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Designing Flood Control Systems Using Wireless Sensor Networks

Inyiama H. C., Obota M. E.
*Dept Of Electronic And Computer Engineering Nnadi Azikiwe University, Awka, Anambra State, Nigeria
**Dept Of Electronic And Computer Engineering Nnadi Azikiwe University, Awka, Anambra State, Nigeria

Abstract

Recent advancement in information and communication technology (ICT) and wireless sensor networks have made new trends to emerge in flood control practice. Proper prevention and management of flood is more needed now for sustainable socio-economic conditions of the people. The paper presents an automated flood control system based on supervisory control, wired and wireless communication. Efficient monitoring and control of water level which however represents an important input on flood prevention and control is realised. This technology, if wisely deployed, could prevent or reduce the incessant flooding and its attendant hazards on the populace. The benefit of this design can be extended to other control systems e.g. irrigation control, oil spillage control etc.

KEY WORDS: Flood, Control, Sensor, System, Controller.

INTRODUCTION

According to “oxford dictionary”, “flood” is a large quantity of water covering an area that is usually dry. Flood may occur as a result of: a heavy rainfall, a river flowed over its banks, a burst of water pipes, etc. Flood hazards are the most common and destructive of all natural disasters. Each year, flood disasters cause tremendous loss of lives and property, thereby causing devastating impact on the socio-economic conditions of the people. At least 25 million people living in coastal regions of Nigeria are at risk of the devastation of floods before the end of the year [NEMA report]. The coastal areas of Lagos, Ondo, Delta, Rivers, Akwa Ibom and Cross River states have already experienced severe flooding impact since the beginning of this year, due to factors such as absence of surface drains and blockage of existing drains, refuse and eroded soil sediment; the plateau experience of July being the worst in the recent months. Frankly speaking, a flood can devastate homes, commercial buildings, agricultural and pastoral lands, public goods and other physical properties. Health sector is not exempted because there are always threats to health and safety during the flood and aftermath. Floodwaters contain disease causing bacteria, dirty oil, human and animal waste [Public Health Laboratory Service 2000]. In Nigeria, the incident of flood disaster is becoming increasingly worrisome; hence the menace cannot be left unchecked. Although, in recent years, risk-based approaches and other measures have continued to receive increasing attention as means to manage flood hazards but all have not yielded the desired results. It is strongly believed that this project when fully implemented would go a long way in preventing incessant flood hazards in Nigeria and the world at large.

Basic Control Concepts

A control system is a device or system that maintains or alters the operation of a process. The whole system consists of: (i) the process being controlled; (ii) the sensing system (to measure the process response if feedback is required); and (iii) the controller (which incorporates both the software and hardware required to control the process). Control systems may be either open-loop or closed-loop: an open-loop control system uses known relationships between the process input and output to adjust the controller parameters, while a closed-loop control system measures the output of the process and adjusts the controller parameters to minimise the `error signal' which is the difference between the input and the measured output. However, difference between these is that closed loop control systems have feedback from sensors, make decisions and apply decisions to the system. On the other hand, open loop control systems apply a preset action, as is done with timers. Since the controller is the brain behind control system, the type of controller used determines control system [1].

Open Loop Control Systems

Open loop control systems use duration or applied volume for control purpose. In this type of controller, the basic control parameters are how often and how long is the water to be pumped. This type of system is based on a pre-defined control concept, with no feedback from the controlled object. The user sets the time to start, the time to end and the time for pause intervals and the water pumping periods. These parameters are pre-set for the entire session as thus:

- How long the pumping session should last

- How often the pumping period should repeat itself.

No checking is done to know whether water is pumped out or not. Open loop control system is said to be time-driven. Open loop control systems have the advantages that they are low cost, readily available, and many variations of the devices are manufactured with different degrees of flexibility related to the number of stations and schedule specification. This type of control system, though relatively simple and cheap but in most cases does not provide the optimal solution to the problem. However, it does not respond automatically to prevailing changes and require frequent resetting to achieve high levels of efficiency [2].

