International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)
Volume VIII, Issue IV, April 2019 | ISSN 2278-2540

Design and Implementation of Level Control Rig for Real Time Data Acquisition

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***Abstract*— A level control rig for real time data acquisition was realized using the ultrasonic sensor. The major issues necessitating the need of the study is that the cost and complexity of data acquisition system is high. The project is aimed at designing a low cost real time data acquisition system for level measurement and also maintaining set point of level. The research work is built round a PIC microcontroller and Ultrasonic Sensor.**

***Keywords*- Data acquisition, electronic circuitry, water level, microcontroller, control, PLC, FCE**

I. INTRODUCTION

To obtain desired result of product from a process plant, various variables must be measured and controlled. These include level, temperature, pressure and flow rate etc. But in the case of this project, emphasis is on level measurement and control. Level is probably one of the most commonly measured variables in the power plant or in a process rig.

The project “Level Control Rig (0-100CM) Real time Data Acquisition” is designed to operate using a Microcontroller to control the level in the process rig. Due to extensive research and advancement in technology, new devices have been developed that can function as to measure as well as control level. [1] These devices are called “Microcontroller” or “Programmable Logic Controllers (PLC)”.

[2,3] A PLC (Programmable Logic Controller) is a digitally operating electronic device that uses a programmable memory for internal storage of instruction for implementing specific functions such as logic, sequencing, timing, counting through digital and analogue input/output modules. PLCs are used in many machines, in many industries. PLCs are designed for multiple arrangements of digital and analogue input and outputs extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact.

A microcontroller is a microprocessor (logic controller) on a single integrated circuit containing a processor core, internal input and output memory (RAM, ROM, and Ports) and programmable input/output peripherals. A microcontroller is used in instrumentation system such as in a process plant to automatically measure and control process variables such as pressure, temperature, level, and flow rate. It is a transducer which converts one standardized instrumentation signal into another standardized instrumentation signal and compares it with a desired (programmed) value, and gives out an output so as to cause the process variable to comply with the set point.

This project employs a Microcontroller instead of a PLC since it is more cost-effective and customizable, and can still effectively perform the function the PLC would perform in the project. The project was design to automatically control the level in a reservoir containing water from 0 to 100Cm, by turning off the pump when the level in the reservoir exceeds the set high point value and turning on the pump when the level falls below the set low point value. The scope of the design was kept concise and simple by not introducing unnecessary complexity.

A. *Significance Of Study*

The project is aimed to show the importance of using a microcontroller in level control as compared to older methods. Such importance includes:

1. The reliability of the system as measurement and control of level is performed automatically with minimal error.
2. The accuracy of the system to level measurement and control.
3. It also tends to save cost since more than one function is performed by a single major component of the project i.e. microcontroller.
4. The project also seeks to showcase efficient and modern means of level measurement and control.

B. *Block Diagram Representation*

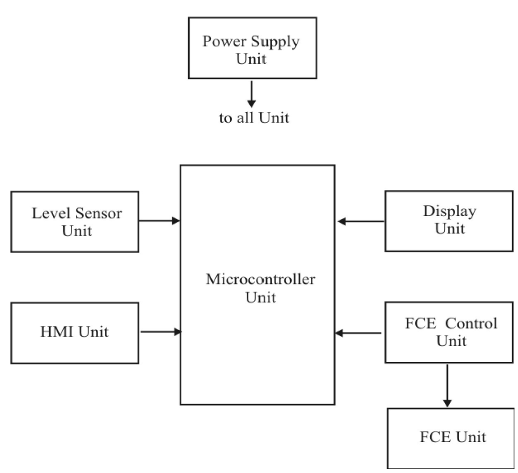

Fig. 1. Block diagram of a Level control Rig for Real Time Data Acquisition

1. Power Supply Unit

This unit converts the 220V AC to 5V DC required by the circuit. It was implemented with the following components:

- 220V/12V step down transformer
- Bridge Diode
- Capacitor
- Voltage regulator

2. Level Sensor Unit

This block contains element that measures the level of the process and convert it into an electrical signal that can be usable by the digital microcontroller.

