Design and Development of an Efficient and Cost-Effective Microcontroller-Based Irrigation Control System to Enhance Food Security

Robert A. Sowah, Stephen K. Armoo, Koudjo M. Koumadi, Rockson Agyeman, Seth Y. Fiawoo

Abstract—The development of the agricultural sector in Ghana has been reliant on the use of irrigation systems to ensure food security. However, the manual operation of these systems has not facilitated their maximum efficiency due to human limitations.

This paper seeks to address this problem by designing and implementing an efficient, cost effective automated system which monitors and controls the water flow of irrigation through communication with an authorized operator via text messages. The automatic control component of the system is timer based with an Atmega32 microcontroller and a real time clock from the SM5100B cellular module. For monitoring purposes, the system sends periodic notification of the system on the performance of duty via SMS to the authorized person(s). Moreover, the GSM based Irrigation Monitoring and Control System saves time and labour and reduces cost of operating irrigation systems by saving electricity usage and conserving water.

Field tests conducted have proven its operational efficiency and ease of assessment of farm irrigation equipment due to its cost-effectiveness and data logging capabilities.

Keywords—Agriculture, control system, data logging, food security, irrigation system, microcontroller.

I. INTRODUCTION

AGRICULTURE is the key to food security in every nation. Food security is a situation in which all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Chief among high crop yield factors is irrigation. Irrigation is the act or process of causing water to flow over lands to nourish plants, or the watering of land by artificial means to foster plant growth [1], [3]-[5]. Irrigation in modern times is practiced in homes, offices and recreational centres. Over the years, the practice has moved away from the traditional watering mechanism using watering cans to sophisticated irrigation systems that are powered by electric water pumps. Properly designed and constructed water distribution structures in irrigation are ultimately targeted at sufficient food production. Irrigation ensures consistent food production and stabilizes agricultural production. It allows commercial production of food for local consumption and exports. It allows increased possibilities of crop diversification that favour high value crops and enhance

R.A. Sowah, S. K Armoo, R. Agyeman, Koudjo M. Koumadi, and S. Y. Fiawoo are with the Computer Engineering Department, University of Ghana, Legon, Accra, Ghana (e-mail: rasowah@ug.edu.gh, skarmoo@ug.edu.gh, rocksyne@gmail.com, gmills@ug.edu.gh, syfiawoo@gmail.com).

attainment of food security [2].

The major components of cost of irrigation systems established in Ghana are (1) inadequate local expertise in planning, design and construction of irrigation projects, (2) inadequate feasibility studies leading to costly design changes during construction, and (3) unsuitable mechanization of construction operations [4]-[7].

Irrigation facilities are classified mainly according to the way they dispense water. There are five (5) main forms of irrigation systems. These are: (1) Sprinkler irrigation (Overhead irrigation), (2) Localized irrigation (Drip or trickle irrigation), (3) Surface irrigation, (4) Sub-irrigation and (5) Manual irrigation using buckets or watering cans.

Sprinkler irrigation is a method of applying water similar to natural rainfall. The water is distributed through a system of pipes, usually by pumping at high pressure. Localized irrigation on the other hand is a system where water is distributed under low pressure through a network of water pipes in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it [1]. Manual irrigation, as its name implies, involves the use of bucket or watering can to transport water from a source onto the field of application.

This paper is divided into the following sections: Section I introduces the concept of irrigation systems and the benefits of irrigation to national development and the enhancement of food security. Section II provides a detailed problem definition and motivation for developing a microcontroller based irrigation control system equipped with Global System for Mobile Communication (GSM) technology. It further highlights the key features of the proposed system which is inherently cost-effective and efficient. Section III presents the literature review of some similar systems that have been implemented; their peculiar strengths and weakness are highlighted and major enhancements needed are emphasized. Section IV presents the system design and methodology used in the development of the GSM based microcontroller irrigation control system which is cost effective and efficient. This section presents the engineering design challenge for the microcontroller based irrigation systems and how it is overcome. The system implementation and testing of the designed and implemented modules are presented in Section V. Extensive performance testing was carried out to ascertain the usability of the proposed system. Section VI presents the conclusions with recommendations for future work. This section highlights some of the engineering design limitations with justifications of the research work.

