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GSM Module based Integrated Smart Irrigation System for Remote Control and Monitoring using Mobile Application

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--*ABSTRACT*--
Irrigation methods are used to ensure availability of water for plants growth improvement. To eliminate human physical effortsand to support a remote control and monitoring of watering, we have designed an electronic system commanded by a mobile application programmed in Java, which manages the irrigation. This smart system, equipped with sensors (soil moisture content, temperature) is managed by a microcontroller, whichcommunicates the collected parameters to the mobile station using SMS over the GSM network. The proposed integrated system consists of solar powered water pump and solenoid valve, managed by the microcontroller for watering decision from the mobile application to guarantee the irrigation efficiency.
Keywords: *Drip irrigation, remote control, irrigation monitoring, ICTs system, mobile application.*

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I. INTRODUCTION

There is a real need in developing countries to considerably enhance agricultural production andproductivity to guarantee food safety.One of the ways to achieve this goal is to adoptICTs as it has been reportedthat increased utilization of ICTs have a significant impact on agricultural production [1] and could have a positive effect on irrigationefficiency[2].

In irrigated agriculture, the preservation of water quality is dependent on the ability of the irrigation system to uniformly distribute water, chemicals, and fertilizers in time and space to the crop being grown. Drip irrigation systems can potentially achieve high application uniformity and can be operated to provide a high application efficiency[3],[4], [5].

Recent advances in irrigation methods, and soil watermonitoring combined with the growing popularity ofICTs devices and cellular mobile networks and internet based technologies other the world make the use of smart systems applicable to agriculture for more efficiency.

1. Review of automated irrigation systems

Smart automated irrigation systemstake into account different methods of irrigation scheduling (based on criteria) and the use of technologies (ICTs) for remote control to providesolutions for watering automatically even in the absence of human.

Methods of irrigation schedulingbased on criteria

Irrigation scheduling is based on irrigation criteria. Irrigation criteria are the indicators used to determine the need for irrigation. Common listed methods bellow are used [6], [7].

- Hand feel and appearance of soil: uses hand probe to evaluate soil moisture content for irrigation decision.
- Soil moisture content measure with different equipment (like sensors)with a require level of accuracy.
- Soil moisture tension measure with tensiometers or electric resistance blocks, affected by tension sensitivity.
- Water management approach taking into account:
  - climatic parameters: temperature, radiation, wind, humidity, expected rainfall,
  - evapotranspiration (ET)model affected by climatic parameters and others factors (variety and plant density, management elements, soil properties, pest, and disease control etc.).
- Self-made model using a combination of different factors and equipment.

Automatic irrigation scheduling consistently has shown to be valuable in optimizing cotton yields and water use efficiency with respect to manual irrigation based on direct soil water measurements [8]. A reduction in water useunder scheduled systems also have been achieved, using soilsensor and an evaporimeter, which allowed for the adjustmentof irrigation to the daily fluctuations in weather or volumetricsubstrate moisture content [9].

Approaches of remote control and irrigation monitoring system design

A classification of remote control and irrigation monitoring systems from a technical point of view was made in [10] for a wide variety of irrigation systems based on differenttechnologies for various applications. Based on this study, we can resume the design approaches in the table1 in two categories.

Table 1. Summary classification of remote control and irrigation monitoring systems

Criteria	1st category	2nd category		
Technology	Use of internet	No use of internet		
	Zigbee, GPRS, Wi-fi, WSN, WAN, LAN etc.	Bluetooth WSN	GSM(SMS), WSN	Wired
Control/ Monitoring station	PC, Mobile devices	PC, Mobile devices	PC, Mobile devices	7 Seg-ment Display, PDA, PC
Real time monitoring	Real-time remote monitoring	Real-time remote monito-ring	Remote monito- ring based on AT requests	Remote monito-ring based on requests
Cost constraints	High cost	Low cost	Low cost	High cost

Ininternet based systems,PC or mobile unit is the remote monitoring station and microcontroller is the main controlling device. The farmer can monitor and control devices remotely from any part of the world where internet access is available. Those systems are spreading through the Internet of Things (IoT).A hard-wired system from in-field sensing station to monitoring station takes extensive time and costs. A wireless sensor network (WSN) based system eliminates the need of hard wire sensor station across the cultivated field and in this way reduces the installation and maintenance cost of wired system.