3. Microcontroller

This is the unit performs the logic of the entire system. It receives the signal from the level sensor through its embedded Analogue to digital converter, it also receives the set point from the user, compares it with the desired value and directly Influences the process plant. The microcontroller also controls the final control element (FCE) which is the pump.

4. FCE Control Unit

This unit enables the microcontroller to control the FCE i.e. the PUMP, it consists of a transistor, relay, resistor and a diode.

5. Display Unit

This indicates the various outputs of the microcontroller in a digital form that can easily be comprehended by the observer. It displays the set point, process variable and the current status of the entire system.

6. Human Machine Interface Unit (HMI)

This unit enables the User to input data into the system representing the SET High and low LEVEL limit.

7. Final control element (FCE)

This unit represents the 220V AC Water Pump that lifts the process (water) from the storage tank into the process reservoir.

C. Ultrasonic Method

An ultrasonic level measurement instrument was used in this research work. It consists of a transmitter and receiver which can be mounted on top of tank that contains the liquid to be measured. The beam is projected downwards by the transmitter and is reflected back by the surface of the liquid contained in the tank. The beam is received by the receiver. The time taken by the beam is a measure of the distance travelled by the beam. Therefore, the time ('t') between transmitting and receiving a pressure pause is proportional to the distance is between the ultrasonic set and surface of the contents of the tank. This is as illustrated below.

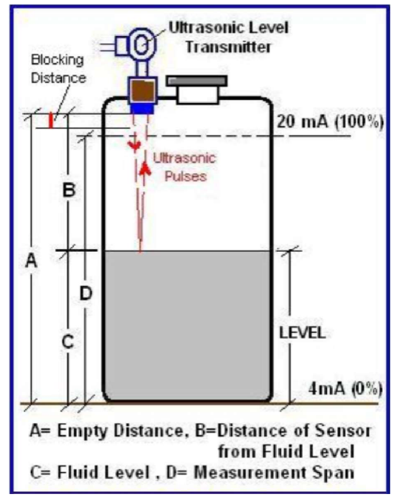

Fig. 2. Measurement Of Level By Ultrasonic Method

D. Importance Of Level Measurement

Level measurement is important in the industry as it gives information about the quantity of inputs and the finished product available. It enables manufacturers to know the amount of quantity of various inputs, chemical, liquid, solid etc. available for production and therefore to determine how long they will operate before the next supply is due. In the petroleum and petrochemical industries, level measurement is important in sales of crude and finished products.

Also, level measurement is essential in Water Company since it allows for automatic control and packaging quantity of water.

II. DESIGN METHODOLOGY

The design analysis of this research work entails, calculations, component selection and design specification. The design was divided into the following units for simplicity and efficiency. Below are the following units of the project:

- The Power supply unit
- The Level Sensor unit
- The Controller Unit
- The Display unit
- The Alarm Unit
- The Human Machine Interface
- The FCE and FCE Control Unit

A. Design Specification

- This System has the following Design Specifications:
- Input Voltage: 220/230V AC @ 50Hz.
- Level Sensor Type: Ultrasonic Level Sensor
- Level Measurement Range: 0CM to 100CM
- Display: Supports Visual Presentation of the Level 16x4 liquid crystal display (LCD).
- Pump Type: ½ HP (500watts), Centrifugal Water Pump.

- Process Type: WATER.
- Controller Type: PIC16F877A Microcontroller from Microchip Corporation.
- Supports Variable Set Points by a 4x4 Alphanumeric Keypad.

B. Power Supply Unit

This unit converts the 220V AC to 5V DC required by the circuit. It was implemented with the following components:

- 220V/12V step down transformer
- Bridge Diode
- Capacitor
- Voltage regulator

Below is the circuit diagram of the power supply unit:

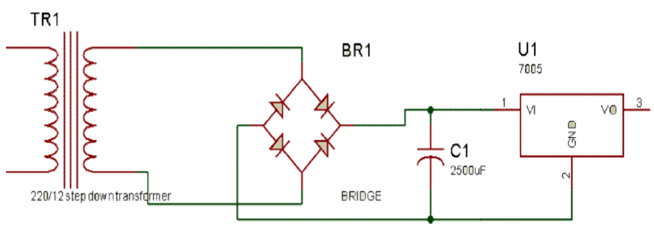

Fig 3. Power Supply Unit

C. The Level Sensor Unit

This unit measures the Process (WATER) level in the Reservoir.