Close Loop Control System

These are based on a combination of pre-defined control concept (feed-forward) and feedback from the controlled object. In this type of controller, there is a feedback of the necessary data to determine when to evacuate water. The controller receives feedback from one or more sensors in the field that continuously provide updated data to the controller about the parameters that influence the system behavior. According to the measurements provided by the sensors and the pre- programmed parameters, the controller decides on when and how far to evacuate the water. Closed loop controllers base their decisions on:

- Monitoring the state variables
- Comparing the state variables with the desired variables or target state.
- Deciding what actions are necessary to change the state of the system.
- Carrying out the necessary actions. A closed loop control system is event-driven and hence responds automatically to prevailing changes thereby achieving high level of efficiency [3].

MATERIALS AND METHODS

Components requirement: sensor probes (water-level sensors), wireless sensor network (wsn) node, poles, controller, water pump for evacuating water, water channels, software component, supervisory component (i.e. SCADA). Generally, the project is realised in units or modules as thus: water level sensor unit, wireless sensor network node unit, control unit, actuator unit, and supervisory unit. Fig1 shows the schematic diagram of the automated system.

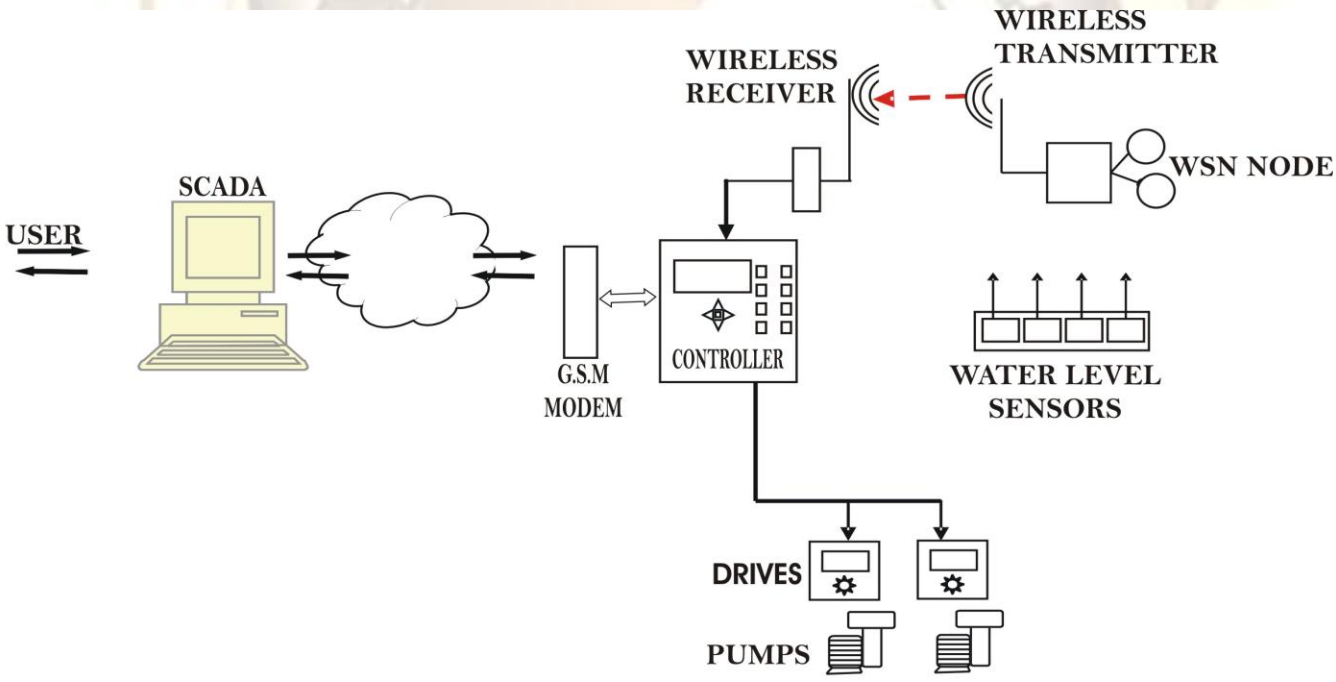

Fig 1 Schematic diagram of the automated flood control system

wireless sensor network (wsn) node is made by coaxial cable. The water level sensor probes are the slave sensors while the wireless sensor network node is regarded as the master sensor.
Wireless sensor network (wsn) node:

