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A Smart Borehole Water Pumping System

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Abstract—Sufficient water supply is one of the main success determining factors in livestock farming, hence a farmer should have a water borehole which can supply enough water for his animals. However, boreholes only hold a certain amount of water at their static levels and this water may not be enough for a farmer's use. Hence farmers pump water into a reservoir and wait for the borehole to recharge then pump again later. Since boreholes have limited yield, farmers may not obtain enough water for their livestock at the first instance of pumping. If water is continuously pumped until a borehole is empty (dry running), air is sucked in instead and this leads to the borehole collapsing or damaging the pumping system. To remedy this, a water pumping system is developed consisting of a microcontroller, level sensors, a liquid crystal display, piezo buzzer and a pump. The system detects water level in the borehole and reservoir and operates the pump based on the sensed levels, it also calculates the yield of the borehole in realtime.

Index Terms—Water pumping system; ultrasonic sensor; borehole yield

1 Introduction

IDEALLY a borehole should hold sufficient water for all livestock availed to a farmer; however, a borehole may have a certain amount of water at its static level and this water may not be enough for the farmer's use. Hence the farmer may have to pump the water out into a reservoir and wait for the borehole to recharge several time before he/she could reach enough water volume for usage. The reason is that a borehole has a limited yield hence a farmer may not obtain enough water for his livestock at the first instance of pumping. If a farmer continuously attempts to pump out water when the borehole is empty, he ends up sucking up air which leads to the borehole collapsing. This then makes it necessary to have a smart borehole water pumping system. In the last couple of decades, a lot of monitoring systems have been developed and accepted[1][2]. An automated system is a system that can turn a device on and off without human intervention. Unfortunately, these systems focused largely on monitoring the catchment tank water level and stopping the feeder pump once the maximum water level has been reached in the tank[3]. This results to a system which is not optimal, thus energy would be lost pumping an empty borehole and also resulting in damage to the borehole walls. A controlling system should take all aspects into consideration and should provide indications or audio-visual alarms at desired water levels. To optimize the system, proper monitoring is needed with distribution linked to sensing and automation. As such, automatic control of pumps based on the user's requirements should be included in water management systems[3]. The most ideal and cost effective way to automate these systems is to use microcontrollers for water level sensing, monitoring and controlling.

The goal of this paper is to present the design and simulation of a smart borehole water pumping system. This system controls the water pump that pumps water from a borehole to a reservoir. A microcontroller is used to determine the water levels in the borehole and reservoir and compares them to the set thresholds. The pump is switched on if there is insufficient water in the reservoir and sufficient water in the borehole. The system then calculates the yield of the borehole. Once the borehole has insufficient water, or when the reservoir is full, then the water pump will not be switched on. This system attempts to find a simple solution to a complex system. The organization of this paper is as follows. Chapter two discusses works related to the proposed systems. In chapter three we describe the materials used to construct this system along with the methods used in designing the system. The results and discussions follow in chapter four. Chapter five concludes this paper.

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1.1 Related Works

There are several pumping systems that have been developed over the years. Knights energy designed a water pumping system that extracts water from lakes, boreholes and rivers based on a photovoltaic solar system which they used to extract the water [4]. Similar systems to the one developed by Knight Energy were developed by [5][6]. Their system differs from the system in question in the sense that they are only concerned with extracting water from underground without taking into consideration the level of the water underground and the level of the water in their catchment tanks. If the catchment tank is full the system does not know this and will keep pumping water which will in-turn spill over thus leading to water wastage.With the technological advances of mobile devices as a motivation Khaled Reza el al [3],based on the electrical conductivity of water proposed a water level monitoring and sensing system based on microcontrollers in a wireless and wired situation. The research result was a flexible, economical and easy configurable system designed on a low cost PIC16F84A microcontroller and finally, proposed a web and cellular based monitoring service protocol to determine and senses water level globally. However, this system only focused on the catchment tank and not the source of the water. Using moisture content in the soil [7][8][9], developed an irrigation water pumping system. Ejiofor Virginia Ebere and company[10] designed a system in which they were monitoring water being pumped into an over-head tank and switching off the pump once the over-head tank was full. They achieved this by embedding control system into an automatic water pump, they also used DC power instead of AC power to reduce the risk of electrocution. Ejiofor Virginia Ebere's system varies from the system being presented in this paper as it does not take into account the source of the water. Several automated water pumping systems driven by embedded microcontrollers have been developed [11][12][13], but, all these systems do not consider the source(wells,boreholes,rivers,lakes) into consideration, they only focus on the catchment tank and its capacity. These systems also do not consider the yield of their respective sources.

