A

PROJECT REPORT
ON

"*DESIGN AND IMPLEMENTATION OF HIGH-SPEED ACQUISITION SCANNER AND 3D DISPLAY SYSTEM USING ULTRASONIC ECHO DATA*"

Submitted in partial fulfillment of the requirements

For the degree of

BACHELOR OF TECHNOLOGY

in

Electronics & Communication Engineering

Submitted by

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MAY – 2020

DECLARATION

We hereby declare that this submission is our own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been in the text.

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CERTIFICATE

This is to certify that the project entitled "**Design and Implementation of High Speed Acquisition Scanner and 3D Display System using Ultrasonic Echo Data**" submitted by *Kanchan Solanki(1613331080), Krishna Kumar(1613331086), Manish Verma(1613331095), Mukul Thakur(1613331112)* in the partial fulfilment of the requirements for award of Bachelor of Technology in Electronics and Communication Engineering from Dr. A.P.J. Abdul Kalam Technical University, U.P., Lucknow under my supervision. The project embodies result of original work and studies carried out by the student's their self and the contents of the project do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ABSTRACT

The purpose of this project was to provide medical or security measures using economical methods and eco-friendly technology if possible, this is very necessary these days, especially for underdeveloped locations.

The scarce availability of advance health care or security measures is a very prominent issue in remote locations of a country.

This project is aimed at employing the technique of using sound waves to penetrate or detect an object. We have used Ultrasonic sensor modules that can be easily connected to a microcontroller directly for usage. We created an array using these sensor modules and complemented it with a custom-made microcontroller for data processing and then using that data to reconstruct the image in a Computer using a software.

The results we achieved were very promising as we were able to obtain 3-D output with good resolutions which can be further improved in future by increasing the frequency of Ultrasonic sensor modules to 1-2 Megahertz.

ACKNOWLEDGEMENT

In the absence of mother, the birth of a child is not possible and in the absence of teacher the right path of knowledge is impossible. This project is by far the most significant accomplishment in our life and it would be impossible without people who supported us and believed us.

We would like to extend my gratitude and my sincere thanks to my honourable, esteemed guide **Mrs. Priyanka Verma** (Assistant Professor (ECE)), Department of Electronics and Communication Engineering, NIET, Greater Noida for their immeasurable guidance and valuable time that he devoted for project. We sincerely thank for their exemplary guidance and encouragement. His trust and support inspired me in the most important moments of making right decisions and we are glad to work with him.

We would also like to give very special thanks to our HOD Sir Dr. V.K Pandey (Professor). Also, we would also like to give thanks to our project coordinator and my teachers for their support, help and encouragement during this work.

We would like to thank all my friends for all the thoughtful and mind stimulating discussions we had, which prompted us to think beyond the obvious.

We have enjoyed their companionship so much during my stay at NIET, Greater Noida. We would like to thank all those who made my stay in NIET, Greater Noida an unforgettable and rewarding experience.

A boat held to its moorings will see the floods pass by; but detached of its moorings, may not survive the flood. The support of all the members of our family (specially our parents, our elder sisters and our loving younger brother) motivated us to work even while facing the Blues. We dedicate this work to them.

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ABBREVIATIONS

TO	Transverse Oscillation
HRI	High Resolution Image
FDBF	Frequency Domain Beamforming
RCA	Row-Column-Addressed
FOV	Field of View
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
PWM	Pulse-Width Modulation
MRI	Magnetic Resonance Imaging
IO	Input/output
ADC	Analog to Digital converter
DAC	Digital to Analog converter
AVR	Automatic Voltage Regulator
RISC	Reduced Instruction Set Computer
ISP	In-System Programmable
EEPROM	Electrically Erasable Programmable Read Only Memory
USART	Universal Synchronous/Asynchronous Receiver/Transmitter
SPI	Serial Peripheral Interface
TQFP	Thin Quad Flat Pack
QFN	Quad-flat no-leads
MLF	Micro Lead Frame
MIPS	Million Instructions Per Second
INT	Interrupt
SCK	Serial Clock
MISO	Master In Slave Out
MOSI	Master Out Slave In
SS	Slave Select
DAQ	Data Acquisition
ISA	Industry Standard Architecture
MCA	Micro channel architecture

PCI	Peripheral Component Interconnect
PCI-E	Peripheral Component Interconnect-Express
CAMAC	Computer-Aided Measurement and Control
NIM	Nuclear Instrument Module
VME	Versa-Module Euro card
TTL	Transistor-transistor Logic
EPICs	Experimental Physics and Industrial Control System
SPICE	Simulation Program with Integrated Circuit Emphasis
PCB	Printed Circuit board
DEMUX	Demultiplexer
MUX	Multiplexer
MATLAB	Matrix Laboratory

LIST OF SYMBOLS

D	Distance
T	Time
C	Speed of sound
V	Voltage
mA	Unit of Current in milli
uS	Unit of Time
VCC	Voltage common collector
GND	Ground
K ohm	Unit of resistance in kilo
pF	Unit of capacitance
kHz, MHz	Unit of frequency in kilo and mega
M/S	Unit of Velocity
$FeCl_3$	Ferric Chloride

CHAPTER 1: INTRODUCTION

1.1 Motivation

The motivation for doing this project was primarily an interest in undertaking a challenging project in an interesting area of research. The opportunity to learn about a new area of computing not covered in lectures was appealing.

Always striving to make use of our learnings and knowledge to create something that will help our society left us with a burning desire to create or work on a project as team.

This project is the result of our motivation and passion towards our subject which makes use of different fields of technology combined together.

1.2 Objective

The primary objective of this project is to use sound waves or pressure waves produced by an ultrasonic sensor for medical and security purposes by employing the use of basic Ultrasonic modules array and a custom-made microcontroller.

The goal was to make it economical as much as possible and also reconstruct the image in a Computer using software for 3D analysis of data.

The stated objectives were:

1) To make use of ultrasonic sensor modules array for collecting basic Echo data.

2) Using a microcontroller IC and designing a CPU board for handling the flow of data from sensor to Computer and it's processing.

3) Designing the Schematic and PCB for all these modules and array for neat and clean connection.

4) Using MATLAB for Image reconstruction using the echo data.

1.3 Organization of Chapters

The rest of the chapters is organized as follows:

Chapter 2: The literature surveys based on existing research in the same field has been discussed in detail herein this chapter. The chapter also discusses the methodology along with implementation of some existing and experimental results subsequently.

Chapter 3: This chapter discusses the background concepts related to this project. The chapter also discusses ultrasound technology and the process of imaging using ultrasonic sensors. The block diagram, signal flow diagram, schematics, PCB designs and required components of the proposed ultrasound system are also mentioned in this chapter.

Chapter 4: This chapter discusses the proposed system's input and output characteristics/properties along with the software used for generating graphical results i.e. the reconstructed images for different types of shapes.

Chapter 5: This chapter provides conclusions regarding the design and implementation of the project along with the further possible advancements/works for the project.

CHAPTER 2: LITERATURE SURVEY

High Frame rates Ultrasound Imaging is combined with Contrast Enhanced Ultrasound Imaging. For High Frame rates, Coherent Compounding technique is used in which Transverse waves are sent in the medium to increase it speed but this technique results in Degradation of the Image quality. To overcome both the issues and get an optimal solution both the techniques of Contrast Enhanced Ultrasound Imaging and Coherent Compounding is used to get Good Quality Image with High Frame rates. [1]

In this paper, a processing framework aimed at improving the Ultrasound Data by using Fourier-domain beamforming of plane-wave. This technique incorporates both Coherent Compounding and Angular Weighting. Angular Weighting involves processing of spectral data using 2-D steering-angle Filtering template. Two widely used Fourier-domain plane-wave ultrasound beamforming methods, i.e., Lu's f-k and Stolt's f-k methods, were integrated in the framework. To enable coherent compounding in Fourier domain for the Stolt's f-k method, the original Stolt's f-k method was modified to achieve alignment of the spectra for different steering angles in k-space. [2]

A dual-curvature focused ultrasound phased-array transducer with a symmetric control has been developed for non-invasive ablative treatment of tumours. The 1.5-D array was constructed in-house and the electro-acoustic conversion efficiency was measured to be approximately 65%. In vitro experiments demonstrated that the array uses 256 independent elements to achieve 2-D wide-range high-intensity electronic focusing. [3]

This paper presents a vector flow imaging method for the integration of quantitative blood flow imaging in portable ultrasound systems. The method combines directional transverse oscillation (TO) and synthetic aperture sequential beamforming to yield continuous velocity estimation in the whole imaging region. Six focused emissions are used to create a high-resolution image (HRI), and a dual-stage beamforming approach is used to lower the data throughput between the probe and the processing unit. The transmit/receive focal points are laterally separated to obtain a TO in the HRI that allows for the velocity estimation along the lateral and axial directions using a phase-shift estimator. [4]

Robotic ultrasound systems have turned into clinical use over the past few decades, increasing precision and quality of medical operations. In this paper, we propose a fully automatic scanning system for three-dimensional (3-D) ultrasound imaging. A depth camera was first used to obtain the depth data and colour data of the tissue surface.

Based on the depth image, the 3-D contour of the tissue was rendered and the scan path of ultrasound probe was automatically planned. Following the scan path, a 3-D translating device drove the probe to move on the tissue surface. [5]

A key step in ultrasound image formation is digital beamforming of signals sampled by several transducer elements placed upon an array. High-resolution digital beamforming introduces the demand for sampling rates significantly higher than the signals' Nyquist rate, which greatly increases the volume of data that must be transmitted from the system's front end. In 3-D ultrasound imaging, 2-D transducer arrays rather than 1-D arrays are used, and more scan lines are needed. This implies that the amount of sampled data is vastly increased with respect to 2-D imaging. In this work, we show that a considerable reduction in data rate can be achieved by applying the ideas of sampling and frequency domain beamforming (FDBF), leading to a sub-Nyquist sampling rate, which uses only a portion of the bandwidth of the ultrasound signals to reconstruct the image. [6]

A double-curved diverging lens over the flat row-column-addressed (RCA) 2-D array can extend its inherent rectilinear 3-D imaging field of view (FOV) to a curvilinear volume region, which is necessary for applications such as abdominal and cardiac imaging. Two concave lenses with radii of 12.7 and 25.4 mm were manufactured using RTV664 silicone. The diverging properties of the lenses were evaluated based on simulations and measurements on several phantoms. [7]

A method of output pressure control for ultrasound transducers using switched excitation is described. The method generates width-modulated square-wave pulse sequences that are suitable for driving ultrasound transducers using MOSFETs or similar devices. Sequences are encoded using an optimized level-shifted, carrier-comparison, pulse-width modulation (PWM) strategy derived from existing PWM theory, and modified specifically for ultrasound applications. The modifications are: a reduction in carrier frequency so that the smallest number of pulses are generated and minimal switching is necessary; alteration of a linear carrier form to follow a trigonometric relationship in accordance with the expected fundamental output; and application of frequency modulation to the carrier when generating frequency-modulated, amplitude- tapered signals. [8]

CHAPTER 3: FUNDAMENTALS

3.1 Ultrasound technology

In the modern world, there are numerous ways by which an object can be analysed at multiple levels where human eyes fail to perceive it. Present technologies involved in such type of analysis may include X-Ray Imaging, Magnetic Resonance Imaging, Thermal Imaging and Molecular Imaging etc.