Requirements of the Level Sensor

- It should be able to measure the process level within the specified range i.e. 0 to 100cm
- It should be easily to use and requires less biasing components
- The power requirements should be reasonable
- it should be cost effective and readily available

Selection of the Level Sensor

The US-100 Ultrasonic sensor was used to implement the level sensor. Below are the choice for the selection of the level sensor:

- Measuring range: 0 to 400cm, which is greater than the required specification (100CM).
- Easy interface to the Controller and Easy principle of operation.
- It require 5V DC to operate
- Cost.
- Availability.

The US-100 Ultrasonic sensor operates on the principle of transmitting sound wave and receiving the reflected wave when it meets an obstacle or there is a change in density. The sensor has a Transmitter and Receiver section. The transmitter sends the 40 kHz sound wave, when the wave encounters a change in density or an obstacle, it reflects back to the receiver section. The time taken for the wave to transmit and reflect is calculated to get the distance.

The US-100 Ultrasonic modules have FOUR (4) Pins i.e. Vcc, Trigger, Echo and GND PIN Respectively. When the Trigger PIN is given High (5V), the module sends the 40 KHZ sound wave. When the wave reflects back to the module, the Echo outputs High (5V). The Time it takes for the echo PIN to come High is total duration for the wave travel and reflection.

Below is a mathematical illustration for the ultrasonic level sensor.

This Unit is Directly Connected to the Controller Unit i.e. PIC16F877A Microcontroller through PIN 29 and PIN 30, i.e. the Trigger and Echo PIN Respectively.

The reservoir is cylindrical in shape with the following dimensions:

Diameter: 20CM; Height: 100CM

The Velocity of sound in AIR is approximately: 360m/s

Assuming the Process level in the Reservoir is 50CM

From Velocity = Distance/Time where Distance = 50CM i.e. 0.5m; Velocity = 360m/s

Time = distance/velocity = 0.5/360 = 0.001389 seconds i.e. 1.4ms

But the Time = Time of Transmission + Time of Reflection of the sound wave

Time=1.4/2 = 0.7ms.

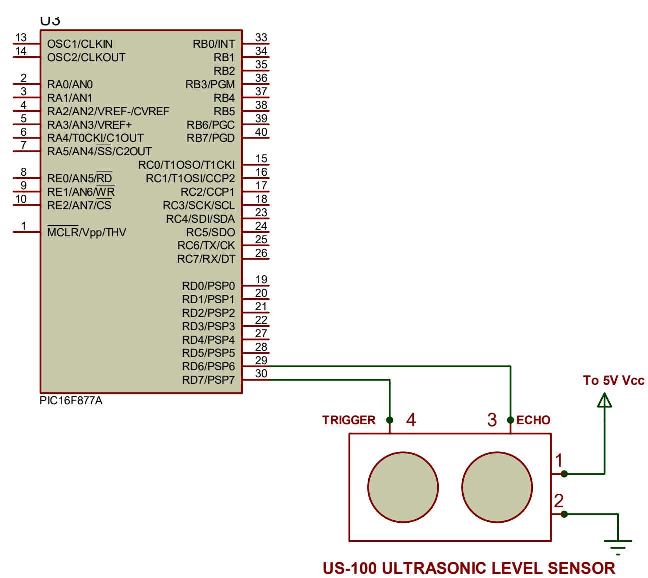

Fig 4 Level Sensor Interface with the Controller unit

D. The Display Unit

This Unit gives a Visual Presentation of the Water Level (in cm) inside the Reservoir. This unit, in-conjunction with the

HMI unit also creates a platform that enables the user to input the SET Point.

Requirements for the Display Unit

- Should be large enough to give a clear visual presentation of the Water level.
- Be Large Enough to Represent the Level of the Process in the Reservoir.
- Should be easy to Use or Programmed.
- Should have an easy connection interface i.e. less biasing components.
- Should be available and Cost effective.

