 10Hz, 1kHz, 41kHz, 115200Hz, 921600Hz. It should be noted that the clock frequency 115200Hz was required for the baud rate of the GSM Modem.

b. Administrative Terminal- Four Digit Time Multiplexer

The 4 digit 7-segment displays are multiplexed with each other. This means that only one can be on at a time.

In order to use all four in such a way that it would seem to be in use at the same time, the signals as to which segment is illuminated and the segment that should be on is changed at a frequency of 1kHz. Multiplexing saves power since each segment is not constantly on as well as FPGA area since there are less signals to drive. The display value is a 32-bit wide signal (4 ASCII bytes) which is then passed through a case statement to recreate possible characters. If a character cannot be represented the segments turn off.

c. Administrative Terminal- Message Generation

This process has to monitor the changes of multiple signals and queue the message for transmission faster than the message is transmitted. In order to have the message readied in the appropriate buffer, the generation was clocked 8 times faster than the transmission speed i.e. at $115200 \times 8 = 921600$Hz. The process only generates a message and converts it into a binary value when the signal in CONFIG_BITS and WARNING_SIGNAL changes state. When the phone number is set, the command to set up the GSM is generated. Similarly, the appropriate messages are generated when the moisture level crosses the user-defined thresholds. Some have a 'CR' character as the modem needs this to identify the end of a message. The message generated is then assigned to a 440 bit-wide signal i.e. a signal that is capable of storing a 55-character ASCII string.

d. Administrative Terminal- UART-TX

This is responsible for transmitting the messages and AT commands from the Spartan 3 to the GSM modem. It consists of two sub-components, 'message_shift' and 'bit_transmit'. The first sub-component takes the 440-bit string from 'Message Generation' and splits it into a byte and concatenates the start and stop bit to it to create a 10-bit signal according to the UART protocol. That 10-bit signal is then sent to the *'bit_transmit'* component where it is serially shifted out to the signal *'tx_line'* according to the default GSM baud rate of 115200baud. It starts to shift out the message generated by "Message Generation" when the phone number is set, when the soil moisture dips below the lower threshold or when it goes above the upper threshold. Each byte of the message is shifted out when the signal 'TX_DONE' goes high. This way the *'uart_transmit'* process controls when the next byte is ready for transmission and reduces the possibility of timing errors.

e. Administrative Terminal- Keypad Data

In this component there are five engage signals, switch, phone_num_en, positive_engage, soil_tol_en and negative_engage. In order to set the phone number, switch and phone_num must be high. Similarly, for the soil tolerance level, switch, soil_tol_en and either positive_enage or negative_engage must be high depending on which the user needs to set. The operation for all three values is the same once that process is engaged. The key values are read in from the key encoder, only when a key is pressed, and passed through a case statement to generate a 15-bit display value (ASCII and segments off) for only the key that was pressed as well as an 8-bit value for the key (ASCII equivalent). Once that is complete the engaged process shifts it up by 8 bits when the next value is entered until the value is entered into the system. When the user is finished, he/she needs to press 'ENTER' to store the value, this will set the relevant CONFIG_BIT high. If the user makes an error, he/she can press 'CLEAR' to reset the buffer and re-enter a new value. Once all the values are set, the soil tolerance values are converted from 16 bits (2 ASCII bytes) to an 8-bit value to be used for comparison against the incoming ADC signal. The keypresses are scanned at a frequency of 1kHz.

f. Administrator Terminal - Buzzer Sequence

This process is clocked at 1kHz, the same frequency as scanning for keypresses. With both processes tied to the same clock, whenever a key is pressed the buzzer sounds for as long as the key is pressed. The buzzer therefore validates whether or not the keypad is working and also gives an audible alert. This is so in the event the system is being configured in bright light (sunlight on a field) where the display will not be visible the user will know that the keypress was registered.

g. Slave Terminal - ADC Input

The signal from the moisture sensor (simulated with a potentiometer for this project) is sent into the ADC and the 8-bit value is sent to the Spartan 3 board. When the value is read in, it is passed through a case statement that generates the display signal of the actual voltage level and the display signal for what percent that voltage is of 3.3V i.e. V_{REF}. It also gives the 8-bit value of that percentage to be used in the comparison against the user defined tolerance value via the same case statement. It should be noted that the percentage values are integers only. This is because the resolution of the sensor the system is anticipated to be used with does not cater to such levels of precision.