The wireless sensor network node is located at the higher ground outside the flood-prone area. Each wireless device also known as NODE has one or more sensors integrated in it. Fig 2 shows wsn node architecture.

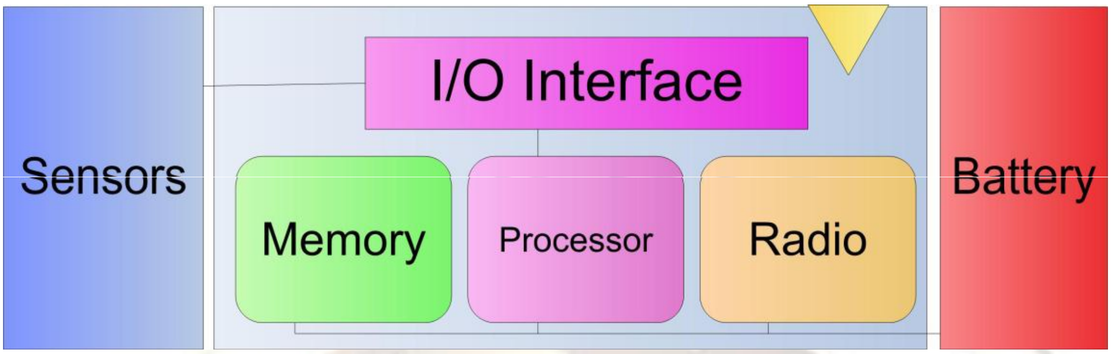

Fig 2 wsn node architecture

In addition to sensors, a node is also equipped with transceiver (transmitter and receiver), actuators, analogue-to-digital and/or digital-to-analogue converters, microcomputer and battery. The sensors cooperatively continuously monitor water level data (water level signal coming from water-level sensor probe). The actuator provides the control function desired (i.e. a switch that turns a motor on or off). The transceiver (transmitter and receiver), is used for wireless communication with other nodes or directly with gateway. The transceiver modulates and transmits, receives and demodulates digital data. The gateway in the transceiver is responsible for transmitting sensor data from sensor patch to remote base station (the central controller). The microcontroller reads the sensor data and, after processing and formatting, outputs the data to the wireless transceiver. The microcontroller is also responsible for any control command directed to the actuator. A resistive wireless sensor network node is designed and built to fit of a wooden plate measuring 5cm wide and 10cm long. This piece is attached to the technology circuitry, sealed inside a plastic case with the antenna installed at its top. The antenna is a dBi gain double dipole. The sensor node circuit board consists of the sensor interface and signal conditioning circuits. The sensor is driven by a 200 KHz square wave. The frequency will be changed according to the water level sensor signal value and the DC output of the filter will indicate the water level. The water level will be between 2 and 3.5 V indicating 0-100% water level in accordance to scale chosen. The output of the filter is fed to a comparator whose output will be active only when the measured water level is less that the pre-set value. The output of the comparator will activate a low frequency generator circuit that produces a square wave of 0.1 Hz. This will be fed to an encoder that carry a unique ID which in turn will feed its output to a wireless transmitter that will transmit the ID of the transmitter and the data that indicate the need for flood to be evacuated. The node is powered by a 5 V, 1000mAh NiCd battery. The nodes are programmed to remain most of the time in a sleep mode and wake up only when the water level goes above the preset value and then communication with the central controller (base station) occurs.