Selection of the Display Unit

16x4 (16 characters per Row, 4 Rows) liquid crystal display was selected. Below are the choice of the selection:

- It gives a clear visual presentation of data.
- It can to represent the Level of the Process in the Reservoir.
- It has an easy connection interface.
- It is cheap.
- It is available.

The display unit gets its DATA from the Controller Unit. It is connected to The PORTD PINS of the PIC16F877A Microcontroller. Below is the circuit interface of the Display unit

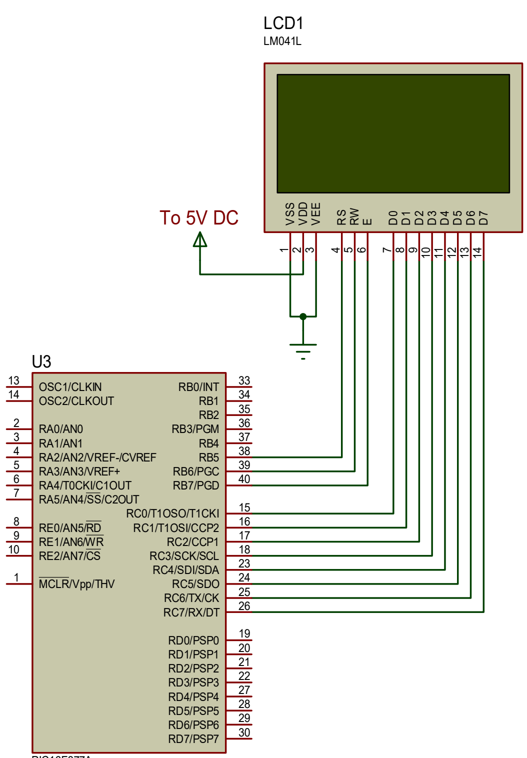

Fig 5 Display Unit Interface with the Controller Unit

E. *The Alarm Unit*

This Unit Gives Audible Sound For when the process level reaches the SET Point. Below is the requirement of the ALARM unit.

Requirements of the Alarm Unit

- Should be able to give a good audible alert.
- Should have feasible connection interface.
- Reasonable power requirements i.e. input voltage and current demand.
- Should be cost effective and readily available.

Selection of the Alarm

The unit was implemented with a DC Buzzer Alarm. Below is the choice of the selection of the buzzer alarm:

- It has a wide operating voltage i.e. 5-24V
- It gives a clear and audible sound.
- It is easily biased with a resistor.
- It is cheap and very available.

The Unit is Directly Controlled by the Controller Unit. It is connected to Pin 19 of the PIC16F877A Microcontroller. It was biased a 1K Resistor. Below is the circuit diagram of the Buzzer Unit:

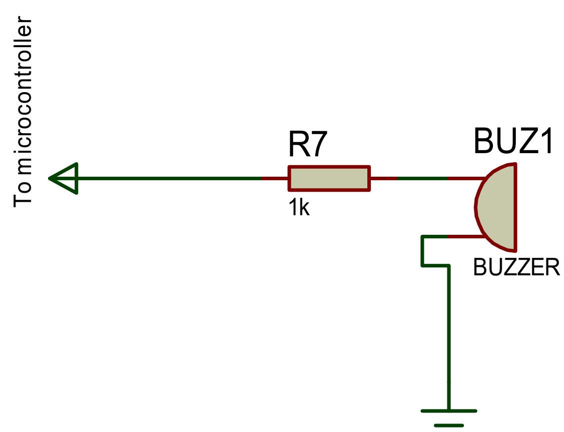

Fig 6 the Alarm-Buzzer Unit Circuit

Buzzer Operating Current

The buzzer operates with a voltage of 5-25V;

Current: 2mA to 10mA;

A pin of the microcontroller can supply 5V (as specified in Pic16f877a microcontroller datasheet)

Supply 5mA at 5V to the Buzzer:

From Ohms law: V=IR;

R=V/I

V=5V;   I=5mA

R = 5/(5x10^{-3}) = 1000;

Therefore R=1K ohms.

F. *The FCE And FCE Control Unit*

The Final control element (FCE) was implemented with a 220V AC 1/2hp Water pump. The FCE Control unit is a switching circuit that assist the Controller unit to switch the Pump ON and OFF. Below are the requirements of the unit:

Requirement of the Switching circuit

- It should not be a complex switch circuit.
- It should be able to Power the Pump.
- It should be easily controlled by the controller unit i.e. easy connection interface.
- The components involved should be available and cost effective.