Also, despite the ADC having 256 steps of 0.012mV each and being able to provide a floating-point voltage value, the percentage value would be difficult to use on an FPGA has it been converted to a floating-point number as well. It is also unlikely that the user will input a floating-point soil moisture percentage into the system. For these reasons it was decided that the percentage stay as an integer value. This process is clocked at 10Hz since the moisture level is not expected to change that quickly.

h. Data Display-Administrative Terminal

This component uses a pushbutton (*display_cycle*) to iterate through the user-defined parameters as well as the real-time ADC voltage and the percentage value of the ADC voltage. Pressing the button advances the display from one parameter to the other, via a case statement, in a loop and displays the value of those parameters on the 4-digit 7-segment displays. When the system has been configured, the process will detect the transition of the 'CONFIG_DONE' bit and allow the phone number to scroll on the displays at a frequency of 1Hz. This component is set up so that the user can manually check how the system was configured and see the values during configuration as they were entered.

i. Administrative Correction – Administrative Terminal

This module toggles the actuation signal (EXT_ACT) whenever the value from the ADC dips below the lower threshold set by the user. It also changes the state of the 2-bit signal WARNING_SIGNAL to indicate whether or not the soil moisture level is under threshold, within range or above the threshold. It only triggers corrective action when the whole system has been configured. This process is clocked at 1kHz in order to have a small reaction time to changing input levels while using an existing divided clock to save power and FPGA space.

j. Administrative Terminal- System Status LEDs

This uses the outputs from the 'Keypad Entry' component and the 'Administrative Correction' component to illuminate the onboard LEDs. As parameters are configured, the LEDs light to signify that the have been set. The warning signals are also routed to the LEDs so that there is an on-board indication of the system status.

k. Control Path Agri Station (FSM logic)

The control path works by enabling a process and waiting until that process indicates that it is finished before moving onto another state. This allows the parallel nature of an FPGA platform to become more serial in the sense that the flow of events is structured in one direction. Initially it was decided that the states would use the 'one-hot' encoding scheme to represent different states. However, we will later see how the Synthesis tool analyzed the implementation and determined a better encoding. The states were still coded according to its specification.