All problemsrelated to transmission distance, high installation and maintenance cost and mobility are solved by GSM based remote monitoring and control systems. The monitoring station (PC ormobile unit) acts as remote monitoring station and controls irrigation efficiently. These systems eliminate one of the drawbacks of real time monitoring and control using internet. In [11],researchers have used three sensors for monitoring and remote control of automated irrigation. The results are displayed in LCD and is further received by the user in SMS form with the help of a GSM modem. However,the SMS chargesremain a challenge for farmer.

Bluetooth based solutions eliminates the usage cost of the network for internet based systems, and at the same time the SMS cost of GSM based systems. Main limitation of Bluetooth technology is its range of operation, which is limited to a few meters. So GSM/Bluetooth based remote controlled systems are proposed for acombined use withGSM to provide long distance control and Bluetooth when the user is within the limited range of few meters to the designated system.

In USA, some irrigation systems are automated through information on volumetric water content of soil and changes in plant size and environmental conditions, using dielectricmoisture sensors to control actuators and save [12]. In India, new innovative IoT applications are addressing these issues and increasing the quality, quantity, sustainability and cost effectiveness of agricultural production [13]. In Taiwan, a complex ICT agricultural environment protection system of six electronic platforms and three mobile devices was designed, for continuous auto-monitoring providing real-time water quality, and quantity data, through intelligently distributed sensors[14].

Integrated smart systems for automated irrigation

Scheduling methods and technical systems use can notbasically guarantee automatedsystem effectiveness in the contest of water budget approach.

- Access anywhere to water control and water saving achievement are necessary, especially in water limited geographically isolated areas
- Continuous power supply mechanism is required in developing countries, where electricity access and energy management are limited.

Severity of water scarcity for irrigation has drawn the attention of manyresearchers towards development, conservation and management strategies ofwater. Many new systems are developed to convert flood irrigation to pressurized irrigation systemswith different management approaches for conserving water.

Community Based Borewell Irrigation Systems, for Improving Productivity and Water Use Efficiency in Dryland Agriculture, are proposed in [15].

The constant cost decreasing of solar panels promotes the usage of solar energy in various sectors.Solar powered irrigation system can be a suitable alternative for farmers in energy crisis context. Sustainability of irrigation systems depends on the optimal utilization of the natural resources without environmental risk. Thus, a combination ofsolar power supply, a green way for energy production providing free continuous energy once an initial investment is made, and water management system can be an integrated smart irrigation system.

In [16] a system, in which the pumping process in the irrigation system is powered by solar, is implemented. This system has the advantage of having application in rural areas, which are not connected to the grid.Also, in [17] the authors proposed an innovative concept of solar powered smart irrigation system based on GSM module as a solution to energy crisis and water consumption.

Analysis of automated irrigation systems review

From the discussion about different aspect of automated irrigation systems, we can conclude that designing a remote monitoring and control systems must be guided by:

- the irrigators or national decision-makers goals,
- ICTs adoption level and infrastructure deployment,
- economic-geographical factors.

Many methods and technical approaches are already developed and can be integrated in innovative smart systems. Each proposed system has its own merits and disadvantages. However, there is still a possibility of designing a cost effective and efficient system with an improved performance for a considered target audience.

2. Problem in Benin irrigation system

Beninirrigation system is still based on hand feel and appearance of soil method to evaluate soil moisture content for irrigation decision.

Generally, agriculture is practiced in Benin in rural areas. In cities and peri-urban areas, there are some market gardens. The common irrigation practices encountered in the country are: manual irrigation (does not raise costs, but requires human efforts), sprinkler irrigation and drip irrigation.

Despite the programs initiated by AfricanGovernments to encourage official public irrigation schemes and formal private irrigation in the market gardening[18],Benin farmers do not have ICTs based strategy to improve irrigation system.

Problem analysis

Analyzing the Benin irrigation system, we can list different obstacles for introducing ICTs in Benin irrigation system for optimization purposes.

- Lack of secure and continuous electricity supply for operating ICT equipment
- Internet connection problems even in cities
- Most of farmers have no ICT equipment other than a simple phone unit or smartphone
- Agriculture is practiced by a large part of rural populations and an infirm percentage of townsfolks, who do not have a digital culture and can adopt only a limited use of ICT devices.

To meet the challenge of optimizing irrigation by introducing ICTs, despite the obstacles, many favorable conditions (political will, good hydraulic conditions, large GSM network access etc.) can be used.