Base station (Control unit):

The control logic of the project is implemented in the controller, which also has the function of integrating all elements of the system. Normally, the type of acquisition system is chosen to be optimal for the control algorithm to be used. The choice of programming language used in the controller is Assembly language. However, any other language could be used depending on the designer's choice since the controller used, At89c51 is in the family of 8051. Fig 3 is the process flowchart showing control algorithm. The pseudo code is as follows:

i. initialize the system
ii. check the water level
iii. check the communication system
iv. read the water level value
v. compare water level with lower limit
vi. switch on the pump if greater or equal
vii. compare the water level with upper limit
viii. switch on the alarm if greater or equal

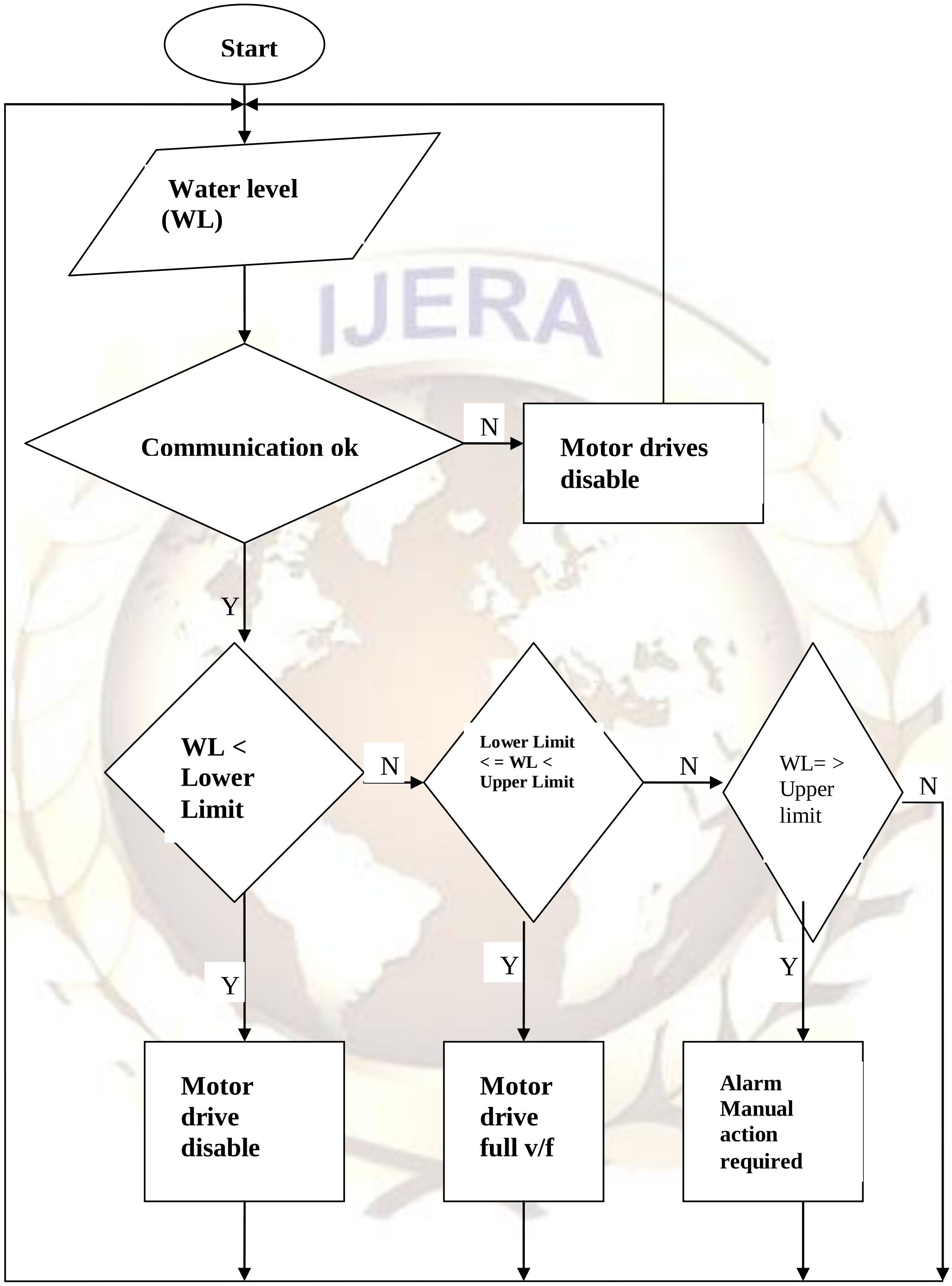

Fig 3 Controller flowchart

This controller uses event-based data sampling technique as against the time-based ones. The commonest controller used is a gain scheduling PI scheme where the controller parameters are changed based on some disturbances. Controller receives information from the sensors and sends the commands to the drives of the pumps. Supervision is established through the SCADA, which can monitor the situation of the controlled object. If the communication with the supervisor fails, the controller starts to operate in stand-alone mode, with a subroutine based on default parameters. The mode of communication between the controller and the supervisory system is wireless and is done by a GSM Modem in DNP3 protocol. Fig 4 shows schematic diagram of communication system.