1.2 Materials and methods

1.2.1 smart borehole water pumping system

The smart borehole water pumping system consists of four subsystems all linked to the microcontroller. The microcontroller determines whether to turn on the pump based on the information provided by the sensors and preprogramed information. Additionally, yield of the borehole is calculated in the microcontroller. System status is displayed to the farmer via an LCD display, the microcontroller controls what is displayed to the farmer. More to this, the borehole water pumping system consists of the pump which pumps water from the borehole into the reservoir. A motor operated by a microcontroller will control the pump. Furthermore, the sensing system consists of sensors in the reservoir and borehole. These sensors obtain the levels of water in the borehole as well as reservoir and sends their readings to the microcontroller for further processing. An example of a use case is if water is being pumped into the reservoir and either the borehole runs out of water or the reservoir reaches maximum capacity, the farmer needs to be alerted to any of these changes so as to take appropriate actions to remedy the situation, and this is achieved through the use of a piezo buzzer which makes up the warning system. An LCD screen is used to display information to the farmer. figure 1.2.1 depicts the subsystems of the system. The system consists of a PIC18F2550 microcontroller, 16x2 LCD display, two ultrasonic sensors, a simple dc motor, a piezo buzzer, two transistors, three variable resistors and three resistors. The materials used for this system are shown in Table 1 below.

Name of component	Description
PIC18f2550	microcontroller
ultrasonic sensor	Hc-sr04 ultrasonic sensor *2
buzzer	piezo buzzer
motor	12v simple dc motor
LCD display	LM016L 16*2 LCD display
Transistors	2N3903 NPN transistor *2
variable resistor	1kΩ*3
Resistor	1kΩ*3

TABLE 1
Material list

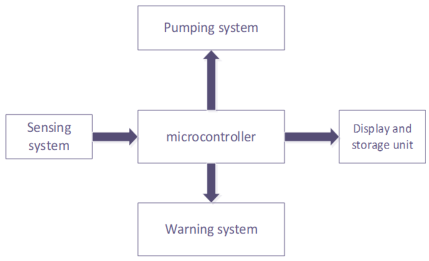

Fig. 1. system block diagram

There are two sensors in the reservoir and the borehole, these sensors obtain water levels in both the borehole and reservoir and sends their readings to the microcontroller for processing. Once data is received, the microcontroller compares the reservoir water level with the preprogramed maximum level to determine if the reservoir should be replenished. Furthermore the microcontroller also compares the borehole water level with the preprogramed minimum level. If water in the borehole is above the minimum required level, then the pump is turned on and the reservoir is replenished. Once the pump is turned on the borehole water level is stored. During the pumping process, the system keeps checking the borehole water level to ensure that the minimum set level is not exceeded. Once the minimum level is reached, the system automatically shuts down the pump. The system also keeps checking if the maximum level of the reservoir is not reached, once reached the system automatically shuts down the pump. When the pump is switched off the buzzer sounds to inform the farmer that the pump is no longer on. Once the pump is switched off

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the current water level in the borehole is stored. Borehole level is stored after a predetermined time, this time allows the borehole to recharge its power source. The yield of the borehole is then calculated using the following formula obtained from[14]

$$k = \frac{2.303 \cdot A}{T} \cdot log_1 0 \frac{H1}{H2}$$

- K is specific yield of a well in m3/hr
- A is the surface area of the borehole in m2.
- T is the time taken by the water to rise from H1 to H2
- H1 is the difference in water levels from the beginning of pumping and stopping.
- H2 is the difference of maximum water and current water level after a certain amount of time