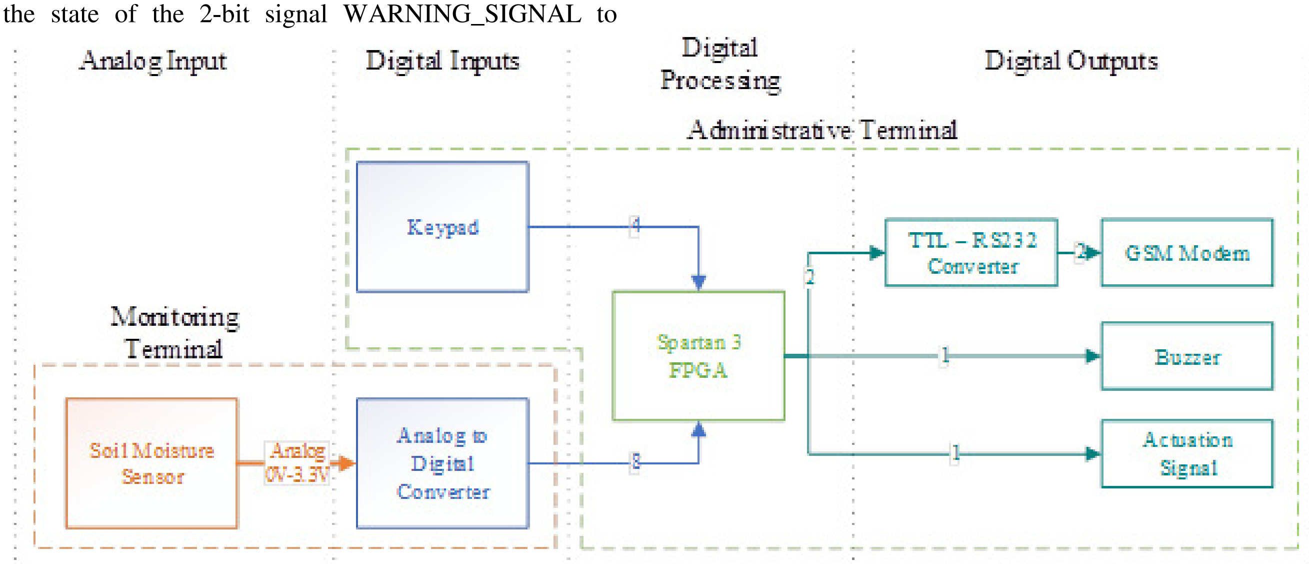

Fig 2: Overview of Front-Interface of Smart Agricultural Irrigation Monitor

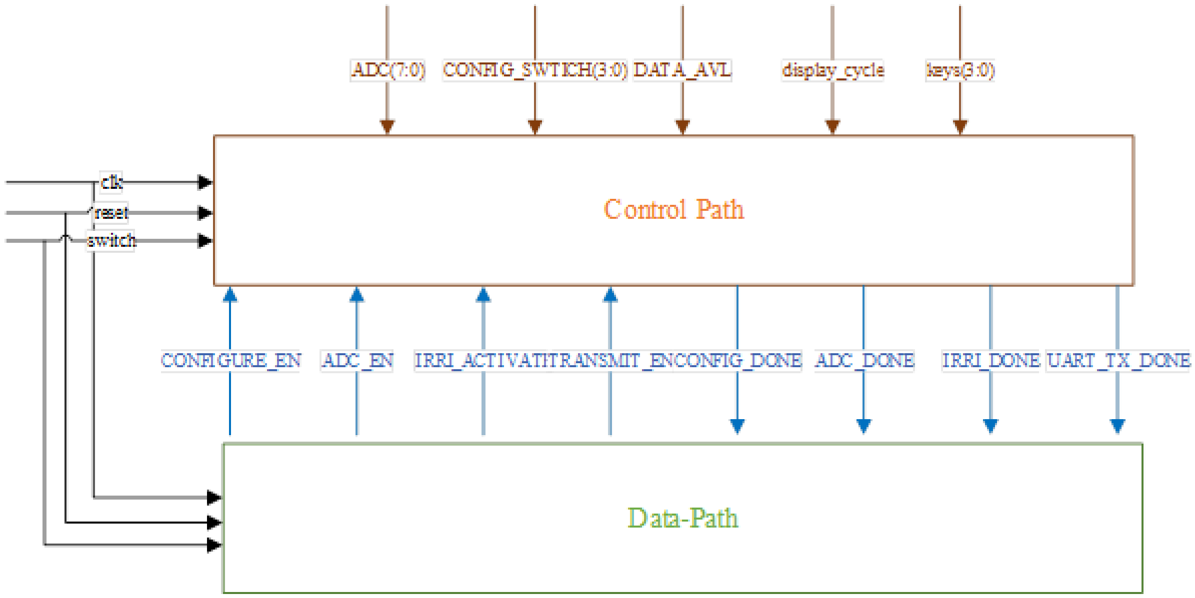

Fig 3: FSM Interface Definition. Relation Between Control and Data-Path

5. Verification of the Front-Interface of Smart Agricultural Irrigation Monitor

System verification is a process where each component of the system is checked for its correctness in terms of the output it produces, for each testing phase. Every component is tested in two phases unit and then integration via on-board testing. Each test phase and each component will be discussed in more detail below. After all tests were completed the system is tested as a whole to ensure functionality of all modules working simultaneously the result of this is shown in section five. The test cases were designed following the IEEE Standard for Software Test Documentation i.e. IEEE Std 829-1998 on documenting test cases.

A serial to USB cable based around the FT232RL IC from SparkFun was used to communicate with the modem for testing through the Arduino COM terminal. This was done to ensure that the modem functioned on its own before attempting to interface it with the FPGA. The test circuit was setup according to the block diagram below. Fig 4 shows a successful communication attempt with the modem, implying that both the modem and MAX232 have been set up correctly. Fig 5 below shows all the implemented circuitry for the developed system.