But like every technology has its own limitations, these imaging technologies also fail in some aspects, be it their usability or effectiveness.

Ultrasound Imaging is one of these technologies which has been present for the past few decades. Ultrasound technology has been found to be more efficient in terms of its effectiveness and the safety hazards that are imposed by other imaging technologies on the environment.

Unlike other imaging technologies which make use of some or other kind of ionizing radiation for efficient imaging, e.g. X-Ray Imaging, Ultrasound technology is based on non-ionizing radiation, like pressure waves in a medium.

Ultrasound technology has the potential to generate high-resolution 3D images of objects with an added advantage of detecting movements of that object.

An ultrasound system basically consists of a transducer which can convert ultrasonic waves into electrical signals and vice-versa. These transducers are manufactured using piezoelectric crystals which exhibit piezoelectric effect. The major advantage of using pressure waves is that they are longitudinal in nature which are less attenuated in comparison to the transverse waves. The detection can be done by the same transducer working in a reverse process.

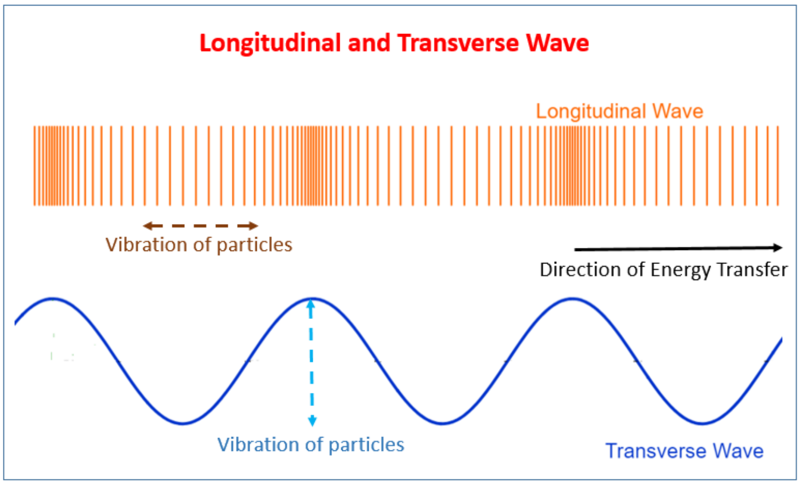


Figure 3.1: Longitudinal and Transverse Wave

Image detection is carried out in a sequence of several steps as discussed below:

3.1.1 Transmission of ultrasonic pulses

This is the first process in which ultrasound waves are generated to insonify the object under analysis. Insonification is analogous to the Illumination effect which happens when a certain amount of light falls on an object. The principle behind this phase is the reverse piezoelectric effect.

The piezoelectric effect is observed when a voltage is induced in a crystal when certain mechanical stress is applied to it. The reverse effect also exists in which vibrations are produced by the crystal on the application of electrical signals.

A customized circuit is designed which generated ultrasonic range frequencies. These are the frequencies above the level which is easily audible to human ear. Typical magnitude of this level is generally 20KHz.

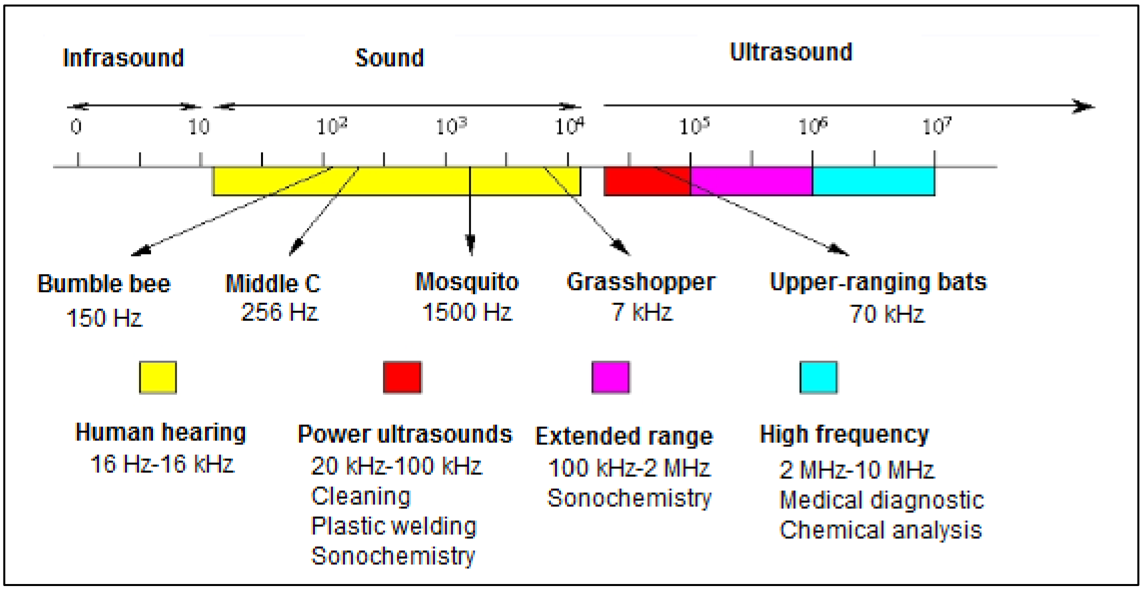


Figure 3.2: Frequency spectrum for acoustic waves

These high frequency signals are then fed to the transducer array which convert these electrical signals into high frequency pressure waves or vibrations. These transducers are fabricated using crystals that exhibit piezoelectric properties e.g. Barium Titanate ($BaTiO_3$)

3.1.2 Reflection of ultrasound waves

This phase is the basis of addition of details into the plain waves transmitted in the previous process. When the waves fall on an object, a portion of the total energy gets reflected back and the rest part of energy penetrates into the object. This reflected energy is sensed back by the same transducers that are used in the transmission phase.

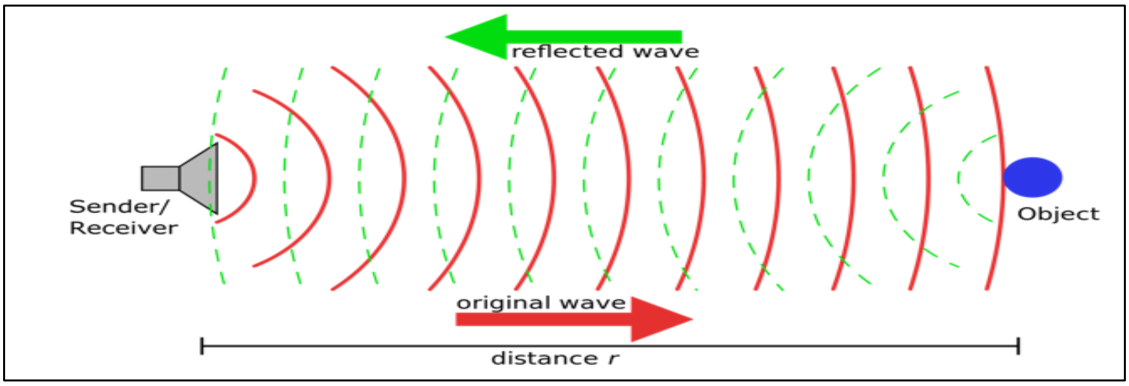


Figure 3. 3: Reflection of waves while striking the object.

Reflection of ultrasonic waves also occur because of change in acoustic impedances in the path of the propagation of ultrasonic waves. These sudden changes can be of any magnitude depending on the density of the media involved e.g. solid-liquid, liquid-gas, solid-gas, liquid-liquid, solid-solid, etc. Hence in other words, it can be understood as the reflections occur at the interface of two different materials.

The parameters of the reflected waves like propagation time for travelling back to the transducer array (receiver), intensity or magnitude and its frequency relative to the transmission frequency can be used to analyse the nature of the insonified object.

3.1.3 Reception of reflected waves

This is the last phase in the whole process which involves sensing of the reflected waves. The basic principle behind this is the piezoelectric effect. When the reflected waves fall back on the transducer, a small electrical signal is generated by the crystal when it absorbs the ultrasonic vibrations. These electricals signals are further processed and converted into digital signals with the help of Analog to Digital Converters and other devices.

The advantages of converting these signals into digital ones is that digital signals can be easily stored in storage media like memory devices. On the other hand, digital signals are processed using Digital Signal Processors which are more flexible as compared to Analog Signal Processors.

The digital signals generated in this phase go through some or other kind of image processing using software. The processing or reconstruction is done in terms of mathematical or graphical filters which produces a more accurate or simplified image that can be easily understood for analysis.

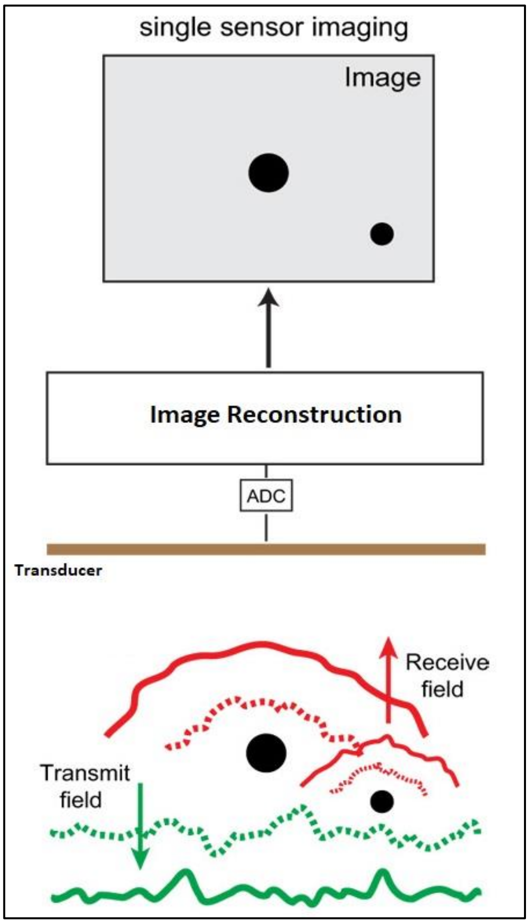


Figure 3.4: Reception of reflected wave front

3.2 Problem Formulation

3.2.1 Environmental Hazard

One of the major issues countered by ultrasound technology is that it doesn't employs any use of ionizing radiation. These waves occur in nature in the form of high frequency variations in Electromagnetic fields.

The hazard imposed by the use of ionizing radiation is that it has the ability to displace the electrons of particles of target object. Hence, in a way, they change the properties of the particles at atomic level which can lead to instability. However, the same activity becomes hazardous when the target object is a human tissue or any living organism. These hazards can lead to dangerous consequences like Skin Cancer, Acute Radiation Syndrome or Chronic radiation Syndrome.