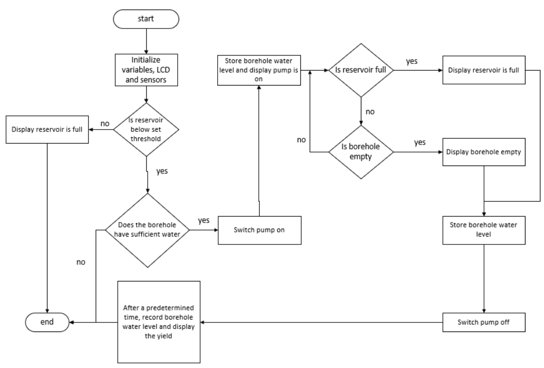

Fig. 2. system flow chart

The schematic of the system is shown in figure 1.2.1 below. The reservoir sensor has a maximum range of 800cm. Reservoirs are around 4m in height so 1cm is equated to be 0.005m meaning that 800cm is now 4m. This sensor is placed at the top of the reservoir. The reservoir is full at 3.8m that is to say a threshold of 40cm is set for the reservoir. If 40cm or anything less than that is sensed by the sensor then the reservoir is full. If the distance sensed exceeds the 40cm threshold, or the reservoir has less than 3.8m amount of water, then the reservoir can be replenished. The sensor placed on the borehole has a range of 500cm. Here 1cm is equated to 0.01m. Since our objective is to ensure that the borehole does not collapse in on its self-due to pumping when there is insufficient water in the borehole, the borehole should always have a minimum of 2m worth of water. If the distance sensed is 300cm or greater, then the system should not pump water into the reservoir. If water was already being pumped into the reservoir before the water reached the 300cm level or 2m capacity, then the system should stop pumping water into the reservoir. Initially, the water level in the reservoir is sensed and the distance sensed is fed into the microcontroller. If the pre-defined conditions set for the reservoir are satisfied then the water level in the borehole is sensed and the distanced fed into the microcontroller. If the pre-conditions set for the borehole are satisfied then the microcontroller switches on the motor which is in turn used to drive the pump and the reservoir is replenished from the borehole. The water levels in both the reservoir and the borehole are closely monitored to ensure that the conditions associated with either of them is not violated. When either the reservoir is full or the borehole level falls below the acceptable level, then the pump is turned off and the buzzer sounds to alert the farmer that water is no longer being pumped into the reservoir. The yield of the borehole is then calculated

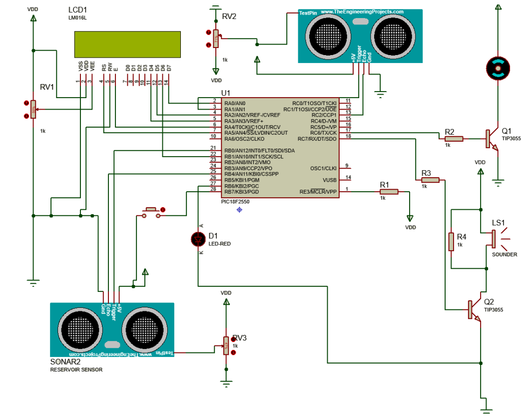

Fig. 3. circuit diagram of a smart borehole water pumping system

1.2.2 Pumping system

Dc motors cannot be driven from a microcontroller directly as a motor requires high current and high voltages that cannot be provided by a microcontroller. Pic18f2550 operates at 3.3V-5V and its input/output pins can provide 25mA of current which is not enough to drive the motor of the pump. Simple dc motors requires 12V and a minimum of 250mA current. Power supply independent from the microcontroller will be used to power the motor. A transistor will be used to act as a switch to provide power to the motor, the transistor will be controlled by the microcontroller.An NPN transistor will be used as a switch to control the motor.

Current flowing from the collector to the emitter is controlled by the current being pumped into through the base. A small amount of current through the base can control a large current flowing from the collector to the emitter. There is a voltage drop of 0.7V between the base and the emitter, meaning the transistor requires a minimum of 0.7V for it to run. The motor will be provided with a 12V power supply. The current flowing through the transistor should be greater than the minimum current needed to drive the motor. That is the collector current should be greater than 250mA.Since the transistor has a gain ratio of 1:100 the minimum current required from the base of the transistor is 2.5mA. the pic microcontroller can provide up

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to 25mA of current.

$$I_B = \frac{V_B - V_{BE}}{R_1}$$

$$R_1 = \frac{V_B - V_{BE}}{I_B}$$

$$R_1 = \frac{5 - 0.7}{0.0025} = 1.72K\Omega$$

The base resistor should be less than 1.72KΩ. If a resistor greater than 1.72K is used then insufficient current will flow through the transistor and the motor will not operate.

1.2.3 Warning system

A buzzer is used to alert the farmer to any unexpected change in the system initiated by the system itself. When the reservoir is being replenished and water in the reservoir falls beneath the set threshold or the reservoir reaches maximum capacity, the pump is turned off and the buzzer sounds to alert the farmer to the change. The transistor operates as in the explanation given in the pumping system above.