II. PROBLEM DEFINITION

Many of the irrigation systems operated worldwide are used on farms or lands that are located on the outskirts of towns and difficult to monitor. The manual operation of these systems over time has resulted in many problems [8], [9]. Chief among them is the possible event of either under-watering or over-supply of water. The consequence of under-watering is reduced crop yield. Similarly, overwatering results in withering of crops in some instances, as not all plant species tolerate excessive water. Over-irrigation further results in leaching of soil nutrients [1], [10], [11]. The manual approach to practicing irrigation is both cost and resource-inefficient. To address these challenges and proffer long lasting solutions for dealing with the perennial over-watering or under-watering of farm crops at remote areas we propose the design of an efficient and cost effective microcontroller-based irrigation control system for enhancing food security.

III. LITERATURE REVIEW ON IRRIGATION SYSTEMS FOR ENHANCING FOOD SECURITY IN GHANA

Irrigation is used to assist in the growing of agricultural crops, maintenance of landscapes, and re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall.

Additionally, irrigation also has a few other uses in crop production, which include protecting plants against frost, suppressing weed growth in grain fields and preventing soil consolidation. In contrast, agriculture that relies only on direct rainfall is referred to as rain-fed or dryland farming. Irrigation systems are also used for dust suppression, disposal of sewage, and in mining. Irrigation is often studied together with drainage, which is the natural or artificial removal of surface and sub-surface water from a given area [2], [6].

Agriculture is vital for the overall economic development of Ghana. It is the largest contributor to Gross Domestic Product (GDP). The irrigable land potential for Ghana is enormous but has been stymied due to lack of properly designed cost-effective and efficient irrigation systems suited for the agricultural sector in Ghana [6]-[8]. There are various cost components for irrigation of farmlands and they depend on the inherent sophistication and ease of operation and maintenance of the associated equipment. Different researchers have approached the problem of designing and developing a cost effective irrigation system incorporating modern technological features for ease of maintenance and efficient operation while utilizing water economically for such activities.

Khiyal et al. [11] focused on the controlling of home appliances remotely and providing security against intruders. This automated system employs SMS text messages and uses wireless technology to revolutionize the standards of living. It is more adaptable and cost-effective.

Zazueta et al. [12] describe an irrigation management software package that includes: (1) computer-aided irrigation scheduling, (2) computer-aided field uniformity information manipulation, (3) an expert emulation program for diagnosis and treatment of slime clogging problems, and (4) real time control software for the operation of trickle irrigation systems. This package of programs was developed to aid in the management of trickle irrigation systems. It includes design of the software modules and the corresponding architectural underpinnings that provides the control and communication functionalities of the irrigation facility. It lacks detailed notification system.

Miranda et al. [13] proposed the design, development and deployment of a low cost solar-powered feedback controller for distributed irrigation control of fixed irrigation systems. Their specific tasks included the controller design (hardware and software), performance evaluation, and power optimization. The designed controller uses soil water potential (SWP) measurements to control the amount of water applied to each specific management zone, and measured system hydraulic pressure to communicate with other controllers. Each controller is autonomously powered by a solar panel and battery, eliminating hard-wire connections among control units. The results published indicated that the controller was effective in maintaining the SWP in the root zone close to a predetermined management allowed deficit (MAD). The power supply was optimized using simulated and measured solar radiation data from two locations.

Kim and Evans [14] present the design, development and deployment of decision support software and its integration with an in-field wireless sensor network (WSN) to implement site specific sprinkler irrigation control via Bluetooth wireless communication.

Wireless in-field sensing and control (WISC) software was designed using four major design factors that provide real-time monitoring and control of both field and sprinkler control data using graphical user interface (GUI). The system was optimized to adapt to changes in crop field design, irrigation pattern, and field location. Sensor-based closed-loop irrigation was highly correlated to catch can water with high correlation coefficient $r^2 = 0.98$.

Umair and Usman [15] proposed the development of an optimal automatic irrigation scheduling algorithm using artificial neural networks. Their paper aims at overcoming the problem many irrigation scheduling techniques have; which are mainly based on monitoring the soil, crop and weather conditions. These variables are quite evasive and controlling the operation of irrigation system machinery based on ON/OFF operating conditions is sub-optimal. Their approach incorporating artificial neural networks (ANN) based controller extensively dealt with the problems of sub-optimal scheduling of irrigation systems.