Selection of the Switching Circuit

The transistor switching circuit was selected. It was implemented with the Following Components:

- 12V 30A Relay
- BC547 NPN Transistor
- Biasing Resistor

The transistor switching circuit was selected because it meant the above requirements. This Unit is directly controlled by the Microcontroller through PIN 15. Below is the Circuit diagram of the entire Unit.

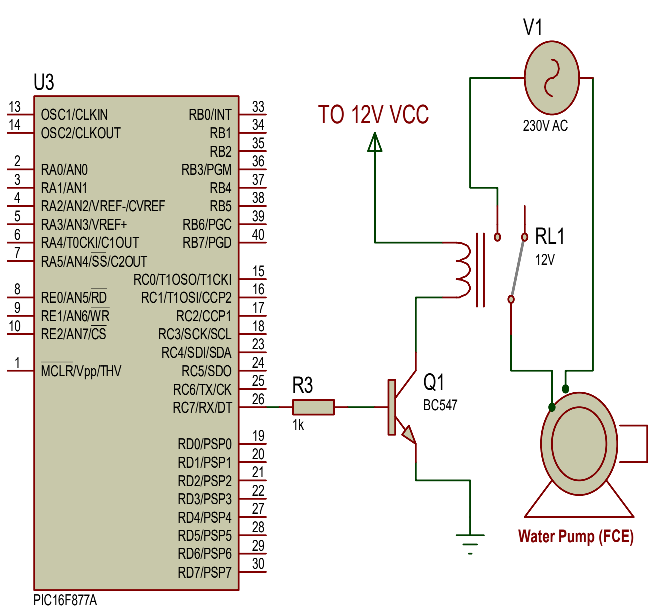

Fig. 7. Final Control Element Control Unit

Selection of the Switching Transistor

The choice of the switching transistor is based on:

a. The supply voltage
b. The maximum collector current

To determine the collector current, Collector current = relay coil current.

$$\text{Relay coil current} = \frac{\text{Relay coil voltage}}{\text{Relay coil resistance}}$$

$$= \frac{12V}{275\ \Omega} = 0.04A$$

= 40mA

The general purpose transistor BC547 was used.

The BC 547 has the following specifications:

Gain (ß) = 120

V_{BE} = 0.7V

I_C(max) = 60mA

Selection of the Relay

The choice of the relay is based on:

1. Supply voltage
2. Relay contact current
3. The Watts requirement of the Pumps

Pump used has the following specification:

Input voltage: 220v AC.

Watts: 500 watts (1/2 Hp).

Using a Relay of 12V 30A DC (JQX12)

Supply voltage in the circuit = 12V.

Power Of the relay: P=IV = 30A x 220V = 6600watts = 6.6KW

Therefore the Relay power is greater than the Pump Power requirements i.e. 6.6KW > 500Watts.

The Human Machine Interface Unit

This unit enables the User to input SET Point into the system i.e. values from 0cm to 100cm.

Requirement for the Input Control Unit

- It should have easy configuration
- It should be easily interfaced to the controller
- It should require accessible and cost effective components to achieve

The Selection of the Input Control Unit

The unit was implemented with a 4x4 Alphanumeric Keypad.