3. Proposed integrated smart irrigation system

Developing a smart automated irrigation system to meet all identified obstacles in Benin goes necessarily through the design of an integrated system based on an adapted system concept and infrastructure.

A water approach is adopted to propose oursmart systemusingdifferentcomponents, to offer an integrated solution to waterand electricity management and remote control/monitoring for irrigation efficiency (fig.1).

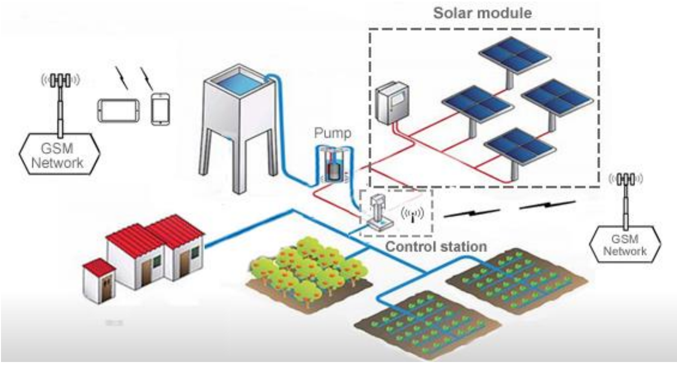

Fig.1 Global layout of proposed integrated smart automated irrigation system

The control station has a solar power supply, sensors (soil moisture, temperature), a GSM module (SIM800L), a processing unit (ATMega328p)and solenoid valves. This control station interacts with a pump and a mobile station with an implemented mobile application using a SQLite database and interfaces.

The adapted integration principle for irrigation efficiency in Benin

To adapt our smart system to Benin realities, we have proposed the next integrated scheme.

- Solar component: solar energy is used to guarantee continuous electricity supply for ICTs equipment resolving the energy problem.
- Watering component: the irrigation is performed by controlling a self-made low cost (for experimental needs) pump connected to a water source (drilling) to take a controlled advantage of hydraulic conditions of the country. Considering the proposed water source being a static edifice, an efficient scheme requires an irrigation device to reduce human effort.

We adopted drip irrigation;a modern technique with many advantages [4], [5], to reduceconsiderably water consumptionby moistening only the portion of soil in the immediate vicinity of the plants roots.

- Measurescomponent: a combination of electronic block and mobile application. The same controlling unit, used to control the watering pump, interacts with sensors to measure various parameters: soil moisture content and air temperature. Collected parameters values are used in an Android application by the farmer for remote control and monitoring through GSM network.

The idea of an SMS based control system was proposed, because mobile phones (using SIM technology) have become a popular communication device in Benin [19].

Watering component architecture

The architecture of the watering componentis shown in Fig.2. This component is used to control the watering process with a solenoid valveconnected to a microcontroller and a self-made pump connected to a water source. The use of a microcontroller gives the possibility to the farmer to perform the on/off control of the watering process by SMS remotely.

Solar component

Solar panels are employed to maintain the charge of the control station and pump battery. From the battery using a converter circuit, it gives power to the water pump which is submerged inside the well. In the proposed automated irrigation system, the water outlet valve is electronicallycontrolled by a soil moisture sensing circuit. All devices receive 12 volt power supply.

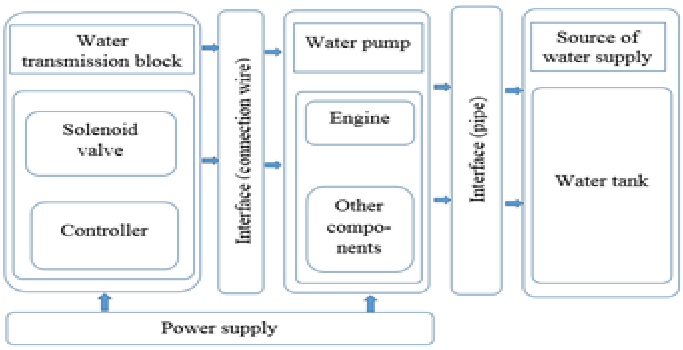

Fig.2 Watering component architecture

Measures component architecture

The architecture of the Measures componentis shown in Fig. 3.

