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Early Flood Warning System Using Long Range Telemetry

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Abstract- The aim of this paper is to develop a real-time flood monitoring and early warning system using long range telemetry for communication. Warning messages are sent to a control and command centre to inform the possible risk of flooding. The developed system is based on using a pair of ultrasonic sensor network to detect flooding by sensing the height of water in a river, dam, or any other water reservoir. WiFi or Internet are not usually available at the flood monitoring points which may be at remote locations. The novelty of the developed system is that communication to the control and command centre is done using long range RF transmitter and receiver pair with repeaters if necessary. Additionally, the developed system dissipates extremely low power and it can therefore operate for very long hours without the need to charge the batteries.

Keywords- *Flooding, Flood Monitoring, Early Flood Warning, Ultrasonic Level Sensing, Long Range Communication, ESP32 Microcontroller*

I. INTRODUCTION

Flooding in many countries can result in large damages to properties and may also involve in the loss of human and animal lives, especially in inhabited areas. The damages caused by flooding can be minimized by efficient detection before it occurs, and then by alerting the relative authorities to take actions in order to minimize or prevent the damages or the loss of lives. In developing countries, the effects of floods are more harmful and cause more damages and lives than in developed countries [1]. In the year 2010, the Yangtze River in China flooded by heavy rain causing the death of 1100 people with the direct economic losses of were nearly U$25 billion [2]. It is well know that the large losses due to floodings in Asia were caused mainly by the lack of early flood warning systems and poor information dissemination at the community level [3]. In late July 2010, monsoon rains caused floodings in Pakistan which affected about 20 million people where the properties and livelihood were destroyed. The death rate was around 2000 with an economic loss of around $US40 billion [4].

Over the last decade, several flood warning systems have been developed in many countries. Natividad and Mendez [5] describe early flood detection and alerting system installed at the basin of a river. This system is based on using the GSM network for communication where SMS message are sent to relevant authorities to warn them early in case of the risk of flooding. The described system makes use of the Arduino microcontroller and uses a network of ultrasonic sensors to detect the water levels at different points of the river. The disadvantage of this system is that it relies on the GSM network which may not be available at the points of interest.

Lai et al. [6] describe a real-time video processing based surveillance system for early fire and flood detection. The proposed system is based on video content analysis in real-time that is used as an effective method for automatic detection of fire or flooding. The method described is basically a video processing application where the feature vectors, colour/grayscale histogram concentration etc. are analysed and the possibility of fire or flooding are predicted. The disadvantage of the proposed system is that like all other video based early disaster detection systems, the useful range of the video signals are limited and also such signals suffer from environmental factors such as fog, rain, humidity and so on.

Jongman et al. [7] present a system of early flood detection using the satellite observations for water levels in the areas of interest, and also relying on twitter based social media reports. The information received from disaster response organizations, the Global Flood Detection System (GFDS) satellite flood data are analysed to detect the risks of flooding. Like the video based systems, the accuracy of satellite based systems suffers greatly from environmental factors such as the fog, rain, humidity and so on. The other problem with satellite based systems is that the data may not be available early enough to make a useful prediction.

Krzhizhanovskaya et al. [8] describe an early flood warning system developed within the UrbanFlood FP7 project. The described system works by monitoring sensor networks installed in possible flood areas, such as dikes, dams, embankments etc. and detects sensor signal abnormalities in these areas using artificial intelligence techniques. The dike failure probabilities are calculated and possible scenarios are simulated to detect flood propagation. The collected information is fed into an interactive decision support system to help the authorities to make informed decisions and to assess the level of the emergency.

Azid et al., [9] present an SMS based flood detection and warning system based on using the GSM mobile telephone network to send SMS early warning messages to the relevant authorities when flooding is expected to occur. This proposed system uses an Arduino microcontroller based water level sensor system where a pipe is inserted into the water and the pressure of the water inside the pipe and hence the level of the water is monitored. When the pressure and hence the water level exceeds a pre-determined level then it is assumed that flooding may have occurred and SMS warning messages are sent to the relevant authorities.