On the other side, Ultrasound Technology uses pressure waves. Since these pressure waves occur in nature in the form of variations in pressure, these variations don't cause any kind of ionization. However, when exposed to large amount, ultrasound waves cause only local heating in the target object. Hence, ultrasound technology needs to be further developed so that the need of ionizing radiation-based imaging services can be reduced.

Figure 3.5: Radiation hazard warning (left) and Effect of ionizing and non-ionizing radiation on body (right)

3.2.2 Maintenance and cost

Other, but not the ignorable advantage of the ultrasound technology is that it is lest costlier than other technologies. Ultrasound technology employs piezoelectric crystals as the main driving elements which are way less expensive than the materials used to manufacture other sources like X-Ray tubes, those heavy magnets used in MRI scanners or the photomultiplier tubes. Also, maintenance and preparation before usage of other sources require either longer time or other expensive assembly e.g. Heating time for X-Ray Tubes, Helium Cooling for magnets, accurate calibration for photomultiplier tubes etc.

When it comes to the application of ultrasound technology in medical sciences for diagnostic purposes, clearly, due to the less expensive systems and less maintenance charges, ultrasound scans are way cheaper than other scans. Also, the print media needed to print the images is just a form of paper. Whereas other imaging techniques usually require special kind of print media like plastic films.

3.3. Applications

3.3.1 Security

The future prospects of this technology involve places where security plays a very crucial role like Airports, Railway stations and important places where a need to check objects thoroughly is a must. Ultrasound imaging systems for security purposes can be developed further that will replace the conventional X-Ray Scanners that are employed at security check-ins. These systems can impose a hazard to the public due to the harmful X-Ray radiation. Also, the radiation dose that the security staff has to bear needs to be reduced to a diminishing level. Placement of Ultrasound based systems at such places will prove to be better for both the public as well as the environment.

Figure 3. 6: A typical X-Ray based security scanner

3.3.2 Quality Control

Ultrasound Technology can find a good use in the quality check of products after they have been manufactured in factories. On configuring the system once, these devices can check for any manufacturing fault even at a very advanced level. We can check the product's internal structure without any need to dismantle the product. Use of this technology can make whole process of Quality Check automated and hence, will save a lot of time with satisfactory results. Since the product to be checked should possess some parameters as specified by the company or regulatory standards either fixed or flexible, these smart systems can adapt to both the fixed and flexible analysis.

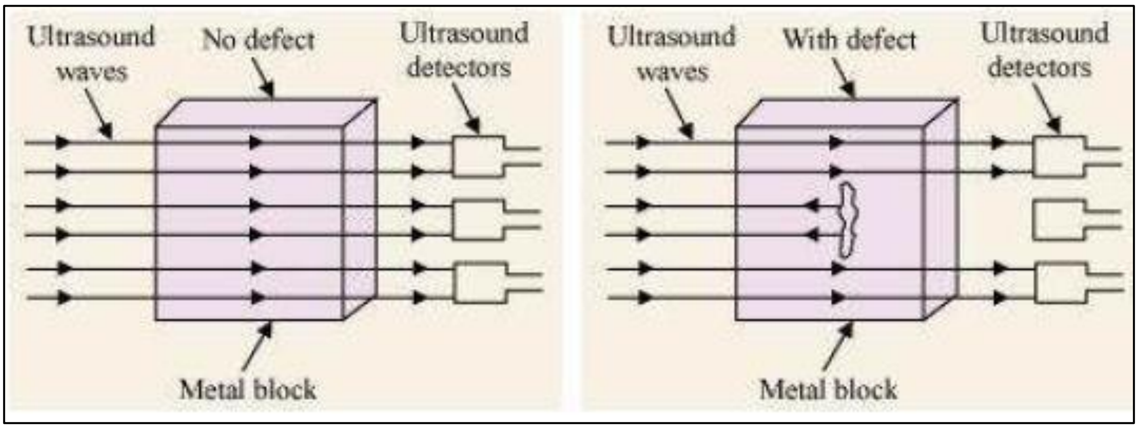


Figure 3.7: Reflection of ultrasonic waves due to defects present in an object

3.3.3 Medical

At present, Ultrasound technology is widely used in medical field and has been developed to a great extent where the results are well detailed and a scan can be done at much less cost. When Ultrasound is used for medical applications, it is generally referred as Diagnostic Sonography or Ultrasonography. Ultrasound technology has been proved to be very effective in the diagnosis of tissues, muscles, tendons, joints, blood vessels etc. Since the technique is based on ultrasonic waves, the risks and hazards involved are very low as compared to other imaging techniques. This technique is mostly preferred by the doctors unless a need for a specific diagnosis is required which cannot be done using ultrasound. Ultrasound Imaging does not require the patient to take any drug, injections or any cuts for the diagnosis which makes it safer for patients also.

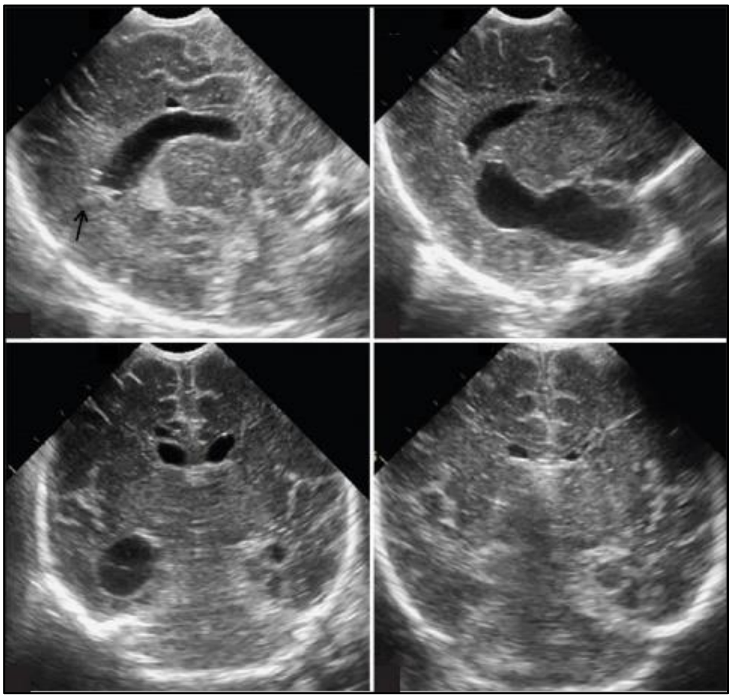


Figure 3.8: Results of a typical diagnostic ultrasound scan

3.3.4 Robotics in defence

The need for visualization of objects without making any actual contact with objects is increasing. Especially in defence applications where unattended objects can prove to be dangerous, there should exist a system for visualising these kinds of objects. As compared to other imaging technologies, ultrasound technology uses pressure waves which are less likely to alter the composition of the material under analysis.

Involvement of robots in more and dangerous tasks like detecting field mines, hidden bombs etc. is increasing due to the importance and need of manpower in defence organizations. Robots equipped with digital cameras will only aid in surface visualizations of unknown objects. Objects can’t be visualized at a deeper level using this technology. But employment of ultrasound-based scanners in such kind of robots will definitely help to a greater extent in the field of imaging and visualization in the defence.

Figure 3.9: An ordinary military robot used for spying purposes.

3.4 Block Diagram

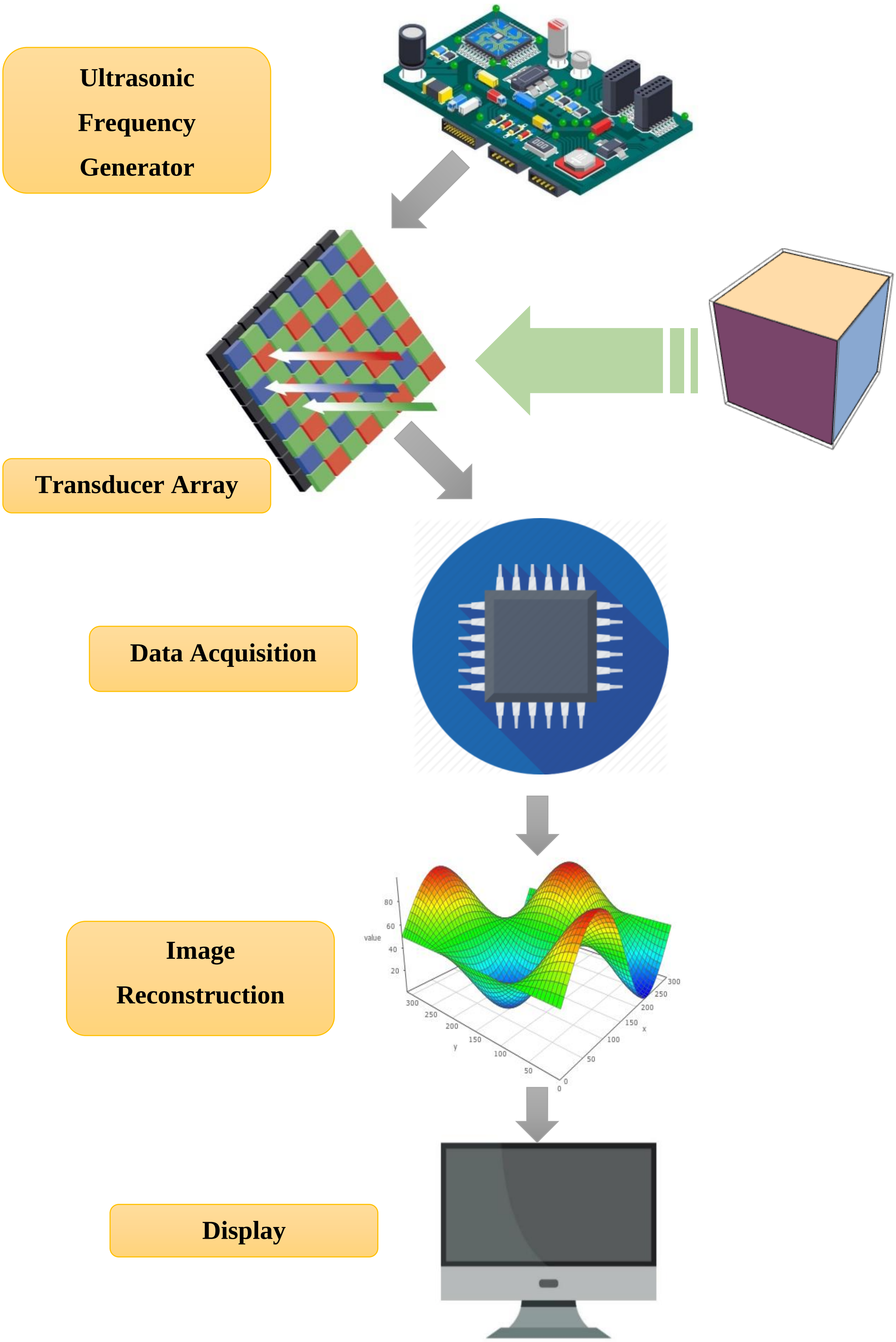


Figure 3.10: Block diagram of proposed ultrasound system

3.4.1 Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules include ultrasonic transmitters, receiver and control circuit. The basic principle of work:

(1) Using IO trigger for at least 10us high level signal,

(2) The Module automatically sends eight 40 kHz pulses and detects whether there is a pulse signal reflected back.