Wen et al. proposed a wireless intelligent valve controller for agriculture integrated irrigation system [16]. They highlighted current problems associated with wired irrigation systems which increases cost of operation and maintenance. They designed a microcontroller-based irrigation control system which can be operated wirelessly via remote control. The controller consisted of the control unit, power unit, wireless communication unit, relay boost driver unit, state feedback switch, etc. It received the control command from the remote control center by the wireless communication unit,

actuated the relay boost driver unit to turn on/off irrigation solenoid valves. Their design results and field tests indicated the effectiveness of their system when deployed on the field.

Ingale and Kasat proposed the design and development of microcontroller-based drip irrigation system [17]. They monitored the changing conditions of humidity levels by weather patterns and soil types and scheduled irrigation activity and proper timing for water supply.

Singh and Sharma proposed an outline of improving throughput and average end to end delay of information gathered from the agriculture field for precision agriculture [18]. They included a computational mechanism that does error checking for ensuring data integrity during transmission to base station for analysis. The novelty in their approach is the aggregation of sensors, microcontrollers and power sources that are efficiently designed and integrated for the multifunctional purposes. The incorporated sensor nodes enable environment sensing and data logging capability and processing with efficient algorithms.

Hedley et al. [19] proposed the design, development and deployment of wireless soil moisture sensor networks for irrigation scheduling. They incorporated within the design an advanced nutrient management system which aims at optimizing plant nutrient use and minimize deleterious environmental effects. Precision irrigation hardware allows irrigation and nutrient inputs to be varied to small defined management zones under the irrigator. The management zones are derived from data layers obtained from electromagnetic (EM) surveys and yield maps. Wireless soil moisture sensor networks (WSNs) are then positioned into these zones to monitor wetting and drying events for precision irrigation scheduling. Their research presents progress in developing a wireless sensor network (WSN) to inform software which initiates control actions for a variable rate irrigation system.

Clark et al. [20] designed and developed a mobile irrigation lab for water conservation. The developed system comprises of several modules, namely: (1) sprinkler irrigation management device and (2) water management and irrigation scheduling software program. The software program has essential functionalities to perform device calibration, fuel cost evaluation, pumping cost evaluation and also scheduling of pumping. The novelty in their design is the integration of both the hardware and software components. The system lacks detailed notifications based on sensed parameters and actions taken by the system when in action.

Guerbaoui et al. [21] proposed the design and development of a PC-based automated drip irrigation system for watering water sensitive tomatoes. The proposed solution involves the development of an integrated system to automate the drip fertilizing irrigation in a farmhouse. The solution adopted involves a data acquisition card PCL-812PG controlled by PC. The irrigation is provided by a hydraulic circuit based on an electric pump. Water needs are evaluated by measuring soil moisture status by soil humidity sensor. The development of the graphical user interface (GUI) using LabVIEW added user friendliness to the system while ensuring efficient

management and monitoring of irrigation and fertilization activities for better crop yields.

Divya and Umamakeswari proposed the design and development of a novel irrigation system using vocal commands [22]. The system incorporates a voice recognition module for initiating the control commands via mobile phone. The control system at the field involves a PIC microcontroller interfaced with GSM modem to receive the command from the farmer and a voice recognition unit for decoding. The motor is turned on/off according to the decoded commands by the controller. In addition, the system has reporting functionalities on actions taken with data logging capability. The data logged via sensing is used for the control of the system.

Rocky Raju [23] developed an automatic irrigation system based on embedded and Global System for Mobile Communication (GSM) technology. The developed system incorporates:

(1) Sensing devices which sense the dry condition of the defined field or farmland and pass the state to the sensing logic of the automation system

(2) A Control algorithm for water flow regulation: Depending on the control algorithm, if the field is dry beyond a threshold, the microcontroller system auto starts the motor to start pumping water

State estimation and awareness query: The state of the operation of the system at any point in time can be queried via Short Message System (SMS). The ATMEL (AT89S52) microcontroller was utilized in the design and implementation. The developed system utilized SIM 300V1.06 Modem for the GSM communication module with a single supply voltage ranging from 3.4V - 4.5V. The SIM 300V1.06 GSM Modem is a Tri-band modem capable of operating on EGSM 900, DCS 1800 and PCS 1900 frequencies. An extra hardware circuitry involving a 12V DC relay and transistor as a switch was used to serve as the driver for the electrical pump.