This paper presents the development of an early flood warning system that can be used anywhere on Earth without the need of GSM, WiFi or Internet communications. The developed system uses a network of ultrasonic sensors to detect the water level at the points of interest and sends appropriate warning messages to a control and command centre which is assumed to be distant from the flood areas.

II. ARCHITECTURAL FRAMEWORK

The architecture of the developed system is shown in Figure 1. The system consists of a network of distributed stations. Each station is equipped with an ultrasonic distance sensor module, built around a low power ESP32 type microcontroller. The reason for choosing the ESP32 is because of its deep sleep mode where the power consumption is reduced to around 5µA. The number of stations to be used depends on the number of flooding points to be monitored. Each station is given a unique identifier by hard-coding 3 of its I/O pins, thus at present up to 8 unique stations can be used and identified in the design. An ultrasonic receiver-transmitter pair in each station measures the water level in the area of interest. The system is normally in deep sleep mode and is waken-up at regular intervals to check the level of the water. If the water level is above a preset threshold value then it is assumed that there is the risk of flooding and a message is sent to the command and control system together with the currently measured water level and the identity of the station sending the message. This message is sent at repeated intervals via a long range RF transmitter. The reason for using RF transmitters is because WiFi or Internet is not normally available at remote locations where the flood monitoring is required. Because the locations of the RF transmitters and the receiver are fixed and known in advance, Yagi type antennas were used in the design to increase the effective communication range. The transmitter-receiver pair used in the design is capable of acting as a repeater so that the range of communication can be extended easily if required. Power to each station is provided by chargeable batteries which are charged by small solar cells located at each station site. Because the power dissipation of each station is very low, fully charged batteries should last for very long times without requiring any charge. This feature of the system is very important, especially in winter times when the solar cell efficiency drops and the demand for flood monitoring increases.

III. THE HARDWARE

The block diagram of a station hardware is shown in Figure 2. Various components of the design are described briefly in the next sections.

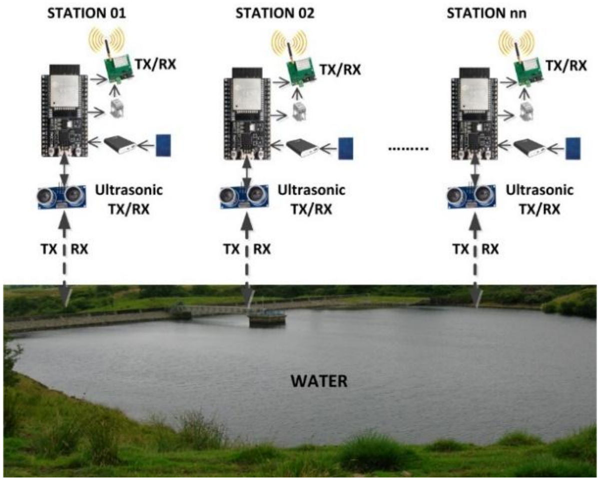

Figure 1. The system architecture

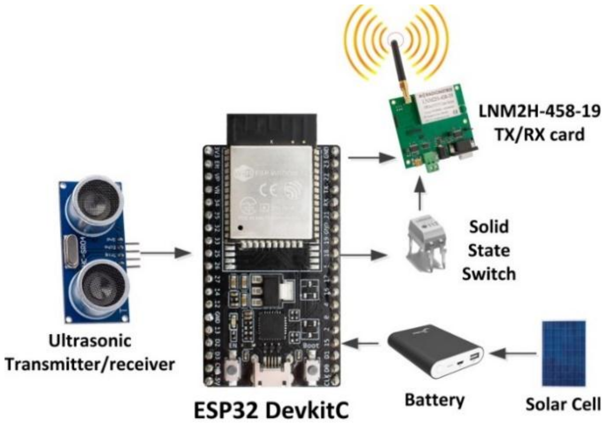

Figure 2. Block diagram of a station hardware

A. *The ESP32 Microcontroller*

Many microcontrollers could have been used in the design, including Arduino, Raspberry Pi, PIC microcontrollers, ARM microcontrollers etc. The important factors when making a choice in this project have been very low power dissipation and long term reliability. Because of these factors, it was decided to use ESP32 type microcontrollers in the design. Every station is equipped with an ESP32 type microcontroller [10]. ESP32 is a low-cost and low-power microcontroller which can be put into deep sleep mode with extremely small power consumption, and this is the main reason why this particular processor was chosen. The popular ESP32 development board ESP32 DevKitC (Figure 3) was used in the design. The basic features of this development board include the following. It is interesting to note that the deep sleep mode current consumption is only 5µA:

- Xtensa dual-core 32-bit LX6 microprocessor with 160MHz clock
- 520KB SRAM
- Wi-Fi (802.11/b/g/n) and Bluetooth (v4.2)

- 12-bit 18 channel ADC
- 2 x 8-bit DAC
- 10 x touch sensors
- 4 x SPI, 2 x I2S, 2 x I2C, and 3 x UART interfaces
- CAN bus 2.0
- Infrared remote controller
- 5µA deep sleep current

Figure 3. The ESP32 DevKitC microcontroller development board

B. Ultrasonic Sensors

An HC-SR04 type [11] ultrasonic transmitter-receiver pair (Figure 4) was used in the design to measure the water level in every station. Ultrasonic sensors work by initially triggering the transmitter with a short pulse. The transmitter module then sends out a burst of 8 pulses at 40kHz (10µs) to the object (water in this case) whose distance is to be measured. The receiver module waits until it receives the echo pulse from the object. The further away the object the longer it will take for the echo pulse to arrive at the receiver module. The distance to the object is then calculated by knowing the speed of sound in medium where the sensors are used, in this case the air (see Figure 5). The features of the HC-SR04 ultrasonic transmitter-receiver pair is as follows:

Here's a list of some of the HC-SR04 ultrasonic sensor features and specs:

- +5V DC power supply
- 15mA working current, less than 2mA quiescent current
- Effectual Angle: <15°
- Ranging Distance : 2cm – 400 cm
- Resolution : 0.3 cm
- Measuring Angle: 30 degree
- Dimension: 45mm x 20mm x 15mm

Figure 4. HC-SR04 ultrasonic sensor pair

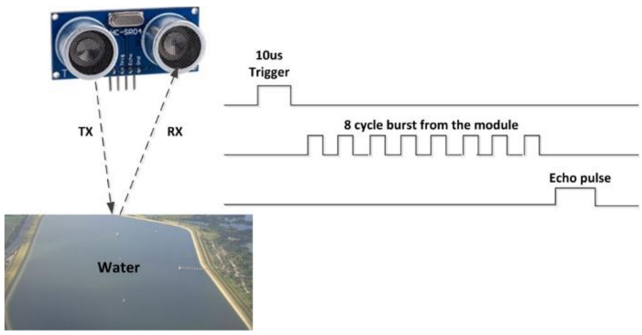

Figure 5. Ultrasonic distance measurement

C. RF Transmitters

Each station monitors the water level and transmits messages to the control and command centre via the RF transmitter modules if there is a risk of flooding. Because the system may be located in a remote place from any towns or villages, there may not be access to the Internet or to a Wi-Fi. Also, Bluetooth communication technology could not be used because the range of any Bluetooth communication is rather limited. The only other option here for communication was to use RF transmitter/receiver modems. One of the requirements has been to use professional quality reliable modems. The required range of the modem depends on the size of the area of interest to be monitored and its distance to the command and control centre. In this project the TX/RX modem cards from Radiometrix with the LNM2H-458-19 type modem chips [12] are used (Figure 6). These modem cards operate with UART serial data and have the following specifications (different modem chips with different operating frequencies are available for different countries):

- 458MHz (UK) TX/RX chip
- 19200 bps data rate
- ETSI EN 300 220-1 Category 1 high performance
- 5V operation

- 500mW transmit power
- USB, RS232. And RS485 interface
- Operation with baud rates from 300 to 38400
- Antenna connector with whip antenna

LNM2H-458-19 modem chips are professional grade, high performance, high power, and programmable, and they have the very useful “Store and Forward Repeater mode” of operation where a modem can be used as a repeater and thus the communication range of the overall system can be increased considerably using pairs of several such modems. This is very important for example when the Command and Control Centre is long distance away from the flood monitoring centres, or if there is a physical obstacle such as a hill between a station transmitter and the receiver. A range test mode and received signal strength indicator are also provided which could be useful in positioning the modems correctly.