(3) In order to calculate the distance between the sensor and the object, the sensor measures the time it takes between the emission of the sound by the transmitter to its contact with the receiver. The formula for this calculation is **D = ½ T x C** (where D is the distance, T is the time, and C is the speed of sound ~ 343 meters/second). For example, if a scientist set up an ultrasonic sensor aimed at a box and it took 0.025 seconds for the sound to bounce back, the distance between the ultrasonic sensor and the box would be:

$$D = 0.5 \times 0.025 \times 343$$

or about 4.2875 meters.

Wire connecting direct as following:

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

Electrical Parameters:

Table 3.1: Electric parameter of Ultrasonic module

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
Measuring Angle	15 degree

Timing diagram:

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8-cycle burst of ultrasound at 40 kHz and raise its echo. The Echo signifies a distance to the object that is represented as pulse width in proportion with the range. You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: us / 58 = centimetres or us / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.

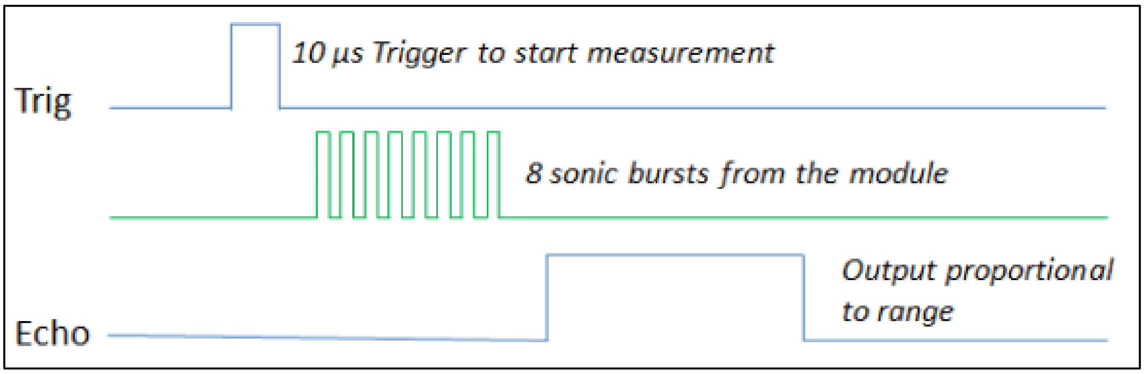


Figure 3.11 Timing Diagram for ultrasonic sensor

3.4.2 Processor Atmega-328p

The Atmel 8-bit AVR RISC-based microcontroller combines 32 KB ISP flash memory with read-while-write capabilities, 1 KB EEPROM, 2 KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit ADC converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts. The device achieves throughput approaching 1 MIPS per MHz .

Through pinout diagram we can understand the configurations of the pins of any electronic device, so you are working on any Engineering Project then you must first read the components' pinout.

Atmega 328 pinout diagram is shown in the figure given below.

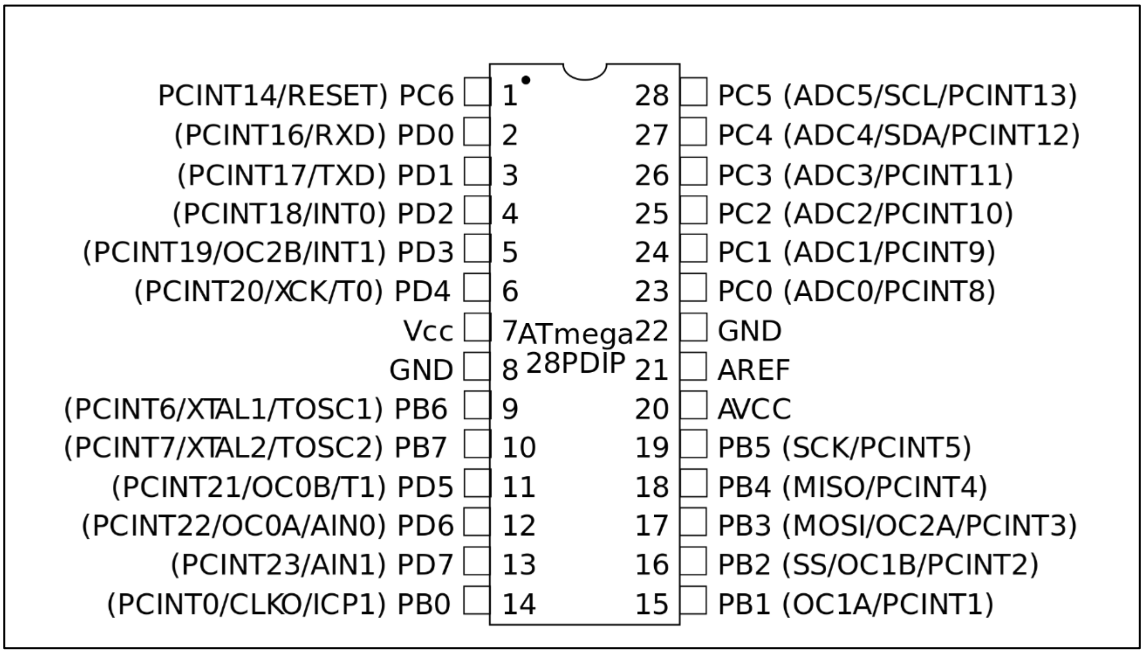


Figure 3.12: Atmega 328 Pinout

3.4.3 Data Acquisition

When making physical measurements such as temperature, strain, or pressure, you need a sensor to convert the physical property into an electrical signal, usually voltage. Then, the signal must be converted to the proper amplitude and filtered for noise before being digitized, displayed, stored, or used to make a decision. Data-acquisition systems use ADCs (analog-to-digital converters) to digitize the signals. Because sensors often produce low-level signals, they need some kind of signal conditioning to bring the voltage into the range of the ADC. That’s where signal conditioning comes in. Today, many data-acquisition systems include signal conditioning, often for many types of sensors.

DAQ hardware is what usually interfaces between the signal and a PC.[6] It could be in the form of modules that can be connected to the computer's ports (parallel, serial, USB, etc.) or cards connected to slots (S-100 bus, Apple Bus, ISA, MCA, PCI, PCI-E, etc.) in a PC motherboard or in a modular crate (CAMAC, NIM, VME). Sometimes adapters are needed, in which case an external breakout box can be used.

DAQ cards often contain multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a bus by a microcontroller, which can run small programs. A controller is more flexible than a hard-wired logic, yet cheaper than a CPU so that it is permissible to block it with simple polling loops. For example: Waiting for a trigger, starting the ADC, looking up the time, waiting for the ADC to finish, move value to RAM, switch multiplexer, get TTL input, let DAC proceed with voltage ramp.

Specialized DAQ software may be delivered with the DAQ hardware. Software tools used for building large-scale data acquisition systems include EPICS. Other programming environments that are used to build DAQ applications include ladder logic, Visual C++, Visual Basic, LabVIEW, and MATLAB.

3.4.4 Image-Reconstruction

Efficient and accurate image reconstruction algorithms are required to accurately produce images of the system property under investigation from the recorded ultrasound data. This paper presents a method of generating the image using a sparse data, the image is reconstructed from an interpolation of a series of line scans.

Interpolation works by using known data to estimate values at unknown points. Image interpolation works in two directions, and tries to achieve a best approximation of a pixel's intensity based on the values at surrounding pixels. Common interpolation algorithms can be grouped into two categories: adaptive and non-adaptive. Adaptive methods change depending on what they are interpolating, whereas non-adaptive methods treat all pixels equally. Non-adaptive algorithms include: nearest neighbour, bilinear, bicubic, spline, sinc, lanczos and others.

3.5 Flow Diagram of Sensor Array Signals

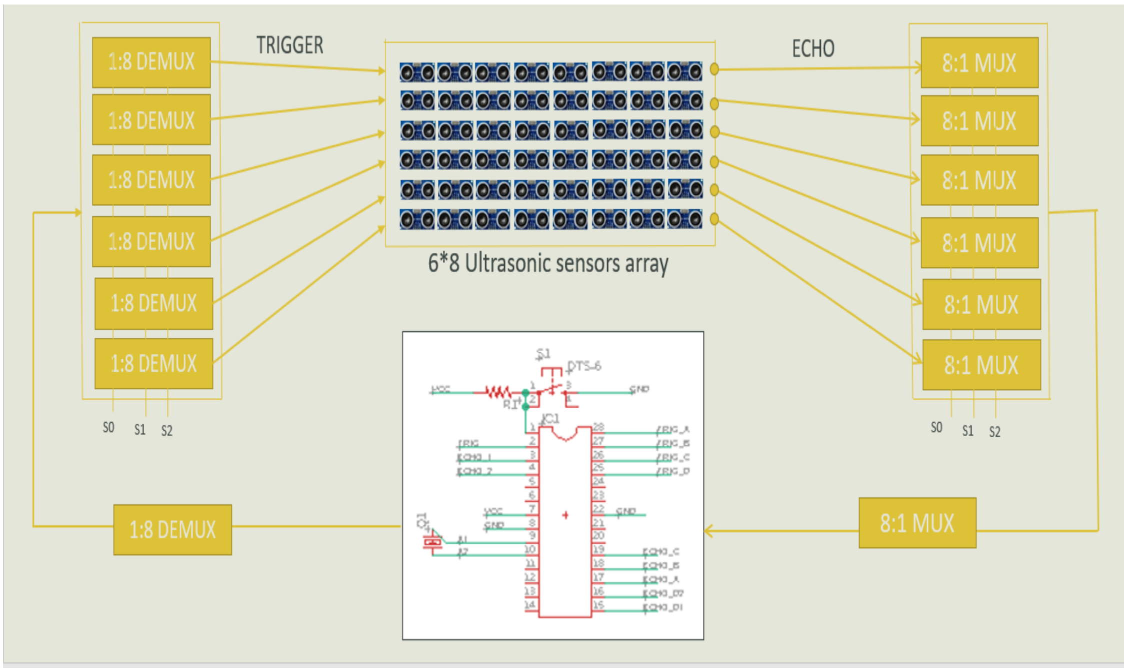


Figure 3.13: Flow diagram of Sensor Array Signals

1. As shown in the given flow chart diagram, the main CPU part will first send a trigger signal to all the ultrasonic sensor row-wise present in the array using 1:8 DEMUX. This will trigger all the Ultrasonic sensor present in the array to send sound waves on the object under observation.

2. After this process, when the sound waves sent by ultrasonic sensor comes back from the object under observation, they are sent to the CPU through 8:1 MUX connected row-wise to the Ultrasonic array.

3. After receiving the Echo data from the Ultrasonic array through MUX arrangement, the CPU processes the data and communicate it to the computer to which it is connected through Com-Port for Image reconstruction using MATLAB software.