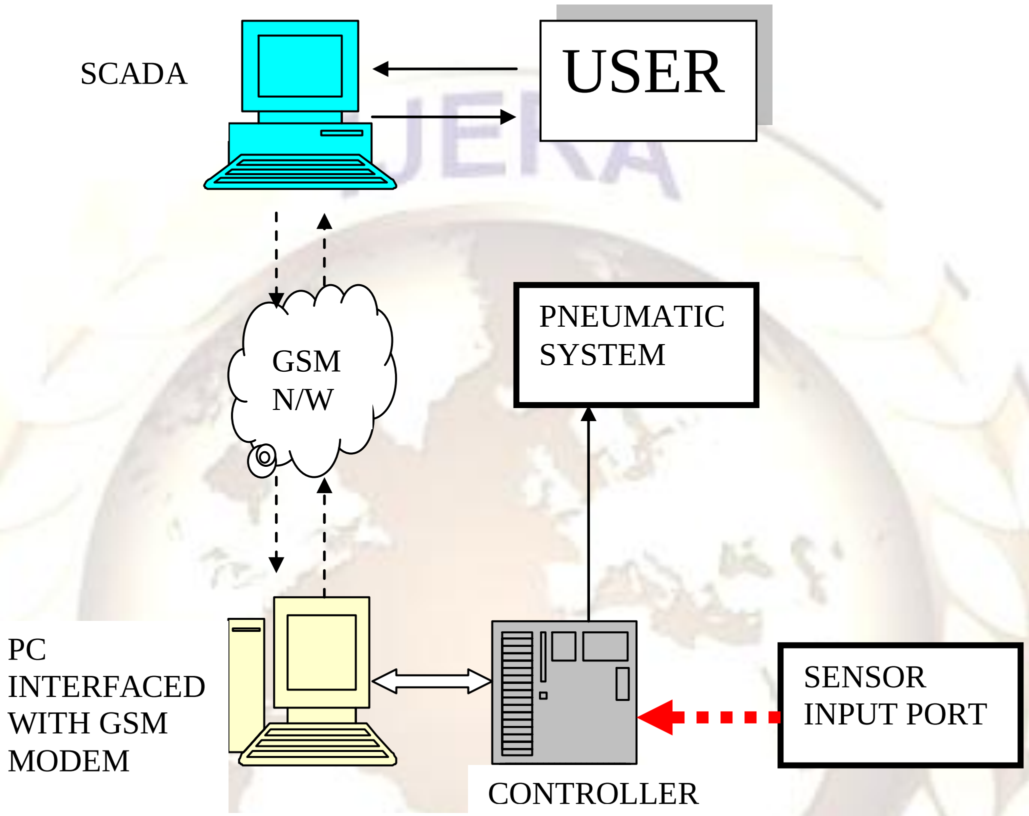

Fig 4 Schematic diagram of the communication system

The choice of these standards is justified by the consolidated use of GSM/DNP3 applications in power systems, such as operation of switches and remote controlled substations.
The DNP3 protocol has time stamped variants of all data so that even with communication failure between the controller and SCADA, it is still possible to recover data to correctly reconstruct the sequence of events after the communication is restored. A particular feature of this controller, which is important to this specific application, is a large number of modules for serial communication ports.

Pumps and Drives

A water pump is used to evacuate water from the flooded area to a sectioned area via a channel. The pumps are normally at low-speed and therefore should be coupled to motors by pulleys and belts for higher efficiency. Fig 5 shows pneumatic diagram of the system.