The deficiencies in this irrigation system were: (1) the system lacked the ability to detect soil temperature, (2) the system had no timer mechanism for irrigation scheduling, (3) the system could not be reconfigured without the use of a computer, (4) the system was unsecured and could be tampered with by unauthorized persons and (5) system activity logging was absent.

Julie S. Chang presented a thesis on an Automatic Irrigation Management System in 2006 [24]. The system, unlike the GSM based Automated irrigation System described above, is not SMS based. It operates on a preprogrammed timing mechanism for the control mechanism. The system comprises a microcontroller unit and a timer system interconnected with the I2C protocol. Due to its timer system, it incorporates scheduling of irrigation activities quite different from the system implemented [13]. Furthermore, it has a complex network of wired soil sensors that periodically feeds the microcontroller unit with discrete soil moisture values through the Analog to Digital Converters (ADC) units. It provides means for system evaluation and corresponding performance of operation. The deficiencies in this system are enumerated below: (1) the system lacks the ability to detect soil

temperature before starting irrigation. This defect to some extent is taken care of by the scheduling component, but still not desirable since it does nothing to check overwatering or underwatering (2) the system timing and scheduling functionalities cannot be reconfigured without the use of a computer and (3) system activity cannot be logged for future assessment of system performance. These limitations are quite profound and require sound engineering design principles to design a cost-effective and efficient irrigation system capable of harnessing the strengths of these systems while overcoming the weaknesses or drawbacks.

IV. PROPOSED SYSTEM DESIGN AND METHODOLOGY

Based on the reviewed literature on automatic irrigation systems we propose a GSM Based Irrigation Monitoring and Control System with the following features: (1) ability to auto start based on predefined system time, (2) ability to check the soil moisture content to verify if the moisture content is up to the defined threshold or not. This is accomplished via moisture sensors. (3) Pre-set level adherence during watering, thus saving water and electricity. (4) System configuration parameters such as the user password and activity logs would be stored on the SIM card of its GSM communication unit. (5) The system administrator would be able to force start the system by sending a formatted command to the system via SMS. Force start in this context means starting the system even when the current time of sending the command is not the predefined time for the system to start. (6) The system administrator may choose to receive notifications from the system anytime it starts or completes an operation. (7) System configuration parameters include Administrator pass code, System start time, Soil moisture threshold and System SMS reply number. The entire GSM based Irrigation Monitoring and Control System was broken down into eight subsystems as shown below.
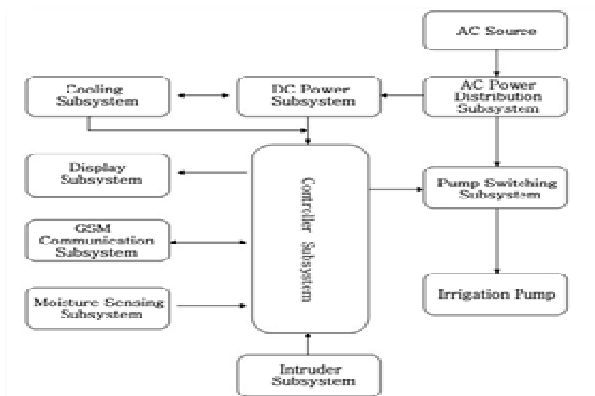
A. System Architecture

Fig. 1 System Architecture with various modules

B. System Components

1) AC Subsystem

The AC subsystem comprised a distribution board supplying 240V to the DC circuit and the relay subsystem.

Details of the power distribution are shown in both Direct Current (DC) power subsystem and in pump switching (relay) subsystem.