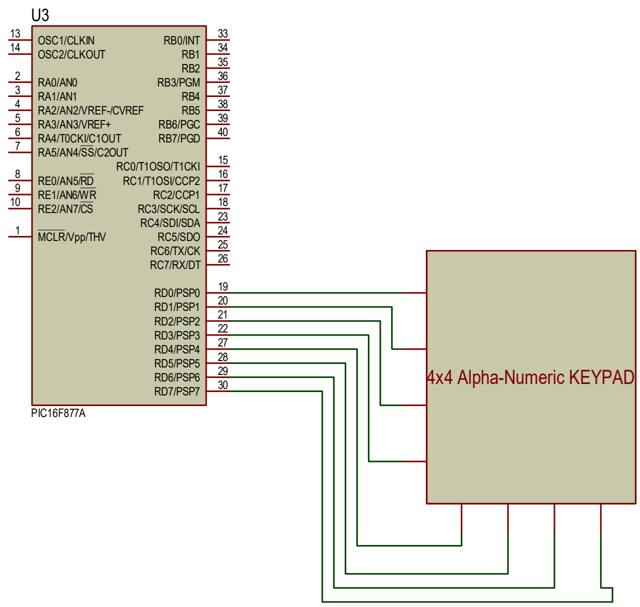

Fig. 8. Human Machine Interface Unit

G. The Controller Unit

This Unit is the Heart of the Entire System. It performs the entire logic of the system. Below is the requirements of the controller unit.

Requirements of the Controller

- Should be able to interface the display unit.
- Should be able to drive US-100 Ultrasonic sensor.
- Should be stable and efficient.
- Should have enough Input/output Pins to accommodate the entire system.
- Should be easily programmed.
- It should available and cost effective.

Selection of the Controller

The PIC16F877A Microcontroller From Microchip Corporation was selected. Below are the reasons of the selection.

- It is a 40pin Microcontroller, it has enough input/output pins.
- A pin in the microcontroller can supply 5V 20mA.
- It has an easy programming interface.
- It is stable, cost effective and available.

The PIC16F877A Microcontroller was biased with a 16Mhz Crystal and two (2) 15pf Capacitors.

To determine the time the microcontroller executes one instruction

One machine cycle is the time taken to execute an instruction

Machine cycle = 4 pulses of crystal oscillator.

Hence, time taken = $\frac{\text{Oscillator Frequency}}{4}$

For one machine cycle

$$= \frac{16MHZ = 4MHZ}{4}$$

1/F= 1/4MHZ = 1µs

The controller executes one instruction in 1 micro seconds.

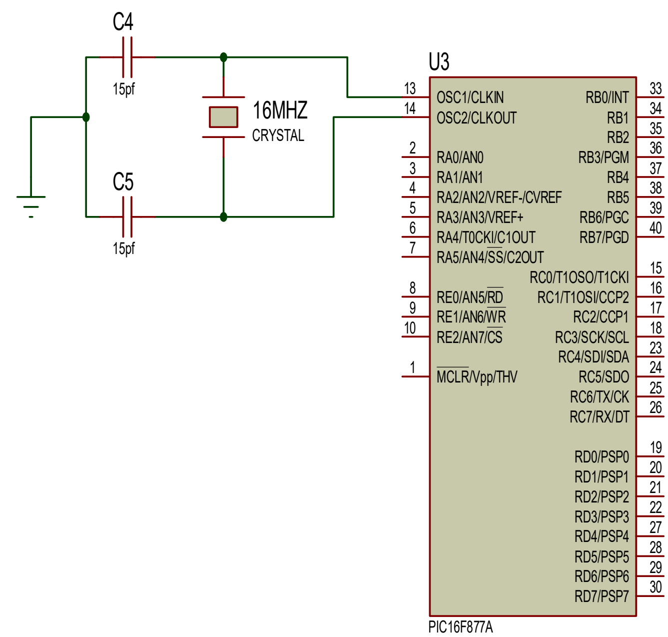

Fig. 9: The Controller Unit

III. RESULT

When the switch is turn ON, the power supply unit supplies 5V DC to the circuit, the pic16f877a (microcontroller) initializes its internal registers, configures Pin 29 to 30 as digital input pins that connects directly to the US-100 Level sensor, when done, initializes the HMI display and sends a value of "000" to the displays.

Whenever a user input SET point through the HMI unit, the controller outputs High (5V) at PIN33 to activate the FCE, then it also outputs 5V at pin 29 connected to the US-100 Ultrasonic sensor, the sensor then sends the 40 KHZ sound wave, the controller then activates its internal timer and also waits for the echo pin of the sensor to come high (5V), when the PIN30 outputs high, the microcontroller computes the distance, then update the HMI display. the microcontroller then compare the distance with the SET distance, if it is equal, the controller deactivate the FCE, then output high at PIN19, to activate the ALARM Unit