As shown in the given figure, the sensor array signals flow with the help of multiplexing technique. Muxing (or) multiplexing can be defined as; it is a way of transmitting various signals over a media or single line. A common kind of multiplexing merges a number of low-speed signals to send over an only high-speed link, or it is used to transmit a medium as well as its link with the number of devices. It provides both privacy & Efficiency. The entire process can be done using a device namely MUX or multiplexer, and the main function of this device is to unite n-input lines for generating a single output line. Thus, MUX has many inputs & single output. A device is called DEMUX or demultiplexer is used at the receiving end which divides the signal into its component signals. So, it has single input and number of outputs.

8:1 MUX: An 8-to-1 multiplexer consists of eight data inputs I0 through I7, three input select lines S2 through S0 and a single output line Y. Depending on the select lines combinations, multiplexer decodes the inputs.

The truth table for an 8-to1 multiplexer is given below with eight combinations of inputs so as to generate each output corresponds to input.

For example, if S2= 0, S1=1 and S0=0 then the data output Y is equal to I2. Similarly, the data outputs I0 to I7 will be selected through the combinations of S2, S1 and S0 as shown in below table.

Table 3.2: Truth table of 8:1 MUX

Selection Inputs			Output
S_2	S_1	S_0	Y
0	0	0	I_0
0	0	1	I_1
0	1	0	I_2
0	1	1	I_3
1	0	0	I_4
1	0	1	I_5
1	1	0	I_6
1	1	1	I_7

1:8 DEMUX: A 1-to-8 demultiplexer consists of single input I, three select inputs S2, S1 and S0 and eight outputs from Y0 to Y7.

The truth table for this type of demultiplexer is shown below. The input D is connected with one of the eight outputs from Y0 to Y7 based on the select lines S2, S1 and S0.

For example, if S2S1S0=000, then the input I is connected to the output Y0 and so on.

Table 3.3: Truth table of 1:8 DEMUX

Selection Inputs			**Outputs**							
S_2	**S_1**	**S_0**	**Y_7**	**Y_6**	**Y_5**	**Y_4**	**Y_3**	**Y_2**	**Y_1**	**Y_0**
0	0	0	0	0	0	0	0	0	0	**I**
0	0	1	0	0	0	0	0	0	**I**	0
0	1	0	0	0	0	0	0	**I**	0	0
0	1	1	0	0	0	0	**I**	0	0	0
1	0	0	0	0	0	**I**	0	0	0	0
1	0	1	0	0	**I**	0	0	0	0	0
1	1	0	0	**I**	0	0	0	0	0	0
1	1	1	**I**	0	0	0	0	0	0	0

3.6 Schematics and PCB Designs of the proposed system

PCB Fabrication process:

1. Schematic Creation: Creating a Schematic of the circuits that are to be made into PCB using a SPICE (Simulation Program with Integrated Circuit Emphasis) Software. SPICE Software is a general-purpose, open-source analog electronic circuit simulator. It is a program used in integrated circuit and board-level design to check the integrity of circuit designs and to predict circuit behaviour.

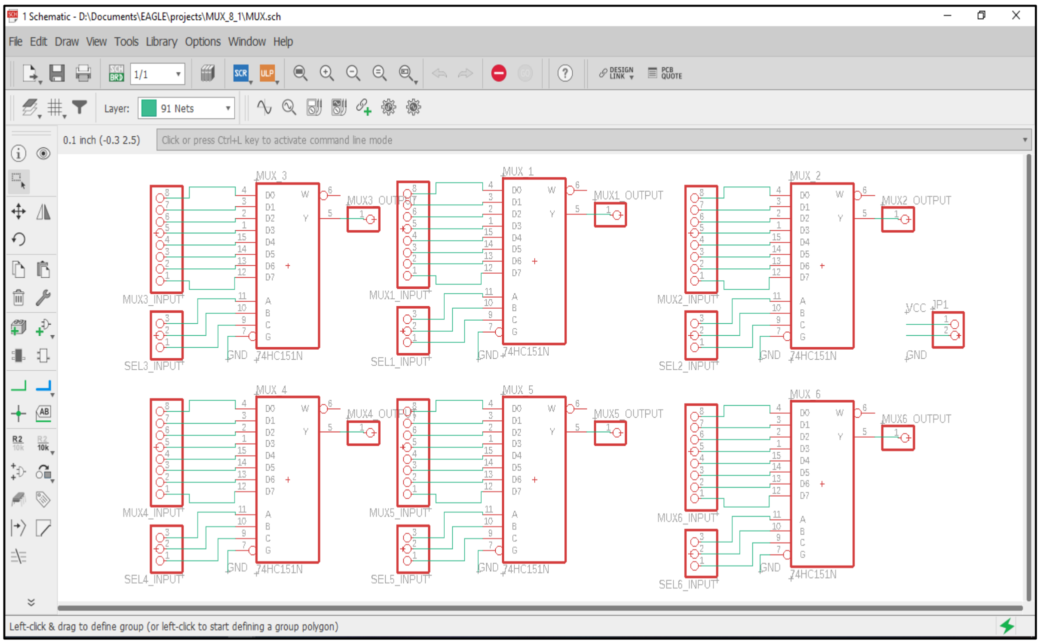


Figure 3.14: Schematics creation environment

2. PCB designing: Now using the Schematic Design created earlier, a PCB can be designed using a PCB designing software such as Auto-Desk Eagle that is used as shown in the image below. While placement of components one has to be careful to place them in such a way that their connections do not cross or touch each other which can cause a short circuit. The routing of the connections should reduce the complexity of the circuit. No components should touch each other as it will affect the process of placement of components.

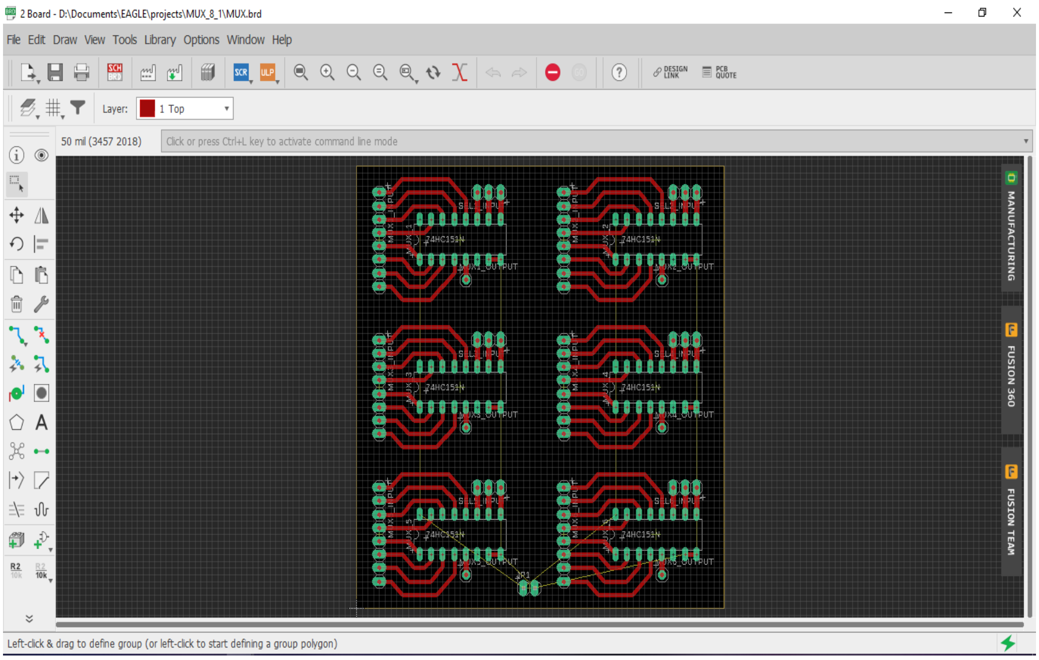


Figure 3.14: PCB designing Environment

3. Printing the PCB Design: The PCB design is then printed on a Photographic paper. To do so first the PCB design has to be exported to an image or document format which can be printed while no dimensions of the design are changed. Extra caution has to be taken to prevent the image from scaling while printing or else it will cause problem during further processes.

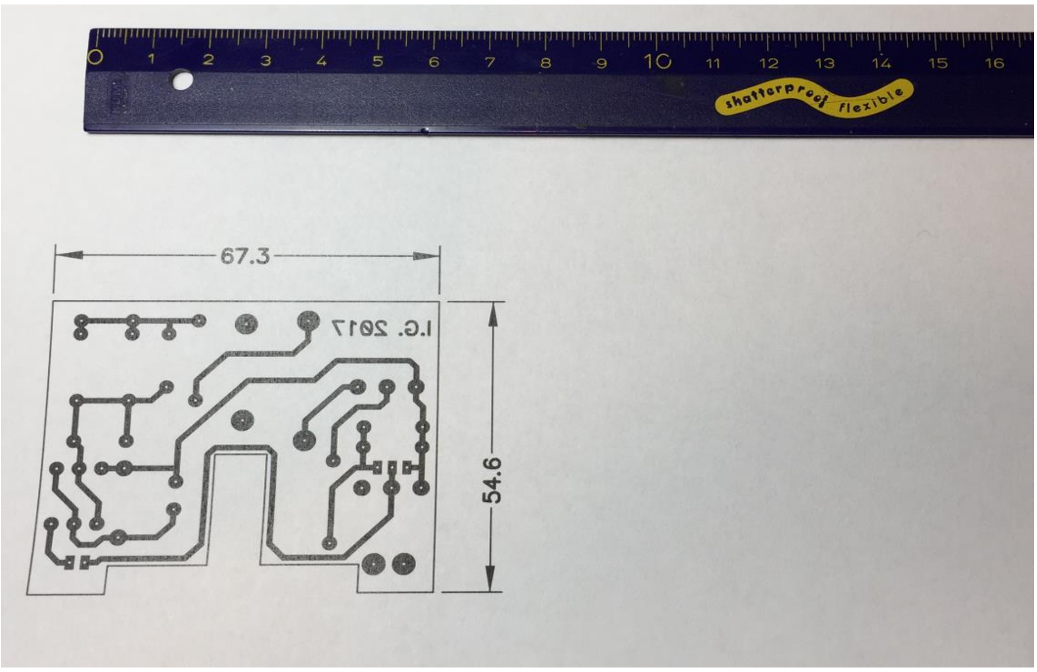


Figure 3.15: Print of PCB design

4. Printing the Design on Copper Board: After the PCB design is printed onto a piece of photographic paper, copper is then pre-bonded to that same piece of photographic paper, which serves as the structure for the PCB. This process can be done using multiple methods in the absence of proper tools or machines. For example, ironing the back side of photographic paper after its printed side is bonded with the surface of copper board. This method takes a little time and patience to get proper results. This method is not recommended for bigger or complex boards as uneven heating during the process can result in improper printing of design on copper board.

Figure 3.15: Printing of PCB design on copper board

5. Removal of unneeded copper: The next stage in the process is that of removing the unwanted copper. We used a $FeCl_3$ chemical solution also known as Ferric Chloride acid. It has to be handled carefully while wearing rubber gloves as the process involves dealings with an acid which can harm skin or cause injury if not handled properly. After dipping the board in the solution and stirring it using a tool or stirrer, the solution will remove all the unwanted and uncovered copper part by a chemical process known as Displacement reaction.