At startup the displays and the LEDs are off and the system waits for the enable switch to go high and then for the user to entire any of the parameters. The system is then enabled and the the phone number is entered. Note that none of the leds are switched on until the user presses '*ENTER*'.After the user presses '*ENTER*'. the leftmost LED lights up. Cycling the displaying to the lower threshold we see the value is empty but that the system is ready for the entry of the lower threshold since the displays read 'Lo'. The value '25' was then entered and it should be noted that the second LED is still off. Pressing '*ENTER*' illuminates the LED and stores the value. This process was repeated for setting the upper threshold at a value of '63'. The phone number is now allowed to scroll across the display since the system has been configured. It is possible to begin clear the value, in the event the wrong value was entered, by pressing '*CLEAR*'.

The system will always generate a message once the levels cross the user defined boundaries. The system did transmit the message but initially there was difficulty in getting the modem to transmit the received messsage. The first test failed, but through experimentation the timing of the system, some sensible output was obtained from the modem. Tables 1-3 give verification results for the system while Fig 6 and 7 gives screen shots of warning messages sent to PC and FPGA from the agricultural maintanace systems based on verification tests.

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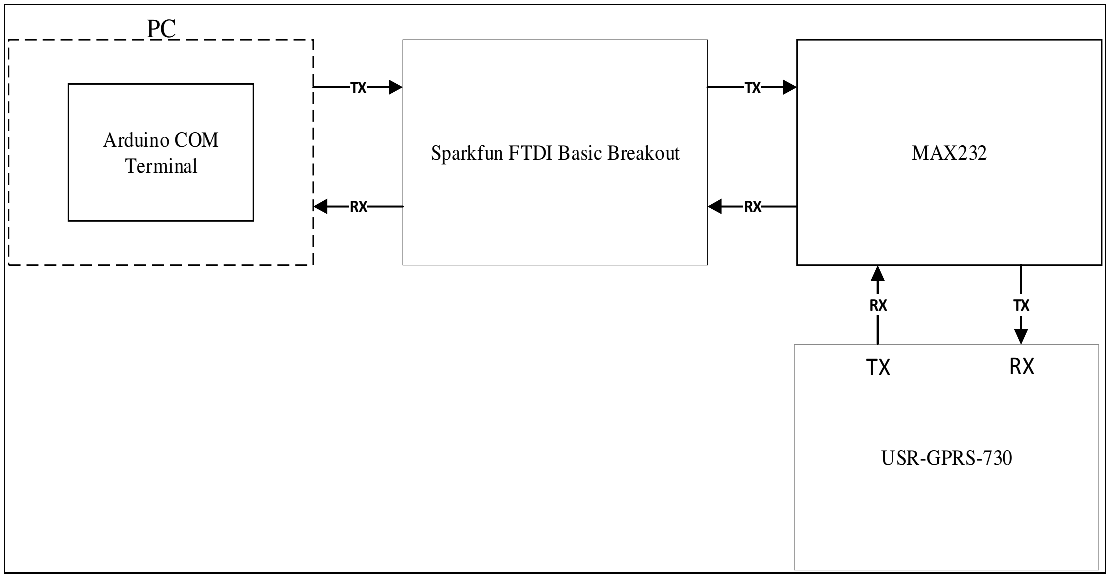