2) Direct Current (DC) Power Subsystem

This component would host the database which would store information that would be captured at the local offices. The data would be hosted in a Microsoft SQL database and accessed by the Android application.
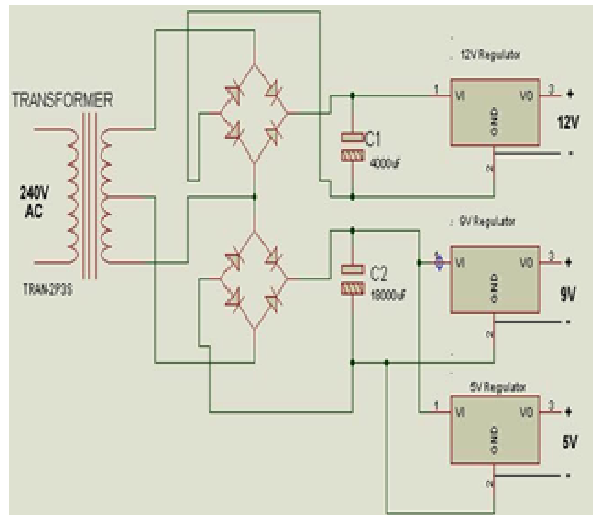

Fig. 2 DC Power Supply Circuit diagram

3) Controller Subsystem

The Controller subsystem is an already assembled module from the Arduino range of controller boards. The chosen board type (Arduino Uno) can take between 9V and 12V DC. It already comes with:

- An onboard 5V voltage regulator
- Atmega328 microcontroller operating at 5 V DC
- 32 KB of flash memory
- An onboard Analog-Digital Converter (ADC) and a Digital-Analog Converter (DAC) with a resolution of 10 bits, and thus can provide 2^{10} (1024) digital values
- 14 Digital I/O Pins (Pins 2 and 3 can be used as interrupt pins)
- 6 Analog Input Pins (A0 - A5)
- 16 MHz Clock

4) Display Subsystem

The display system is made up of a Red-Green-Blue (RGB) background 16X2 LCD and a potentiometer (trimmer) to set the contrast. Eleven out of the eighteen pins were used. The table below shows the function (s) of the proposed pins and how they connect to the microcontroller board.

5) GSM Subsystem

The GSM subsystem (SM5100B Cellular Shield for Arduino) was made up of:

- A SM5100B cellular module which has GSM, GPRS, and TCP/IP functionalities.

- A SIM card socket for SIM cards
- A SPX29302 voltage regulator configured to regulate 5V to 3.8V maximum and
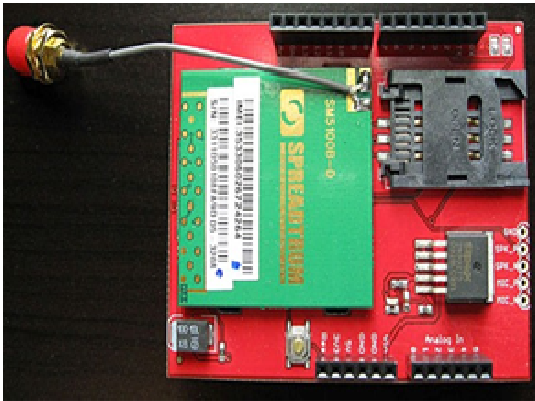- A Quad band Antenna

Fig. 3 SM5100B cellular module

6) Moisture Sensor Subsystem

The type of sensor designed was a resistive sensor. It used the two probes to pass current through the soil, and then read that resistance to get the moisture level.
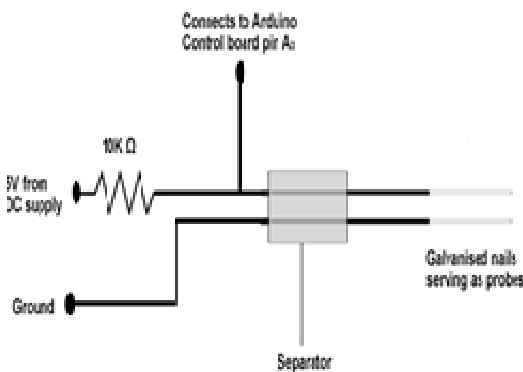

Fig. 4 Design of moisture sensor monitor module

$$V_{A3} = \left(\frac{R_P}{R_P + R_S} \right) \times 5 \text{ V} \qquad (1)$$

V_{A3} is the voltage signal to analog port A3 of the controller board, Rp is the resistance of the potentiometer and Rs is the varying resistance of the probes as and when they are in a conducting (water) medium. It can be inferred that, the lower the resistance of the probes, the higher the volts (V_{A3}) to the analog pin A3. The board has a ten bit (2^{10}) resolution ADC for converting analog signals to digital signals. Its domain values range from 0 to 1023 (a total of 1024 digital values) with 5V set as the default reference value.