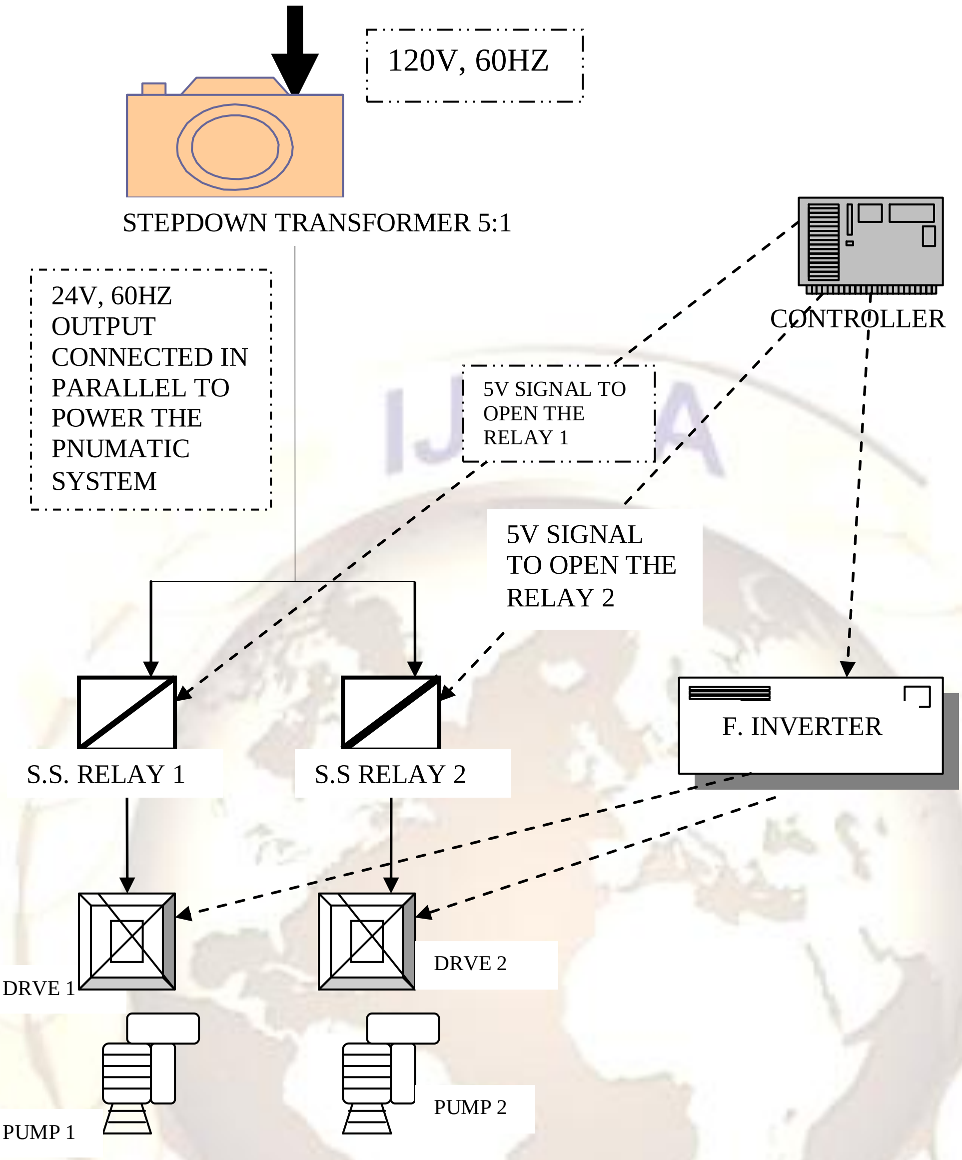

Fig 5 Pneumatic diagram of the system

The speed of the pumps is controlled by frequency inverters. It receives the command from the controller through 5V, 4-20mA channels. The irrigation pump system uses three-phase AC power supply. Due to supply constraints at the some certain sites, the inverters also have the capability of converting the single phase local grid to three-phase. It adopts three-phase solid state relay (SSR) SSR-24V, 5A to the controller. Singlechip is connected to the SSR. When system receives flood evacuation command, control signal will be low and open SSR to power the pump to evacuate water out of the flood area. When the system receives a stop command, control signal becomes high and the system stops pumping.

During the maintaining of the water level, the frequency of the drives is adjusted according to the difference between the reference value of water level and the value measured by the sensors. A hysteresis loop based on limits of water level is established to prevent the pumps from switching on or off at undue situation. Above the lower limit, the drives are fully activated, according to the rated values of V and f to evacuate water from the flooded zone. The upper limit of water level is used to trigger an alarm that requires manual intervention to open up sections of the field, because the action can no longer be controlled automatically.

GSM Modem

The wireless telemetry unit, model G24 (Motorola / Itech) is used to establish communication between the controller and supervisory system. This model has the ability to automatically manage the GSM connection and perform the compatibility of this technology to the DPN3 protocol transparently (without protocol conversion) with the supervisory system used.

Supervisory Control and Data Acquisition (SCADA)