Figure 3.16: Removal of unneeded copper using FeCl3

6. Drilling holes for placement of components: After the PCB is dried and checked that no error is there during etching process, we proceed to the next step of drilling holes by matching it with the PCB design. A driller machine is required with the very small drill bits. This process is to be done with precision as slight error can either break the PCB or make the holes bigger than it was meant to. After the Drilling process comes the placement of all the components according to the PCB design. After placing the components at their right places it’s soldering is to be done using a solder machine.

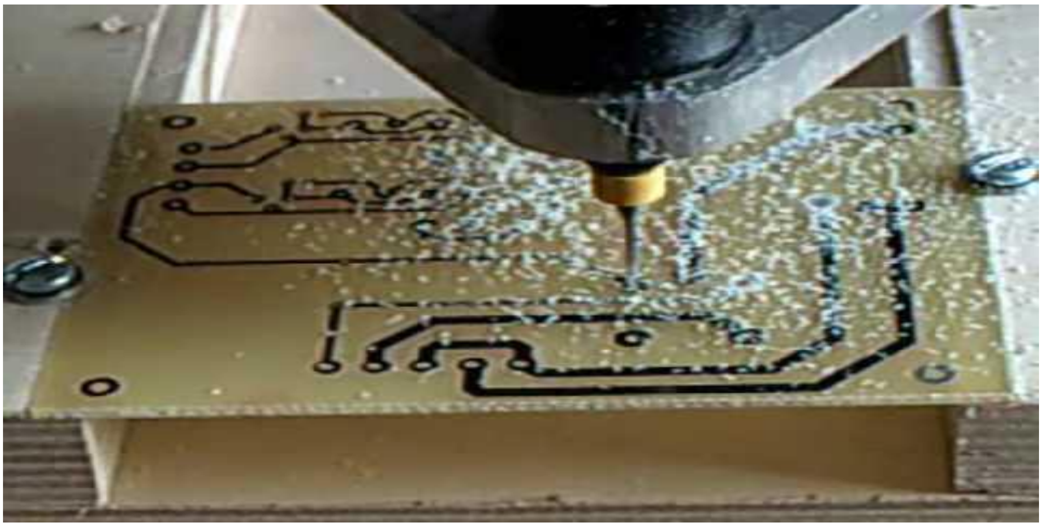


Figure 3.17: Drilling of holes for placement of components

7. Checking the PCB: The last process is to check the PCB that it is performing all the functions that were planned to be done using the PCB and the results match the planned data. Check that the soldering process is done properly and no components that are placed should be faulty.

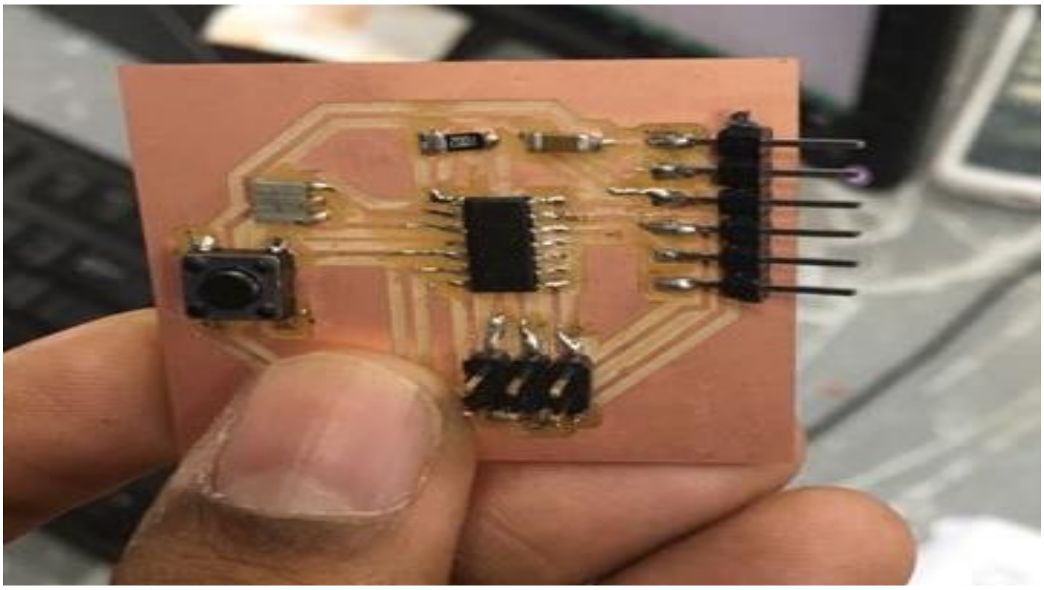


Figure 3.18: Checking of the PCB after soldering

Using the above-mentioned PCB Fabrication process, the schematics and PCB designs for the ultrasound -Imaging System are as follows:

1. Schematic design for re-routing Ultrasonic sensor signals to be connected with MUX and DEMUX units:

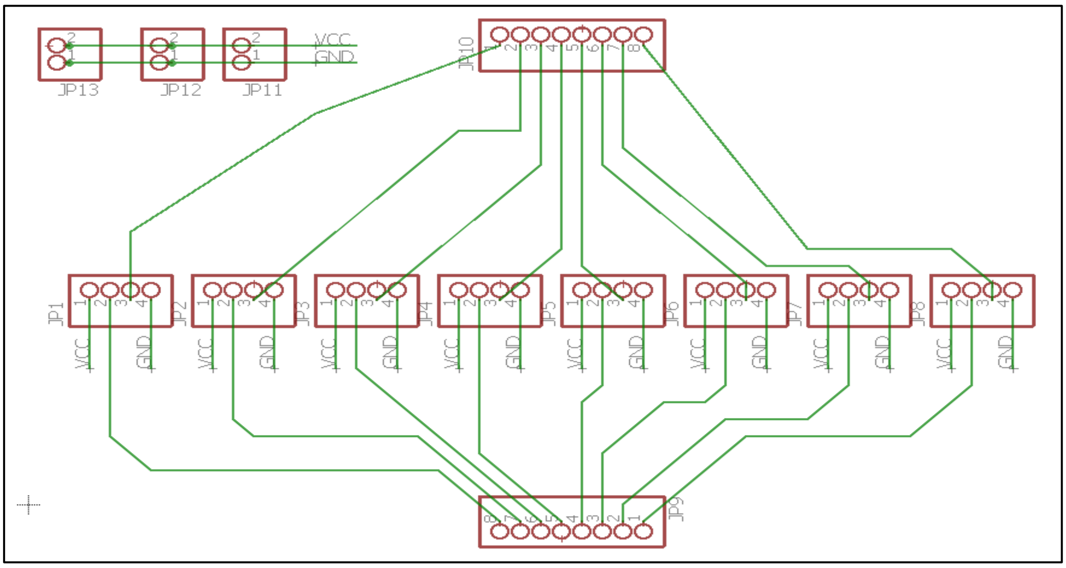


Figure 3.19: Schematic design of each row in ultrasonic sensor array along with MUX and DEMUX

2. PCB layout for re-routing Ultrasonic sensor signals to be connected with MUX and DEMUX units:

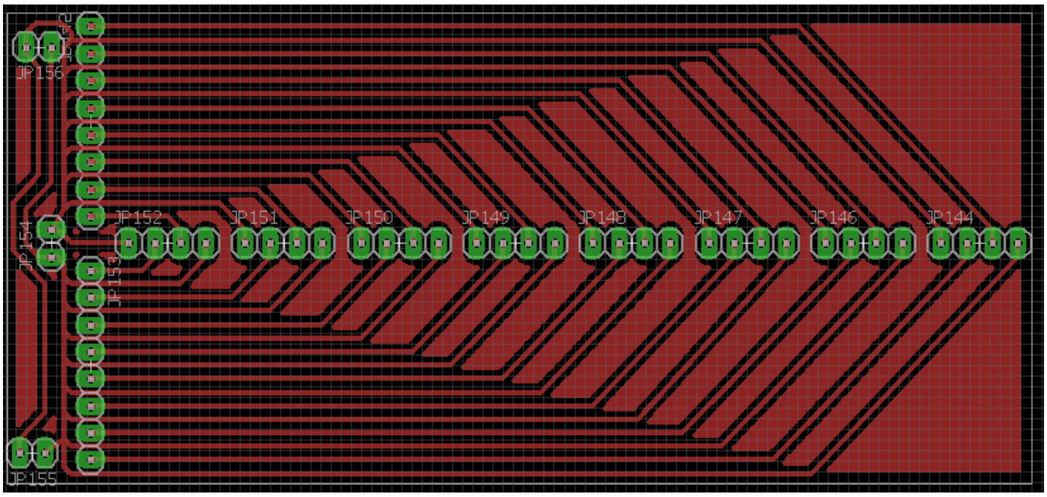


Figure 3.20: PCB design of each row in ultrasonic sensor array along with MUX and DEMUX

The CPU environment schematic of the proposed system is divided into multiple sections as given below. It should be noted that signals having common names across multiple schematics are logically connected. i.e. They represent the interconnections between multiple sections of the same CPU environment.

3. Demultiplexing block for Trigger Signals:

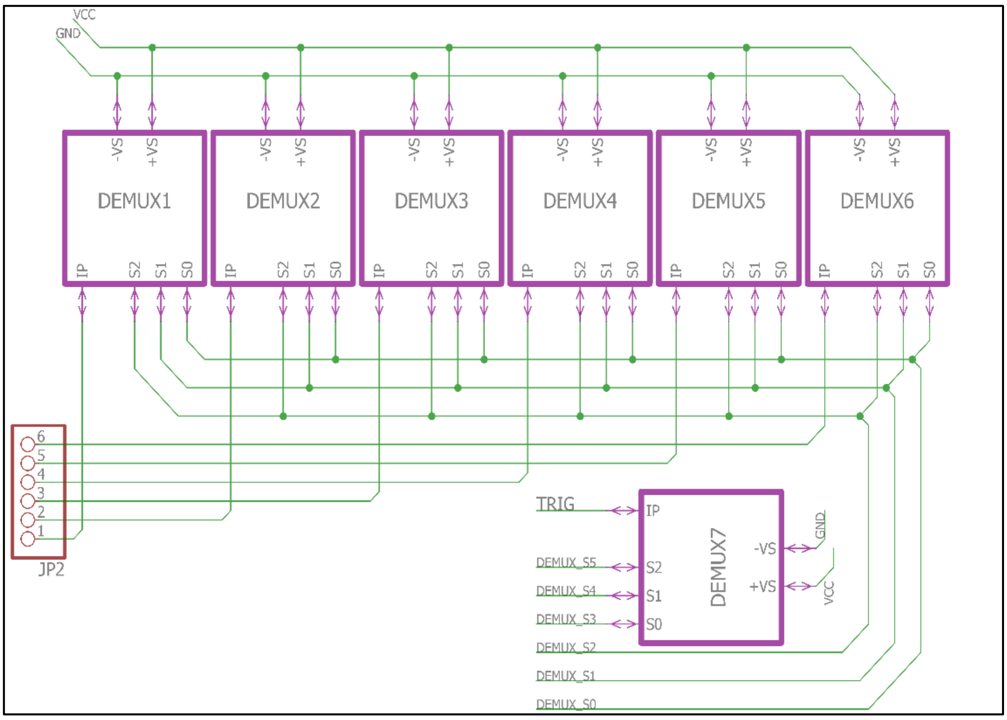


Figure 3.21: Demultiplexing blocks for Trigger Signals.