7) Intruder Subsystem

The design of the intruder system is similar to that of the soil sensor. The components used for this are:

- A 10K Ω resistor and

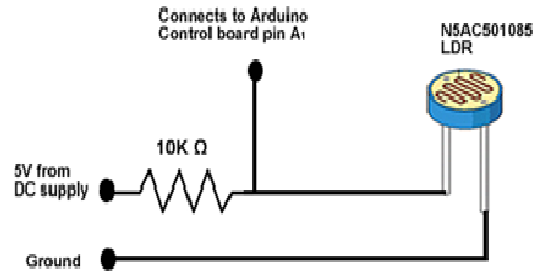- One N5AC501085 light dependent resistor (LDR)

Fig. 5 System intruder circuit diagram

8) Pump Switching Subsystem

This subsystem is controlled largely by a relay. When electrical current is passed through the electrical coil of the relay, an electromagnetic field is set up, causing a magnetic effect. This magnetic effect pulls the armature to create a link between the contacts, thus turning its state to "ON".
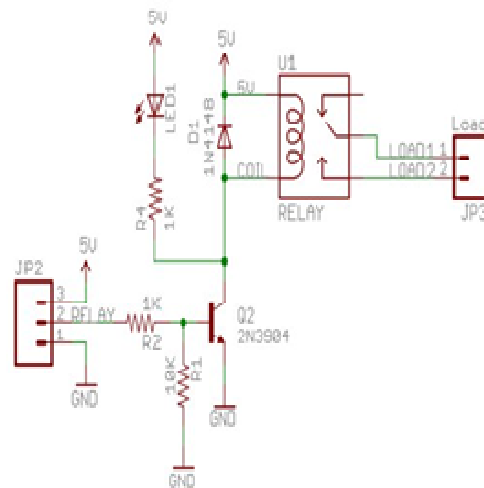

Fig. 6 Switching Subsystem Architecture

V. SYSTEM IMPLEMENTATION AND PERFORMANCE TESTING

The figures below show the interior and exterior views of the system after the design and implementation phase, ready for integrated testing of the different modules together.

A. System Performance Evaluation

Five (5) main test categories were performed on the system namely:
(1) Auto start and shut down tests
(2) Soil moisture tests
(3) Feedback on system operations tests
(4) Intrusion detection tests
(5) System Administration tests

Fig. 7 Interior view of the integrated system

Fig. 8 Exterior (LCD, Antenna and Sensor port) view of the system

TABLE I
AUTO START AND SHUT DOWN TESTING RESULT WITH EXPLANATORY REMARKS

Operation	Performance	Remarks
Auto starting at user defined time	100%	System able to start the irrigation pump at the pre-set time (5:00 GMT)
Auto stop during watering when the tolerable water level is reached	90%	Stopping mechanism highly dependent on the resistive sensors, deviations in sensor resistances affected the control algorithm
Put irrigation pump on via text	100%	System responded positively all the time
Put irrigation pump off via text	100%	System responded positively all the time

TABLE II
SOIL MOISTURE TESTING RESULT WITH EXPLANATORY REMARKS

Operation	Performance	Remarks
Check the soil moisture level to determine if watering is needed.	90%	Because the sensor is a resistive type, temperature affects the resistance, thereby varying the value set for threshold at different times

TABLE III
FEEDBACK ON SYSTEM OPERATIONS TESTING RESULT WITH EXPLANATORY REMARKS

Operation	Performance	Remarks
Send SMS upon starting and completing a scheduled task	100%	The system upon sending a message logs a delivery report by default. After sometime, if it receives no confirmation, it resends the message. This ensured that messages were always delivered.
Send SMS upon the occurrence of an event such as mains power failure	100%	The system upon sending a message logs a delivery report by default. After sometime, if it receives no confirmation, it resends the message. This ensured that messages were always delivered.
Make an enquiry to the system via text	100%	So long as a user received a confirmation or delivery report on his or her phone, the message to reach the system for processing and replies were sent accordingly.
Display relevant messages on the LCD screen	97%	Every message was successfully displayed on the screen. The only problem was that the contrast needed to be set every time the system was reset.