The SCADA software allows monitoring of the controlled object, flood. It also provides a friendly interface for the user and allows access to parameters and control variables of the flood especially at a critical situation e.g. flood rising to bridge sensor probes of level 2. This critical situation can be addressed through the capability of the alarm screen of the developed system. An important SCADA feature is the alarm management. It has an application which contains all information on all warning conditions. For each source of alarm it is possible to set limits, the message on the event occurrence, its priority and the acknowledgment requisition. The priority indicates how important the occurred alarm is. It may assume one of the following levels: *Low*, *Medium* or *High*. These levels can be used for filtering and sorting messages.

OPERATION OF THE SYSTEM

When the water level in the field begins to rise, a time may reach when it touches two or more probes at the lower level. The affected probes are now bridged. The bridged probes now send signals to the base station (central controller) via wsn node. Fig 6 shows the architectural diagram of the entire project. The control logic is implemented in the base station by articulating and integrating all elements of the system based on the pre-set parameters, controlled object and the deployed programme. The controller however sends command to the drives of the pump. The water pumps will continue to evacuate water from the field in as much as the water level has not dropped below the lower limit. In a case where the rate of water rising outweighs the volume of water being evacuated, the flood may get to the upper limit sensors. The signals sent due to the bridge of the probes at this level triggers alarm which is accompanied by colour change to be seen from the SCADA by the user. The alarm signifies that the flood has gone beyond the control of the system and hence needs immediate external support or intervention before flood hazards occur.