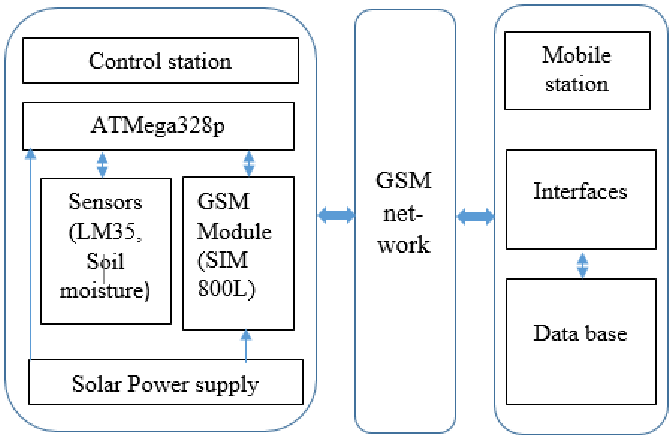

Fig.3 Measures component architecture

Theproposed architecture includes a mobile application that allows remote control/ monitoring of the system bythe farmer using GSM network without internet. In this scheme, the soil moisture content and the air temperature arecommunicated to the mobile station by the microcontroller using SMS over the GSM network. The GSM moduleis manufactured for cellular data standards. The module uses serial communication to interface with the mobile station and needs AT (Attention, [20]) commands for communication with the microcontroller.

The smart control principle

When the electronic system is switched on, the GSM module starts and connects to the GSM network. Then, the microcontroller and the sensors are turned on for the first time using the ignition button.

As long as the system is powered by electricity, the farmer using the mobile app can make a query about the state of moisture and temperature, the state of the pump or the solenoid valve. The parameters values are transmitted to the mobile app by the microcontroller using SMS. The farmer can trigger a watering, stop a watering, change the default watering time and the phone numbers used by him and by the system.

1. Triggering the watering: the farmer launches watering from the mobile app. Depending on thereceived request from the GSM module, the microcontroller triggers the solenoid valve and then the pump.
2. Stop watering:this operation is the opposite of the triggering watering. Watering is stopped in 3 different cases :

a. the farmer sends a request to the system to stop watering
b. thesoil moisture content returned by sensors indicates that the board is wet.
c. the default watering time has elapsed.

3. Change the default watering time: in the app settings, the farmer can change the default watering time (in minutes) and validate the new value. The control station (microcontroller) receives this value by SMS and defines it as the new default watering time.
4. Edit phone number: the SMS based scheme requires a sender phone number (mobile station) and receiver's phone number (control station). For security purpose, the farmer can specify from the mobile application to the electronic system,which number will send the instructions and which number will receive the commands.

The table 2 summarizes the operating regimes of the system.

Table 2. Operating regimes of the proposed smart system

Regime	**Start mode**	**Stop mode**
Manual	The system is started by the user	The system is stopped by the user
Automatic	The system is started by the user Or The system starts automatically at the scheduled time	1- Automatic shutdown happens when the system returns the wet state of the soil 2- The system is stopped when the default watering time is reached out

Hardware and software implementation

Drip irrigation being uniform, the humidity of a whole board can be measured in a single point. However, to appreciate the state of a board with more accuracy, we have tested three soil moisture sensors per board (one in the middle and two in the extremities). The microcontroller, after collecting the three values of soil moisture content and by the use of logic gates NAND, returns a single state to our application (0 : dry & 1 : wet). The converted value of temperature is transmitted to the mobile application in numerical form.

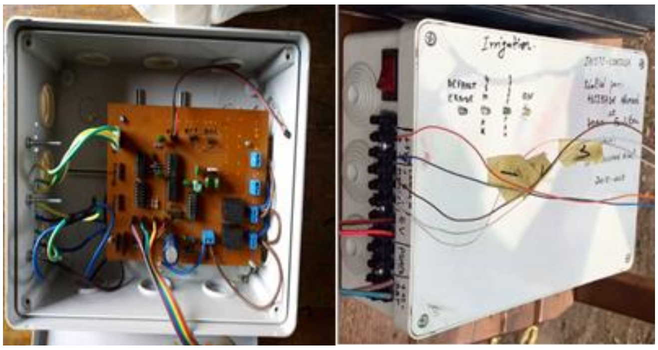

Photo 1. Prototype of the hardware component of the smart irrigation system

The proposed mobile applications for remote irrigation control is developed in the Java programming language using the Android Software Development Kit. Watering archive and sensor readings are stored in SQLite database.
Some layouts of Android application are shown in Fig.4.