4. Multiplexing block for Trigger Signals:

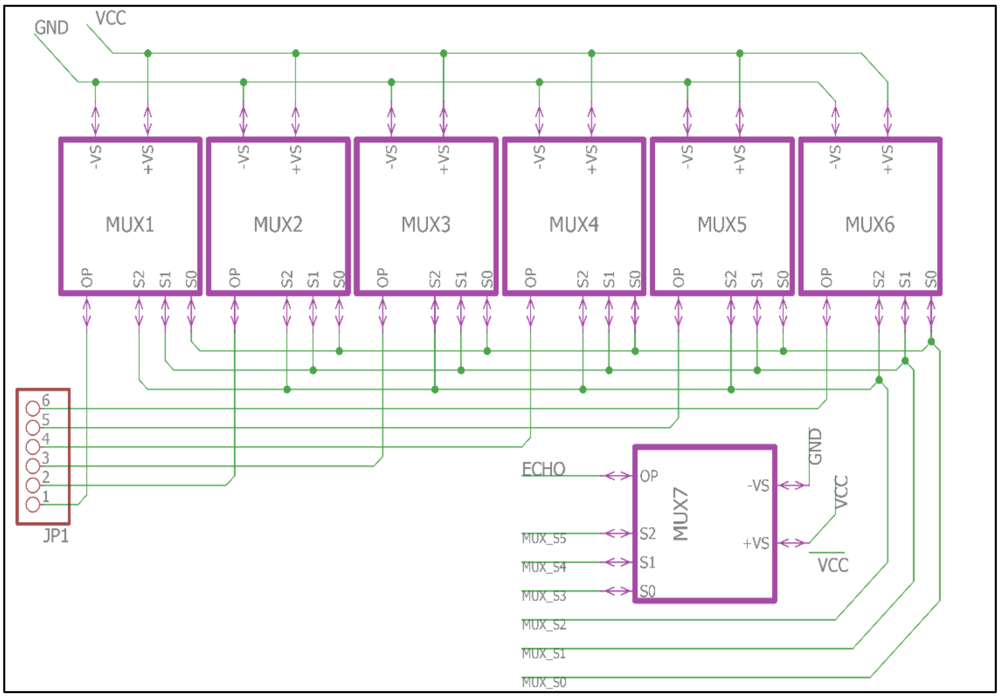


Figure 3.22: Multiplexing blocks for Trigger Signals.

5. Multiplexer and Demultiplexer modules used in the previous sections have their internal circuit connections as shown below:

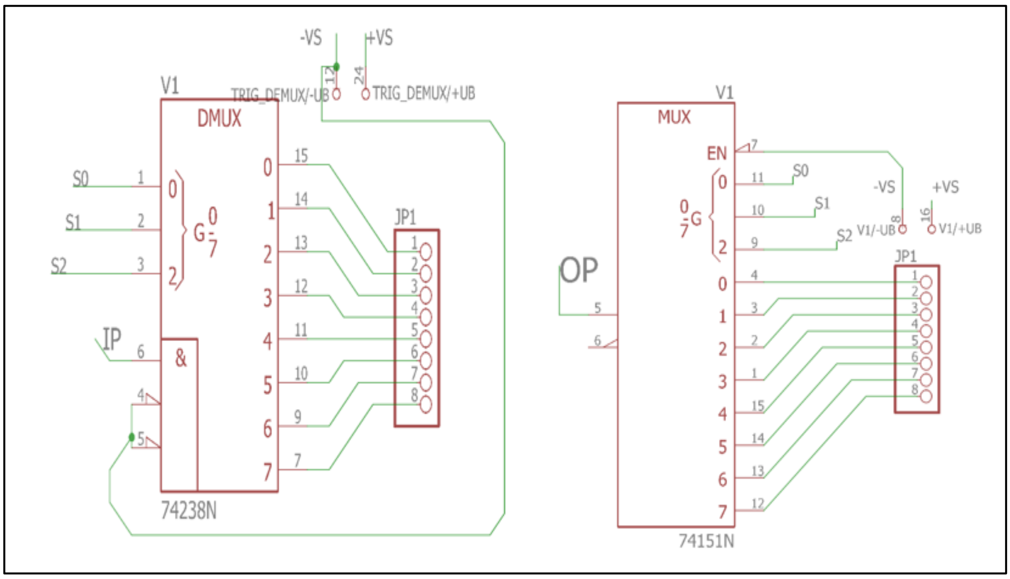


Figure 3.23: Multiplexer and Demultiplexer modules used in above schematics.

6. Main CPU Environment:

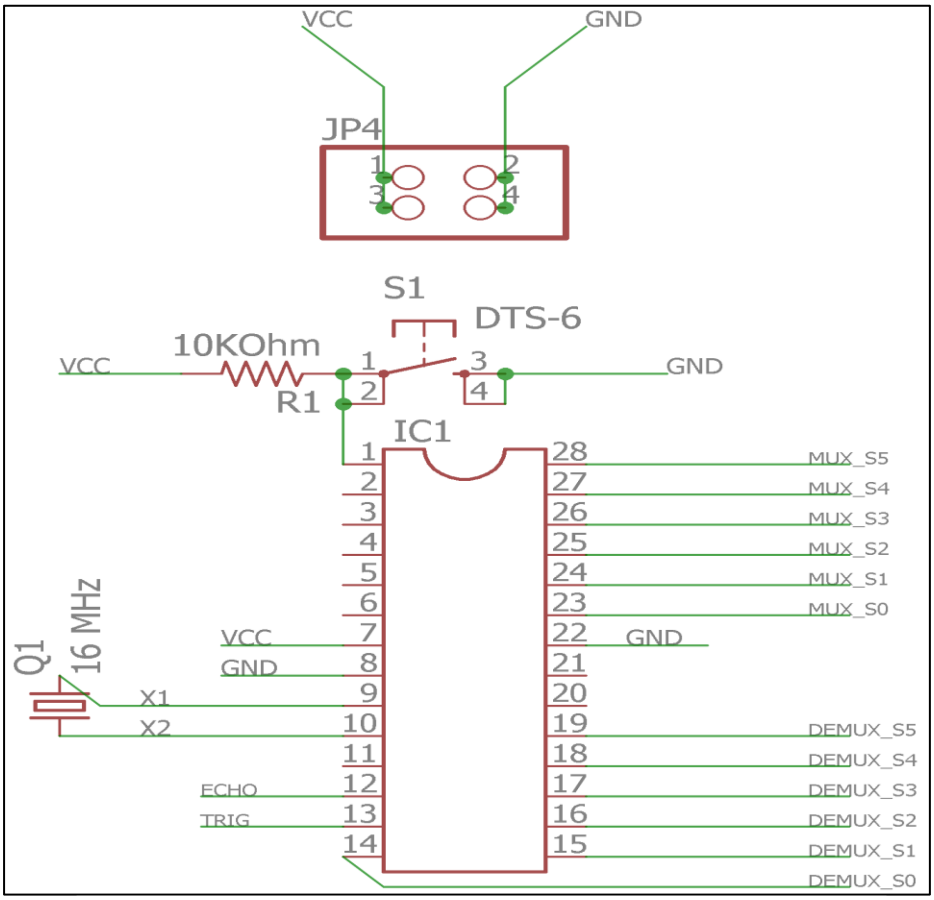


Figure 3.24: Main CPU Environment.

The components/parts being used in the design of hardware are listed in the below table with their specifications.

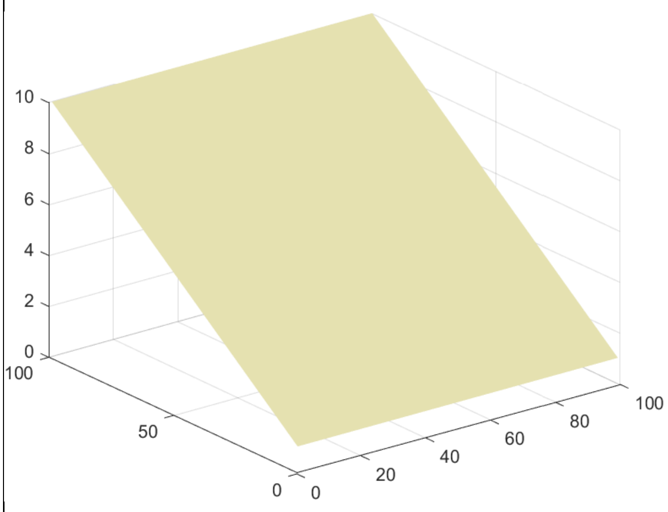
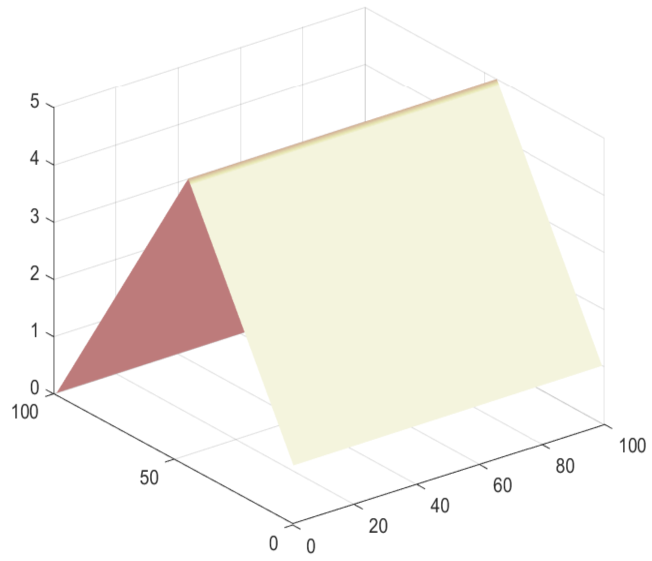
Table 3.4: Components used in the design of hardware