Fig 4: Interfacing the GSM Modem with a PC

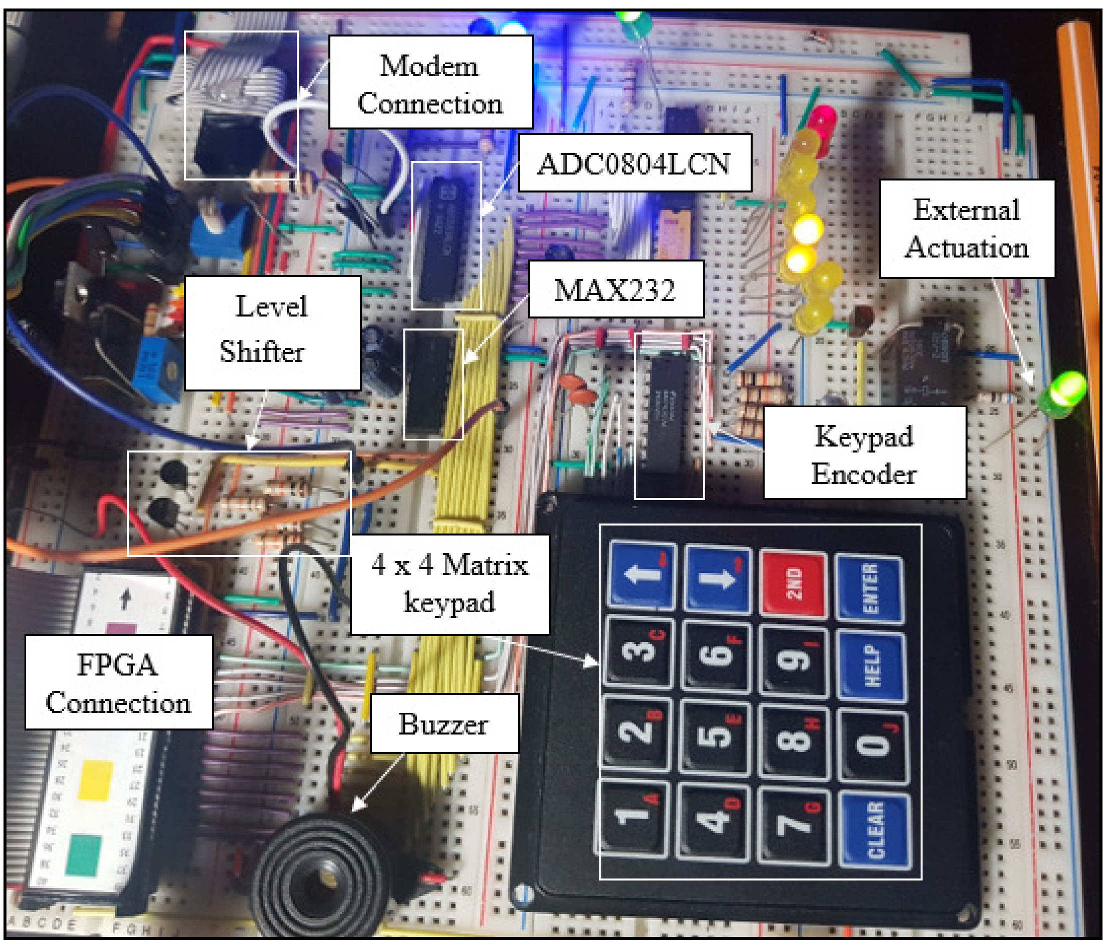

Fig 5: Breadboard Setup to Interface with FPGA

Table 1: Linearly Ascending Soil Moisture Levels with Lower and Upper Thresholds of 35% and 63%

Soil Moisture Percentage	Actuation Signal	Warning Message
2	ON	No message sent
11	ON	No message sent
22	ON	No message sent
28	ON	No message sent
33	ON	7951: Warning! Soil Moisture under threshold: 35%
35	ON	7951: Notice! Soil Moisture within range
40	OFF	No message sent
49	OFF	No message sent
57	OFF	No message sent
62	OFF	No message sent
63	OFF	No message sent
69	OFF	7951: Warning! Soil Moisture over threshold: 63%
71	OFF	No message sent
80	OFF	No message sent
86	OFF	No message sent
99	OFF	No message sent

Table 2: Linearly Ascending Soil Moisture Levels with Lower and Upper Thresholds of 35% and 63%

Soil Moisture Percentage	Actuation Signal	Warning Message
99	OFF	No message sent
86	OFF	No message sent
80	OFF	No message sent
71	OFF	No message sent
69	OFF	No message sent
63	OFF	7951: Warning! Soil Moisture over threshold: 63%
62	OFF	7951: Notice! Soil Moisture within range
57	OFF	No message sent
49	OFF	No message sent
40	OFF	No message sent
35	ON	7951: Warning! Soil Moisture under threshold: 35%
33	ON	No message sent
28	ON	No message sent
22	ON	No message sent
11	ON	No message sent
2	ON	No message sent