TABLE IV
INTRUSION DETECTION TESTING RESULT WITH EXPLANATORY REMARKS

Operation	Performance	Remarks
Call the user's phone continually during an intrusion	94%	Power availability from the chargeable battery affected the rate at which phone calls were initiated. The lower the voltage, the lower the chances of the GSM shield initiating and sustaining a phone call

TABLE V
SYSTEM ADMINISTRATION TESTING RESULT WITH EXPLANATORY REMARKS

Operation	Performance	Remarks
Receive formatted SMS commands from an authorized user	100%	So long as a user received a confirmation or delivery report on his or her phone, the message was sure to reach the system
Auto recharge credit balance based on preformatted SMS	100%	So long as a user received a confirmation or delivery report on his or her phone, the message was sure to reach the system for processing.
Set / change current password to a different one	80%	8 out of every 10 store operations to the SIM card failed. Reasons could not be accurately provided
Set / change the time that the system is expected to start operating	80%	8 out of every 10 store operations to the SIM card failed. Reasons could not be accurately provided
Set / change SMS notification or system reporting status.	80%	8 out of every 10 store operations to the SIM card failed. Reasons could not be accurately provided
Set / change the phone number to which all emergency notifications should be sent	80%	8 out of every 10 store operations to the SIM card failed. Reasons cannot be accurately provided
Set / change the phone number to which all SMS notifications should be sent.	80%	8 out of every 10 store operations to the SIM card failed. Reasons cannot be accurately provided
send the list of operation commands to the system administrator via SMS	80%	8 out of every 10 store operations to the SIM card failed. Reasons could not be accurately provided

VI. CONCLUSION AND RECOMMENDATION

The GSM based Irrigation Monitoring and Control system was successfully implemented. The aim of the project was to address the pressing challenges of cost-effective and efficient operation of irrigation systems in Ghana such as : (1) the difficulty in monitoring the efficiency of farm irrigation systems located at outskirts or at places far away from residences (2) human inefficiencies such as under-watering and or over-watering that have over the years contributed significantly to reduced crop yield and annual revenue losses (3) leaching of soil nutrients due to excessive irrigation and (4) the high cost of operating these devices due to utility (water and power) wastage. These challenges have been sufficiently addressed with the design and implementation of microcontroller based irrigation systems.