As already calculated in the pumping system resistor R1 needs to be less than 1.72KΩ. since the buzzer has magnetic properties when the buzzer is disconnected; the magnetic field collapses and this causes a voltage spike which could damage the transistor. To avoid this, we include a resistor to discharge its capacitance. A 1kΩ resistor is used to protect the transistor.

1.2.4 Sensing system

Ultrasonic sensor will be used to obtain water level in both the borehole and the reservoir. The sensor requires 5V power supply to operate, this module includes ultrasonic transmitter which transmits high frequency sound pulses which travel at the speed of sound until they reach their target. An ultrasonic receiver which waits for the transmitted pulses and receives them as an echo signal. A control circuit which computes the distance based on the time difference between emitting the signal and receiving the echo.

Using I/O trigger for at least 10us high level signal(5V), the sensor sends bursts of 40KHZ this is to determine if there is an obstacle in front. If an obstacle is detected the bursts are reflected back. Echo goes high once the bursts are transmitted from the sensor and goes low once the signal is received back. Since the signal takes time to reach the obstacle and takes the same amount of time to return to the sensor, the distance has to be divided by 2 to obtain time taken to reach the obstacle. To calculate the time, we have to consider the medium in which the bursts travel, which is air. The speed of Air is 34000cm/sec. thus distance becomes

$$d = \frac{34000 \cdot time}{2}$$

To obtain the time it takes for the signal to return to the sensor we need to be able to tell how long the echo was high and this is achieved through the use of a timer specifically the timer1 module. Timer1 module includes two 8-bit registers TMR1H and TMR1L which are readable and writeable and increment from 0000H to FFFFH. These registers will be used to determine the duration of the signal. An internal clock (Fosc/4) is used with a prescaler of 2 that divides the internal clock. An oscillating frequency of 8MHZ is employed.

$$Time = TMR1H : TMR1L \cdot \frac{1}{InternalClock} \cdot Prescaler$$

$$Internalclock = \frac{fosc}{4} = \frac{8}{4} = 2MHZ$$

$$Time = TMR1H : TMR1L \cdot \frac{2}{2000000}$$

$$Time = TMR1H : TMR1L \cdot \frac{1}{1000000}$$

SINCE

$$d = \frac{34000 \cdot time}{2}$$

Then

$$d = \frac{TMR1H : TMR1L}{58.82cm}$$

1.2.5 Display

Once the sensors obtain the water level in both the borehole and the reservoir the farmer has to be notified the values sensed by both sensors and also has to be informed of the status of the pump, this is achieved by the use of a liquid crystal display (lcd) screen to display all information the farmer needs to know. The lcd is connected to the microcontroller and the displays read-write pin has to be grounded as information will be displayed on the lcd and nothing will be read from the lcd.

2 Results and Discussion

Testing was carried out using proteus-8 simulation software after designing the smart borehole water pumping system. Initially the system checks the water level in the reservoir to determine if the reservoir is at maximum capacity or if the reservoir needs to be replenished. Remember a threshold of 3.8m is set for the reservoir,so if the capacity of the reservoir is below 3.8m then the reservoir is believed to have insufficient water and can be replenished. if the capacity of the reservoir is greater than 3.8m then the reservoir is full and cannot be replenished. Figure 4 shows the results obtained after the system checked capacity of the reservoir.

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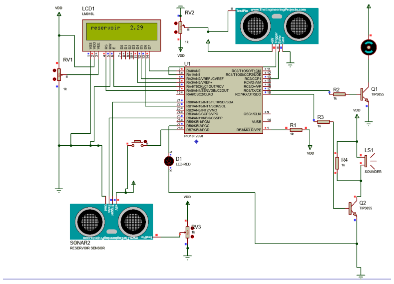

Fig. 4. detected reservoir water level

Since the reservoir is not at maximum capacity it can be replenished but the amount of water in the borehole needs to be checked to ensure that it contains sufficient water. Figure 5 shows the results after the capacity of the borehole was checked. The borehole is assumed to have

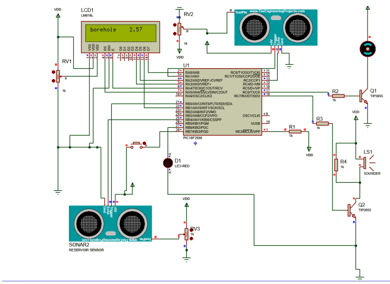

Fig. 5. detected borehole water level

insufficient water if its below 2m capacity. The borehole has sufficient water so the reservoir can be replenished. The pump is turned on and this is depicted by the turning of the motor, the status of the pump is then displayed on the lcd as shown in figure 6. While water is being pumped into the