Table 3: Randomized Moisture Levels Input with System Output

Soil Moisture Percentage	Actuation Signal	Warning Message
43	OFF	7951: Notice! Soil Moisture within range
54	OFF	7951: Notice! Soil Moisture within range
65	OFF	7951: Warning! Soil Moisture over threshold
82	OFF	7951: Warning! Soil Moisture over threshold
38	OFF	7951: Notice! Soil Moisture within range
56	OFF	7951: Notice! Soil Moisture within range
37	OFF	7951: Notice! Soil Moisture within range
89	OFF	7951: Warning! Soil Moisture over threshold
97	OFF	7951: Warning! Soil Moisture over threshold
88	OFF	7951: Warning! Soil Moisture over threshold
93	OFF	7951: Warning! Soil Moisture over threshold
14	ON	7951: Warning! Soil Moisture under threshold
41	OFF	7951: Notice! Soil Moisture within range
73	OFF	7951: Warning! Soil Moisture over threshold
42	OFF	7951: Notice! Soil Moisture within range
80	OFF	7951: Warning! Soil Moisture over threshold

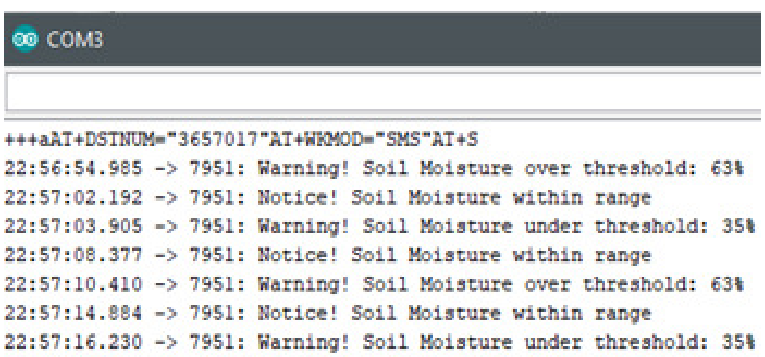

Fig 6: Output from FPGA to Arduino COM Terminal on PC

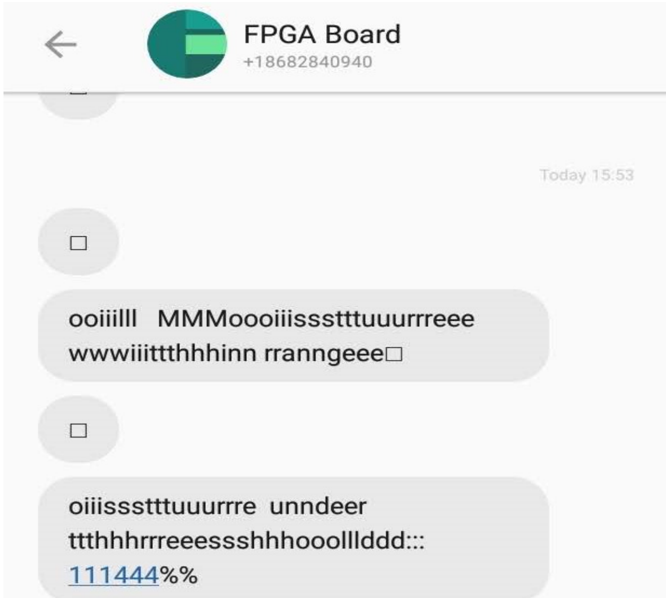

Fig 7: Text Messages Transmitted by GSM Modem to Cellular Phone

6. Conclusions

This paper entailed the actual development of a front-interface of a Smart Agricultural Irrigation Monitor to benefit crop production in Trinidad and Tobago. In the rainy season excessive rainfall may result in too much moisture being applied to land so this system will also be capable of indicating to administrator the status of soil moisture during rainfall. The developed system was able to accept user values and generate the appropriate warning messages when the comparison was done between the real-time value and the threshold. The interface was also able to activate any existing actuation system by manipulating an actuation signal until the soil moisture returned to an acceptable range. This system ensures that crops will experience their optimum moisture conditions. The system can be further upgraded to incorporate the regulation of other parameters such as soil PH and soil nutrition. Finally, the system can be upgraded to incorporate flood monitoring capabilities which will inform the CAT of the imminence of flooding on the parcels of land under crop production. Without doubt this system will be invaluable to farmers in Africa nations and can possibly reduce production cost by minimizing wastage of water supplies while guaranteeing that crops experience optimum moisture conditions.

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