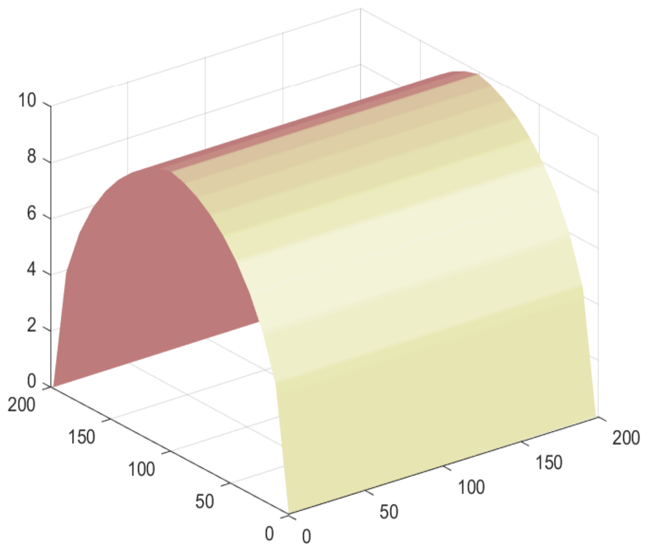
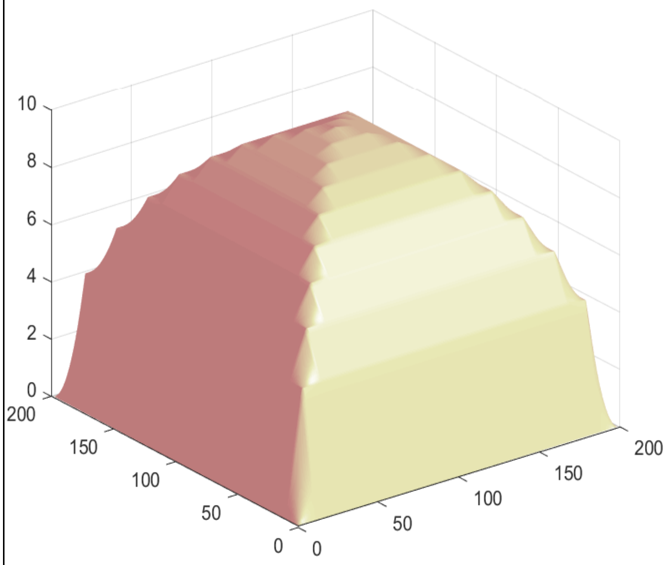
S. No	Description	Part Number
1	Microcontroller	ATMEGA328P
2	Ultrasonic Sensor	HC-SR04
3	Multiplexer- 8:1	IC74151
4	Demultiplexer- 8:1	IC74238
5	Power Supply 5VDC	
6	Resistor	10K Ohm
7	Quartz Crystal	16 MHz
8	Ceramic capacitors	22pF
9	Tactile switch	
10	Connecting wires	

CHAPTER 4: RESULT AND DISCUSSION

Example code output for different type of objects in MATLAB software:

Table 4.1: Exemplar Image-Reconstruction outputs

S.no.	Reconstructed image for different type of shapes	Description
1	 Figure 4.1: Inclined surface	Output image representation as generated for an object's surface tilted/inclined at a certain angle.
2	 Figure 4.2: Two surfaces forming an acute angle	Output image representation as generated for exterior of an object having two surfaces making an acute angle.

3	 Figure 4.3: Cylindrical object	Output image representation as generated for a cylindrical object.
4	 Figure 4.4: Spherical object	Output image representation as generated for a spherical object showing the upper hemispherical surface.

As expected, our algorithm generates the objects shape accurately using MATLAB Software.

MATLAB is a high-level language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical applications include:

- Mathematical computations
- Algorithmic development
- Modelling, simulation, and prototyping of mathematical/theoretical models.
- Data analysis, exploration, and visualization.
- Scientific and engineering graphics design and processing.
- Application development, including Graphical User Interface building.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of time. We can write programs in a scalar non-interactive language such as C or Fortran.

The structure of the proposed software design is as follows:

Input Type: Sensor array data in the matrix form used as the input for the image-reconstruction algorithm.

Image-Reconstruction: The basic principle applied for reconstruction is interpolation that works at a particular resolution. A variable named as 'res' in algorithm can be used to increase the resolution of image. All you need to do is to change the 'res' value for better results.

Output type: The surfl function displays a shaded surface based on a combination of ambient, diffuse, and specular lighting models.

surfl(Z) creates a surface and uses the column and row indices of the elements in Z as the *x*- and *y*-coordinates. It creates three-dimensional shaded surfaces using the default direction for the light source and the default lighting coefficients for the shading model. X, Y, and Z are vectors or matrices that define the *x*, *y*, and *z* components of a surface.

CHAPTER 5: CONCLUSIONS AND FURTHER WORK

5.1 Conclusions

In this thesis, we addressed the problem of using ionizing radiation in the field of medical imaging or security applications and proposed the use of non-ionizing radiation for object detection. One of the main contributions of our work is to eliminate the ionizing radiation technology, that is not good for human body and to propose methods to solve it based on sound waves (non-ionizing radiation), high speed acquisition scanning and 3-D Image-reconstruction. First an array of ultrasonic sensors and a main processing unit has been designed, and second the data acquisition based on transmission, reflection and reception has been performed. The main focus of our thesis was on the optimization itself. Finally, another contribution based on an Image-Reconstruction algorithm was introduced for displaying 3-D image. The idea behind the used algorithm was to convert the input data array into the high-resolution reconstructed image. Our contribution in this part was to create and implement the above said 3-D image-reconstruction algorithm. This contribution allows now to plot high resolution 3-D graphs. This experiment was performed for the acquisition of different type of shape of objects. For e.g. tilted surface, inclined surfaces, cylindrical object, spherical objects etc. Results show that our approach obtains better results

5.2 Further work

Many different adaptations, tests, and experiments have been left for the future due to lack of time. Future work concerns deeper analysis of particular mechanisms, new proposals to try different methods, or simply curiosity. The following ideas can be tested:

1. It could be interesting to test the experiment on different frequencies and consider data images with different importance, depending on their size or their specific meaning with respect to the recognition process which can be accomplished with the use of convolutional neural network algorithms.

2. The way the model is constructed could be also changed: instead of using one typical image (prototype), it could be based on different images, in order to provide some information on the variability among the different images, and introduce it in the attributes. Unfortunately, in the type of images that we have taken as real examples the

construction of a model from each image is a tedious task and no further study in this direction could be performed. Image-Reconstruction algorithm has been applied to fixed angle acquisition, but not for the multi-angle acquisition (360-degree FOV) and such a mechanism could help to improve object detection technology by having richer graphs, with more attributes.

3. Regarding the more data acquisition speed, an extension for the near future is the use of more powerful processor in order to improve the processing speed.

APPENDICES

Image Reconstruction Code: The following code is divided into multiple segments, each playing a different role.

- The first segment takes raw input data in the form of a 2D vector and stores it in a variable named as ‘d’.
- The second segment creates a new 2D matrix herein referred to as ‘canvas’ having the size of the required output image that can be calculated using the dimensions of the input data along with the “res” value at which the image reconstruction is working.
- The third segment places the raw input data in newly created ‘canvas’ by placing consecutive samples sparsely having blank spaces in between them. The number of blank spaces between two consecutive samples is configured using the same ‘res’ variable that defines the resolution at which the image reconstruction code is working.
- The fourth segment of the code is an iterative algorithm that fills up the blank spaces (created previously) between consecutive samples. The data to be placed in these blank spaces can be calculated using mathematical models of straight lines, curved lines, planes and solids. However, here, we have used the model of straight lines. Hence this segment traverses the ‘canvas’ row-wise and fills up the blank spaces in each row by placing collinear coordinates respective to the consecutive samples.
- The fifth segment works the same way as the fourth segment. The only difference is that it traverses the ‘canvas’ column-wise filling the blank spaces. At the end of this algorithm, the canvas array is completely filled with values that represent the output image.
- The sixth segment displays the generated output data in the form of a 3D plot. The position of data in the ‘canvas’ represents the x-y coordinate and the numeric value of the data represents the z coordinate. Hence, as a result, a high-resolution image of the 3D plot is displayed on the monitor.

```
clc;
close all;
clear all;
 %First segment
```

```
%Take input data and display it
d=input('Enter values of matrix: \n');
disp(d);
s=size(d);
fprintf('\n Dimensions of your data: %drows %dcolumns\n \n',s(1),s(2));

%Second segment
%Blank points
res=10;
disp(res);

%Creating a blank canvas array for image storage
disp(s(1)+res*(s(1)-1));
disp(s(2)+res*(s(2)-1));
z=zeros(s(1)+res*(s(1)-1) ,s(2)+res*(s(2)-1));
% disp(z);

%Third segment
%Saving raw acquired data into blank canvas array
m = 1;
n = 1;
for ( i = 1 : s(1) )
   for ( j = 1 : s(2) )
        z(m,n) = d(i,j);
        n = n + res + 1;
   end
   n=1;
   m = m + res + 1;
end

%Display message
fprintf('\n Blank space created \n');
% disp(z);
```

```
%Fourth Segment
%Reconstruction code working row-wise
 for ( i = 1 : s(1))
     m=1;
    roff = (i-1)*res + i;
    for ( j = 1 : (s(2) - 1) )
        ip = z(roff,m);
        m = m + res + 1;
        fp = z(roff,m);
        slo=(fp - ip)/(res + 1);
        coff=(j-1)*res+j;
        for ( k = 1 : res )
            val= slo*k + ip;
            z(roff ,k+coff)=val;
        end
 end
% disp(z);

%Fifth segment
%Reconstruction code working column-wise
zsize=size(z);
 for ( i = 1 : zsize(2) )
     m=1;
    for ( j = 1 : (s(1) - 1) )
        ip = z(m,i);
        m = m + res + 1;
        fp = z(m,i);
        slo=(fp - ip)/(res + 1);
        roff=(j-1)*res+j;
        for ( k = 1 : res )
            val= slo*k + ip;
            z(k + roff ,i)=val;
        end
```

```
 end

%Sixth segment
% disp(z);
surfl(z)
colormap(pink) % change color map
shading interp    % interpolate colors across lines and faces
```

Serial Communication Code: This code segment helps the imaging terminal to interact with the proposed data acquisition system to gather input data which is then transferred to the image reconstruction algorithm to further process the image.

- The interaction is performed by communicating with the data acquisition system using a serial connection. The serial connection being used follows the Universal Asynchronous Receiver Transmitter (UART).
- Both the sides perform a virtual handshaking that help them to identify each other. The handshaking can also be implemented to using different kinds of passwords that can be authenticated by the terminals to enhance security.
- Following the handshaking procedure, the data is transferred in the form of blocks. Each block representing a frame/array of raw input data acquired from the sensors.
- Then each received block, represented as an array, is forwarded to the image reconstruction code.
- As an initialising procedure, the code creates a new Serial object named as ‘atmega’ being connected to the physical COM port of our imaging terminal.
- The port is then opened which indicated to other programs that the particular port is already in use by the imaging terminal. After completion of data transfer, the port should always be released/closed.
- Then the properties of the recently created ‘atmega’ object are displayed on the screen. The properties of the serial object can be COM port number, name of object, baud rate being used, different protocol parameters like even/odd/no parity, 7bit/8bit data.

```
%Serial communication code
user = input ('Enter 7 to connect to Data acquisition system:');
```

```
if (user == 7)
    atmega=serial('COM13');
    disp(atmega);
    fopen(atmega);
    disp(atmega);
    write(atmega,48,'uint8');
     pause(0.5);
     fprintf(atmega, ‘Hello');
     pause(0.5);
     tline = fgets(atmega);
     disp(tline);
     for(k=1:s(2))
            d(k)=fread (atmega, s (1));
     end
     disp(d);
    fclose(atmega);
    disp(atmega);
end
```

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