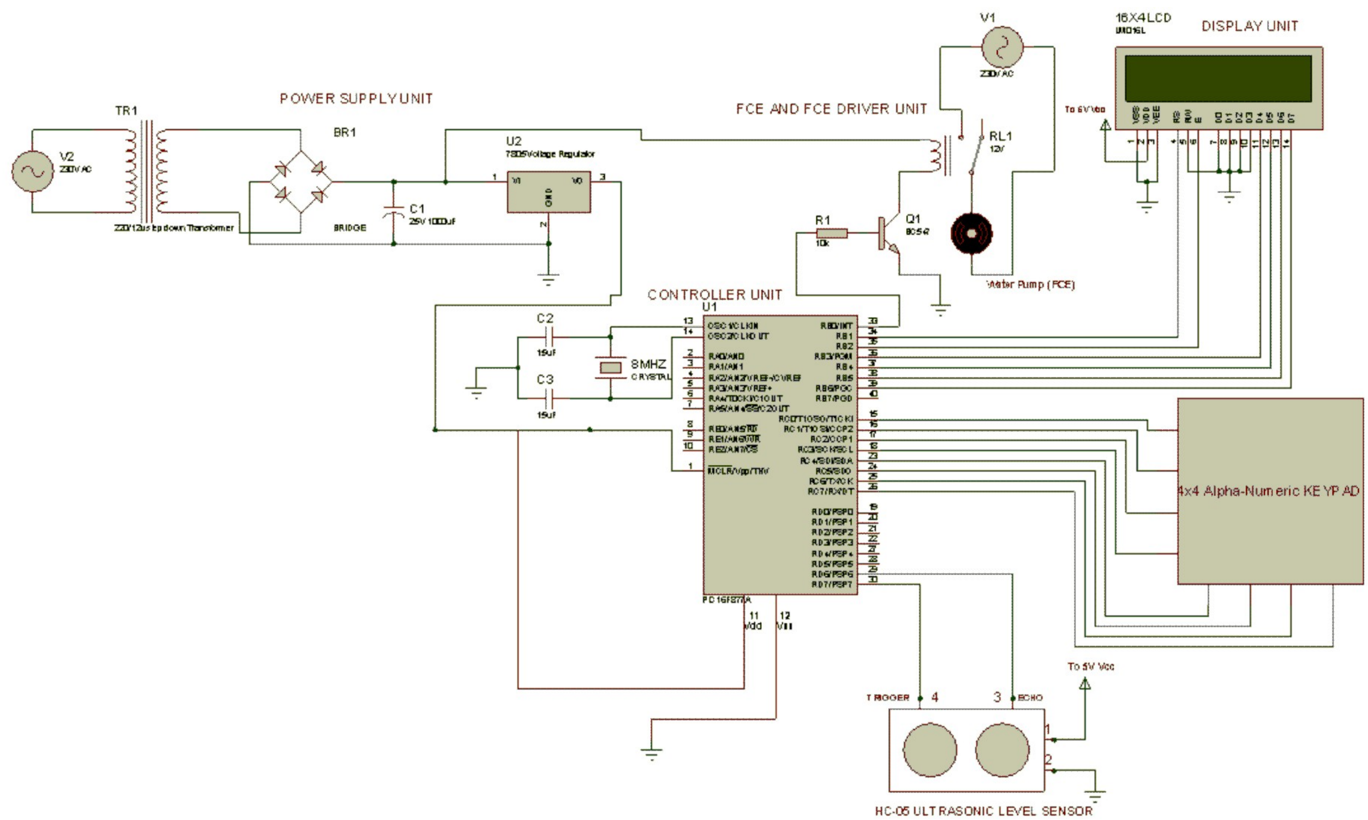

Fig. 10. Of level control rig for real time data acquisition

IV. CONCLUSION

A successful attempt has been made to design and implement a Real time level Rig (0-100cm) using locally available material. The system is capable of enhancing level measurement and control. The completed work had been tested and worked satisfactory.

A research approach was adopted in the implementation of this system, from whence a workable circuit was designed. The design was done using embedded system technology. This is to reduce component count, keep the system simple and cost effective.

ACKNOWLEDGEMENT

This research work was supported by the staff and students of Electrical and Electronic Engineering Department, Petroleum Training Institute, Effurun.

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