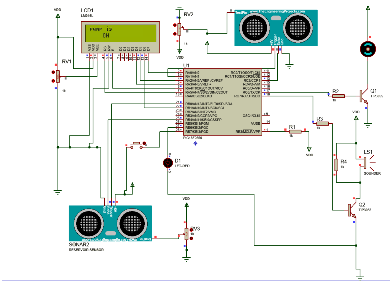

Fig. 6. pump status

reservoir the water levels in both the reservoir and borehole are periodically checked to ensure that their thresholds are not reached. Once either threshold is reached the pump is switched off and its status displayed on the lcd screen. Along with the status of either the reservoir or the borehole, which ever one reached its threshold as displayed on figure 7 and 8 respectively.

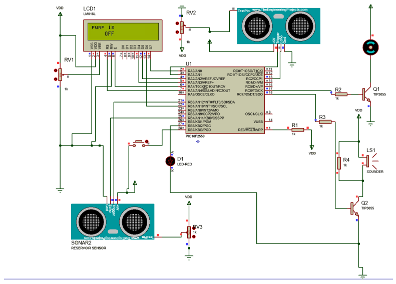

Fig. 7. pump status

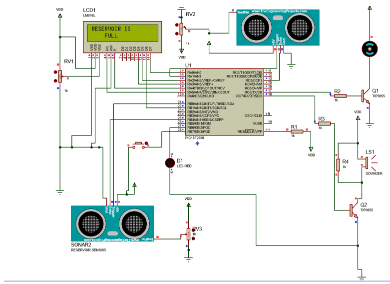

Fig. 8. results of either borehole or reservoir depending on which threshold was reached

After a determined time, the water level in the borehole is detected. This time allows the borehole to recharge itself and the depression heads are calculated as depicted by figure 9 and 10 respectively. The calculated depression heads are then used to compute the yield of the borehole which is displayed on the lcd screen.

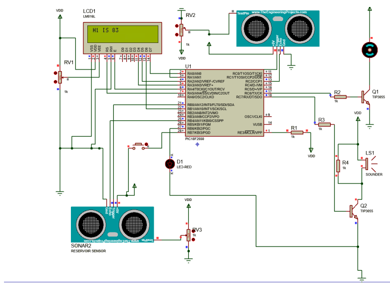

Fig. 9. first depression head

3 Conclusion

This paper presents the design and simulation of a smart borehole water pumping system. Ultrasonic sensors were

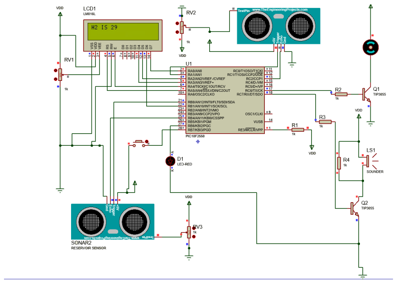

Fig. 10. second depression head

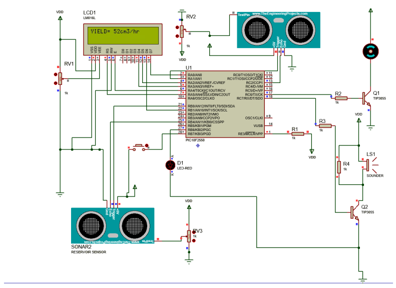

Fig. 11. the calculated yield

used to determine the capacity of the borehole and reservoir. A PIC18F2550 microcontroller was used for processing and controlling the entire system. The system is helpful to farmers as it prevents the farmer from pumping water from the borehole when it is at low levels hence prevents boreholes collapsing in on themselves. Knowing the yield of the borehole throughout the year, farmers are in a better position to find alternative ways to water their livestock around those times when the borehole has poor yields. The system automatically shuts down when the reservoir is at capacity, therefore limiting human interaction. This system was designed and simulated in Proteus simulation software and coded using Mikroc for pic of which is a C compiler for Microchip microcontrollers.In future the system could be equipped with a GSM module so that it can send the daily yield to the farmer's phone for a more detailed record. The system could use a wifi module, more specifically an ESP8266 module and store its daily yields in a cloud account. This will allow the farmer to visit this data at their own convenience and act accordingly based on these records. The system could be interfaced with a dial pad so that the farmer could obtain either the borehole water level and reservoir water level or obtain the previously calculated yield all from the press of a button.

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