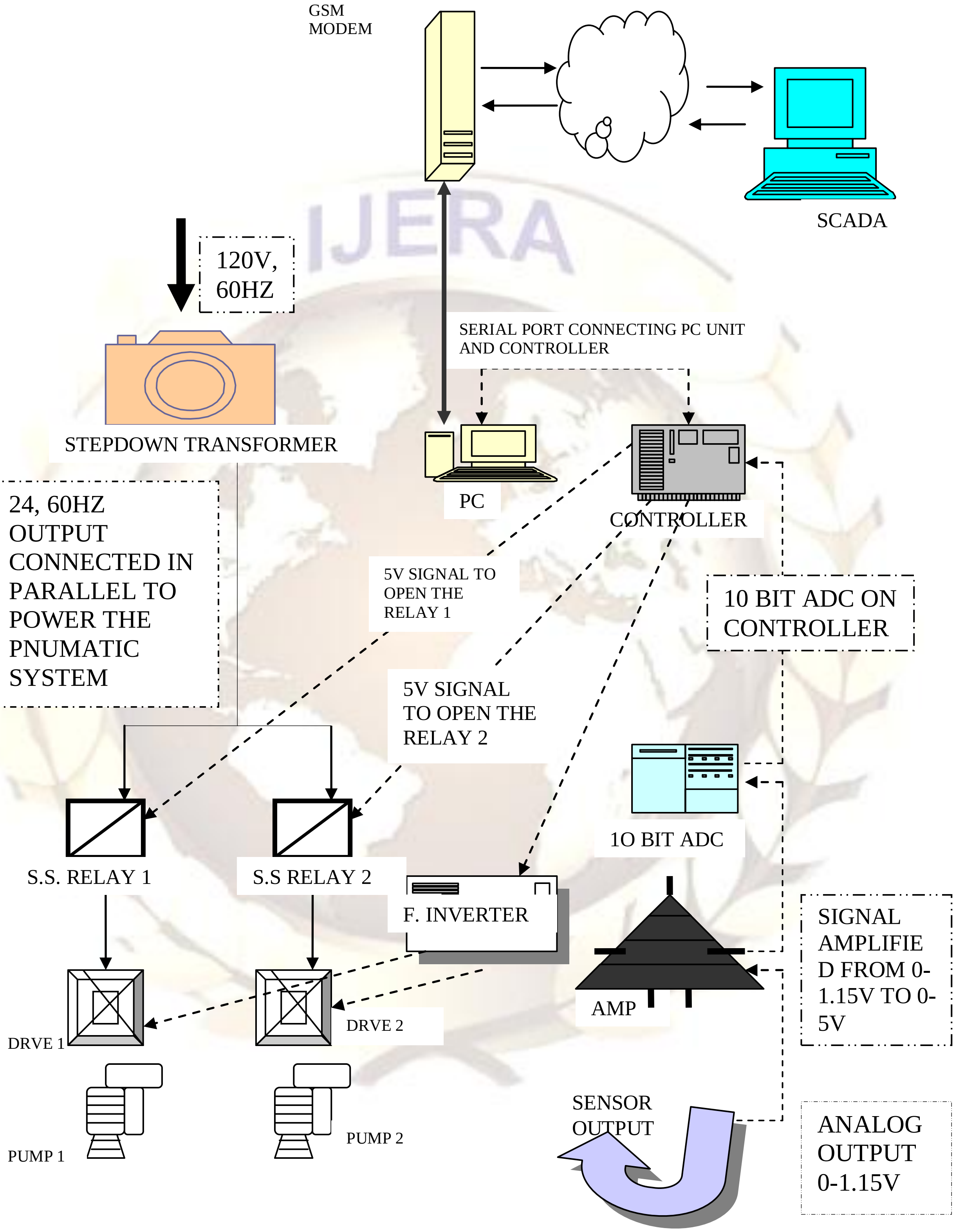

Fig 6 Architectural diagram of the entire project

CONCLUSION

The work presented in this paper has demonstrated ability to automatically control flood based on the water level using water level sensor probe and wireless sensor network (WSN). The system technique has provided more supervision and control than in traditional method of flood control. Available equipment especially water level monitoring devices provided needed information to the control system. The developed system gives a framework for further research on the quality of flood control through the intersection of historical water level data and whether data. The control system has met all the desired objectives.

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