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REFERENCES

[1] Think Exist, (February 05, 2012), http://thinkexist.com/dictionary/meaning/irrigation/
[2] Agodzo, S. K. and Bobobee, E. Y. H. (1994). Policy issues of irrigation in Ghana: 1960-1990. Proceedings of the XIIth World Congress on Agricultural Engineering, Milano, 28 August-1 September 1994. CIGR Vol. 1 pp 335-343.
[3] Clothier, B. E. (1989). Research imperatives for irrigation science. Journal of Irrigation and Drainage 115(3): 421-448.
[4] FAO. (2005). Aquastat: Country data on Ghana. FAO, Rome. Cited from www.fao.org/ag/agl/aglw/aquastat/countries/ghana/index.stm (date accessed: 20/11/2011).
[5] FAO. (1987). Consultation on irrigation in Africa. Irrigation and Drainage paper 42. FAO, Rome.
[6] FAO. (1985). Survey of irrigation development costs in Nigeria, Ghana, Liberia, Sierra Leone and the Gambia. FAO, Rome.
[7] Ferguson, C. A. (1989). Modelling water utilization in large-scale irrigation systems. A qualitative response approach. Water Resources Bulletin (AWRA). 25(6): 1199-1204.
[8] Kyei-Baffour, N. (1994). Future irrigation prospects and actions in Ghana. In proceedings of the 1st National Conference on Agricultural Engineering at the Department of Agricultural Engineering, KNUST, Kumasi from 25-29 September 1994. (eds Dzisi, K. A., Twum, A. and Lamptey, D. L.) pp 65-75.
[9] Memuna, M. M. and Cofie, O, O. (2005).Effects of farming practices on the performance of rice (Oryza sativa) in selected farms of Ashaiman Irrigation Project. In Hunger without Frontiers. (Eds. Bobobee, E. H. Y. and Bart-Plange, A.). GSAE/WASAE, Kumasi, Ghana p.244-254.
[10] Types of Irrigation, (February 07, 2012), http://types-of-irrigation.blogspot.com/
[11] SMS Based Wireless Home Appliance Control System (HACS), (October 29, 2011), www.iisit.org/Vol6/IISITv6p887-894Khiyal592.pdf.
[12] Zazueta, F. S.; Smajstrla, A. G., and Harrison, D. S. (1983): "Microcomputer control of irrigation systems. 1: Hardware and software considerations", Proc. Soil & Crop Science Society, Florida Volume 43, 1983: pp. 1
[13] Miranda, F.R.; Yoder, R.E.; Wilkerson, J.B. and L.O. Odhiambo (2005): "An autonomous controller for site-specific management of fixed irrigation systems", Computers and Electronics in Agriculture Volume 48, pp. 183–197.
[14] Kim, Y. and Evans, R.G. (2009): "Software design for wireless sensor-based site-specific irrigation", Computers and Electronics in Agriculture Vol. 66, pp.159–165.
[15] Umair, S. Muhammad and Usman, R. (2010): "Automation of Irrigation System Using ANN-based Controller", International Journal of Electrical & Computer Sciences IJECS-IJENS, Volume 10, No: 02, pp. 45-51, Available online: www.ijens.org/104602-5757%20IJECS-IJENS.pdf (date accessed: 28/06/2013)
[16] Wen, Nannan; Li, Daoliang; Ma, Daokun; and Ding, Qisheng (2011) "A Wireless Intelligent Valve Controller for Agriculture Integrated Irrigation System ", Computer and Computing Technologies in Agriculture IV IFIP Advances in Information and Communication Technology Volume 347, pp. 659-671
[17] Ingale, H. T. and Kasat, N. N. (2012): "Automated Irrigation System", International Journal of Engineering Research and Development, Volume 4, Issue 11 (November 2012), pp. 51-54, e-ISSN: 2278-067X, p-ISSN : 2278-800X, www.ijerd.com
[18] Singh, Sukhjit and Sharma, Neha, (2012): "Research Paper on Drip Irrigation Management using wireless sensors", International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501, Vol.2, No: 4
[19] Hedley, Carolyn; Ekanayake, Jagath; and Roudier, Pierre (2012): "Wireless Soil Moisture Sensor Networks For Precision Irrigation Scheduling", Available online: www.massey.ac.nz/~flrc/workshops/12/Manuscripts/Hedley_2012.pdf (date accessed: 28/06/2013)
[20] Clark, Gary; Rogers, Danny; Alam, Mahbub; Fjell, Dale and Briggeman, Steven (2013): "A Mobile Irrigation Lab For Water Conservation: I. Physical and Electronic Tools", Available online at www.ksre.k-

state.edu/mil/Resources/Conference%20Papers/16.pdf   (date accessed: 28/06/2013)

[21] Guerbaoui, M.; El Afou, Y.; Ed-Dahhak, A.; Lachhab, A. and Bouchikhi, B. (2013): "PC-Based Automated Drip Irrigation System", International Journal of Engineering Science and Technology (IJEST) ISSN: 0975-5462 Vol. 5, No.01, pp. 221-225.

[22] Divya, V. and Umamakeswari, A. (2013): "Smart Irrigation Technique Using Vocal Commands", International Journal of Engineering and Technology (IJET), ISSN: 0975-4024, Vol. 5, No. 1, pp. 385-390.

[23] GSM Based-Automatic Irrigation System, (October 29, 2011), http://www.scribd.com/doc/63175740/Gsm-Based-Automatic-Irrigation-System(date accessed: 29/10/2011).

[24] Automatic Irrigation Management System, (October 29, 2011), wwu.edu/changj7/project/docs/proj-%20description.pdf