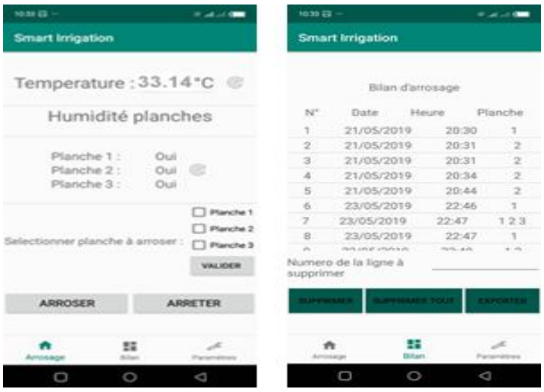

Fig.4 a) Parameters browsing page b) Archive page

II. RESULTS AND DISCUSSIONS

Test and empirical results

An experiment was conducted to test the remote control of irrigation using android app, ATMega328p and low cost sensors. This study is based on a board of market gardening of tomatoes using drip irrigation. We have used two SIM cards (mobile station and control station) of a local GSM operator of Benin with a good network coverage.

We have installed the mobile app on a smartphone, testedthe hardware consistency andchecked the software validation at different distances (in kilometers) from the control station.
Temperature variations are shown with precision in the range of 29.35° C to 33.14° C during the test period.

Table 3. Requestsexecution timesas a function of MS to CS distance

Distance between Mobile Station (MS)and Control Station (CS)	SMS sending time from MS to CS	SMS sending time from CS to MS	AT Command Treatment times by the CS[(1)]
100km	10 sec	5 sec	
70km	10 sec	5 sec	
40km	5 sec	3 sec	5 sec
10 km	5 sec	3 sec	
10 m	5 sec	3 sec	

(1) Concerned AT commands:on and off state switching command for the pump, solenoid valve, watering and the value of the air temperature or the soil moisture content.

The results in tables 3 confirm the validation of all implemented commands. A performance evaluation, in terms of execution time, demonstrates that:

- SMS take less time to go from control station to mobile station regardless of distance. This can be explained by the good signal level of the GSM module,
- the AT command treatment time by the microcontroller (start watering for example) is the same for all commands,
- all requests from the mobile station to the control station, and commands at the control station side are executed rapidly.

Risks related to the functioning of the system

- Risk 1: the user's phone can be discharged when watering is in progress, while the farmer is away from the site. The process can no longer be controlled remotely in non-automatic regime.
- Risk 2: there may be disconnection of the solenoid valve due to a high pressure of water accumulated between the solenoid valve and the pump if the pump is open before the solenoid valve during irrigation.
- Risk 3: the system status information is not returned in the monitoring application. The two possible reasons are:

1- the GSM module does not start
2- the SIM used by the system fails to send SMS because there is no more credit.

- Risk 4: malfunction of the power supply device leading to the shutdown of the pump and solenoid valve.

Risks avoidance concept

The proposed smart system integrates a risk avoidance concept to secure the automated irrigation.

- Solution for risk 1: a default watering time is set by the farmer. Once this time has elapsed the system stops the watering.
- Solution for risk 2: a time spacing is defined between the opening of the solenoid valve and the pump opening. The solenoid valve opens before the pumps.
- Solution for risk 3:
  - Case 1: unplug the system power and turn it back on.
  - Case 2: purchase units on the SIM used by the system.
- Solution for risk 4: an external power source, such as a charged battery, or a generator, is required while waiting to the maintenance of the power supply.

III. CONCLUSION

In this paper, we presented the architecture and the implementation of a smart automated irrigation system for remote control. The system consists of two types of sensors to measure the soil moisture content and the air temperature. The collected parameters are transmitted by a microcontroller to a mobile application through GSM network for irrigation decision. We adopted a water management approach based on the use of a pump and a solenoid valve to send the water to the drip irrigation equipment under pressure. The on/off mode of the pump and the solenoid valve is controlled from the mobile application through the microcontroller connected to a GSM module. The GSM module uses serial communication to interface with the mobile station through AT commands.

For more irrigation efficiency, we introduced a solar component for continuous electricity supply and a risk avoidance concept to secure the system. The designed system can be used by a farmer without a high e-culture and in rural areas with internet connection limits.

Performance evaluation showedthat our system manages to prevent underwatering and overwatering problemsdue to watering.The rapid response time of the requests in the up and down links guarantees a sustainable work of the system.

In future work, we plan to use self-made sensorsthat must be more resistant to climatic conditions and a community approach of water management.

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