Figure 6. LNM2H-458-19 modem card

D. Solid State Switches

The Transmiter/Receiver modem card consumes large power when in operational mode, i.e. when flooding has been detected. In order to minimize the power consumption in the system, the modem card module is normally turned off using a MOSFET solid state switch under the control of the ESP32 microcontroller. If flooding has been detected by a station then the solid state switch is activated which in turn supplies voltage to the transmitter/receiver modem card to transmit the early flood warning message to the command and control centre. A G3VM-61A1 type MOSFET solid state switch [13] is used in the design, capable of switching loads with current up to 500mA.

E. Station IDs

Each station processor is given a unique ID which is hardware programmed by configuring the ESP32 processor I/O pins. Currently 8 unique IDs can be configured from 00 to 07 by configuring 3 of its I/O pins. This unique ID is transmitted to the command and control centre together with a message when flooding is detected so that the exact location of flooding can easily be determined by the relevant authorities.

F. Station Antennas

In general, the locations of each station and that of the command and control centre are fixed and are well known. Because of this, it is possible to use directional antenna such as Yagi antennas [14] to establish reliable long distance communications between a station and the command and control centre. It is estimated that the average range of the transmitter is around 20km with line of sight between the transmitter and the receiver antennas while using standard antennas. This range is expected to be much higher with the Yagi type antennas.

G. Solar Panels

The system is powered using rechargeable batteries. Although the power dissipation of the overall system is extremely low, a small solar panel was used in the design to provide continuous charge to the batteries. This is important so that the flooding area can be monitored at all times of the day and all days of the year.

IV. THE SOFTWARE

Power saving has been one of the main aims of the system developed in this paper. As a result, the ESP32 station processor is put into deep sleep mode most of the time and it wakes up at pre-defined intervals and checks the ultrasonic sensor pair to determine if the water level is above the preset value, i.e. if flooding is expected in the monitored area. If the water level is at acceptable level then the station processors go back into deep sleep mode. If on the other hand flooding has been detected by a station processor then the station processor sends an early flooding risk warning message to the command and control centre. Figure 7 shows simplified operation of a station software as a pseudocode.

```
BEGIN/MAIN
    Configure the ultrasonic sensor pair
    Set deep sleep mode
    Call PROCESS on wake up from sleep mode
END/MAIN
BEGIN/PROCESS
    Set the water level threshold
    Send a trigger pulse via the ultrasonic transmitter module
    Read the echo time via the ultrasonic receiver module
        Calculate the water level
        IF water level > threshold THEN
          Get station ID
          Transmit early flood warning message with station ID
        ENDIF
          Set deep sleep mode
          Call PROCESS on wake up from sleep mode
END/PROCESS
```

Figure 7. Operation of a station software

V. CONCLUSIONS

The design of a low-power early flooding detection and warning system has been described. The novelty of the developed system is that its power consumption is extremely low while in standby mode while monitoring the water level. This is important because in remote monitoring locations the only way to charge the batteries is via solar or wind energy and here solar energy is utilized with solar panels. These panels are not efficient in winter months when the weather is usually cloudy, foggy, or rainy. Winter months are also the season when flooding is most expected. By using extremely low power monitoring stations the batteries are expected to last much longer times. The system is based on using multiple sensor stations scattered around the area of interest, such as a dam, river, lake etc. When a station detects that the level of the water is above the maximum allowed threshold value then a message is transmitted to the command and control centre together with the station id so that the necessary precautions can be taken before the actual flooding occurs.

The developed system can be enhanced in several ways. Currently, a warning message is transmitted when the water level is above a preset threshold value. It may be useful to send the actual water levels at periodic intervals to the command and control centre so that the relevant authorities can analyse the data early and in real-time. Additionally, other water level sensors could also be incorporated into the system to improve the overall reliability as well as the accuracy of the system.

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