Ministry of Education and Science of the Russian Federation
National Research Tomsk Polytechnic University

Research School of Chemistry & Applied Biomedical Sciences
Biomedical Sciences and Engineering

Master Thesis

Title
Digital Signal Processing of Acoustic Array **Цифровая обработка сигналов акустической решетки**

УДК: 620.179.16:621.372.037

Student

Group	**Name**	**Signature**	**Date**
1DM6I	Pallippat Clinton Charly		

Scientific Supervisor

Position	**Name**	**Education**	**Signature**	**Date**
Associate Professor	Alexey I. Soldatov	PhD		

Consultant
Financial management, resource efficiency and resource saving

Position	**Name**	**Education**	**Signature**	**Date**
Associate Professor	Artem Dankov	PhD		

Social Responsibility

Position	**Name**	**Education**	**Signature**	**Date**
Associate Professor	Yulia V. Anishchenko	PhD		

Admit Thesis for Defense

Position	**Name**	**Education**	**Signature**	**Date**
Master program supervisor	Fedor A. Gubarev	PhD		
Head of R.S.C.H.B.	Mekhman Yusubov	Doctor of Science		

APPROVED:
Head of the School & Master supervisor

________ _________ Mekhman Yusubov

Document

Master Thesis

Student

Group	**Name**
1DM6I	Pallippat Clinton Charly

Title

Digital Signal Processing of Acoustic Array	
Director approval order	
Date of Submission	

Major Information	1. Abstract 2. Introduction 3. Assessment of algorithm 4. Trails and Results
Content	1. Abstract 2. Introduction 3. Literature Review 4. Theory 5. Principle of Operation 6. Algorithm and trails

	7. Experimental setup 8. Financial Management and Resource Efficiency 9. Social Responsibility 10. References
Assigned Date	

Task assigned by

Position	Name	Education	Signature

1. Abstract

Digital signal processing of an acoustic array is very useful in the field of non-destructive testing of various medical instruments and other industrial applications. Total Focusing Method (TFM) is used to detect the deformities and it requires the data acquisition of time domain signals by using an ultrasonic array.

This data acquisition process is done with the help of software's as it usually involves very large amount of processing to obtain the desired amount of data for various position of the acoustic array. A 16x1 and 32x1 acoustic array is studied and the data acquisition along with its processing is discussed and performed with the help of MatLab software. Then the array is used to detect deformities such as holes in a welded metal block. The image reconstruction is done in matlab with an algorithm and is studied which displays the deformities present in the given sample.

2. Introduction

Qualitative analysis of the instruments used in various industrial and medical fields by non-invasive methods has been recently increasing in popularity. The main method used is the Phased Array (PA) technique. The main advantages of this method over other conventional means is that with the application of acoustic beams, the inspection process can be performed rapidly and is easy to understand thus reducing the operational training required to get used with the system. Also the deformities can be easily detected and viewed directly and evaluated immediately,

It is also possible to create a 3D image with the flaws present in interior parts of the sample and can be viewed and analyzed easily. Different methods of inspection can be achieved by simply changing the acoustic wave parameters. All these merits makes the Phased Array technique to have more advantage over other conventional methods.

The type of data capture technique determines the method of phased array technique used, full matrix capture is the method of data capture technique used in this project. A clear interior image of the specimen can only be formed when the acoustic waves are focused to a focal point. Appropriate time delays should be introduced so that each element of the array pulses at different time to focus the waves towards a point.

Various literature studies showed that the total focusing method (TFM) which uses full matrix capture has the highest array performance due to superior focusing. This method also can be used to generate high quality images with greater contrast and improved resolution for higher sensitivity.

However the data processing involved to obtain such high quality images is a tedious process and involves in very large amount of calculations depending on the size of the acoustic array. The data acquisition and signal processing involved with the TFM technique is the important aspect of this paper. The usage of matlab to perform the data processing part of the ultrasonic array is stressed and its advantages over other methods of data processing is discussed.

3. Literature Review

3.1 “Full Matrix Capture and the Total Focusing Imaging Algorithm using Laser Induced Ultrasonic Phased Arrays”, Theodosia Stratoudaki, Matt Clark and Paul D. Wilcox.

Laser ultrasonics is a technique in which a laser is used to generate and detect ultrasound instead of the standard piezoelectric transducers. The technique is a non-contact and free process that is compatible for inspection of components of complex shape and hard to reach environments. Full matrix method (FMC) is the method adapted for laser image capture, it captures all the laser generations and the Total Focusing Method (TFM) is applied to the captured data which focuses each point of the reconstruction area. The beam forming of the ultrasound is done at post processing. In this paper the shear waves that are obtained is used for imaging, since they are more efficiently produced when compared to the longitudinal waves. The results were presented by using this method with the help of aluminum block with few side drilled holes at depths varying between 5 and 20mm from the surface.

3.2 “Demonstration of Application of Total Focusing Method in the Inspection of Steel Welds”, Matthias Jobst and George D. Connolly.

Phased array technique offers many advantages over other conventional methods involving single element probes in the field of non-destructive testing for industrial applications. In this paper the comparison of two methods for inspection involving phased array namely, the swept sector scan and the total focusing method is discussed. Total focusing method needs data acquisitions of signals in the time domain from all combinations of the used ultrasonic array and then computation of time delay laws which allows focusing at the post-processing stage. It can be done by two different methods namely, the common source method and the synthetic aperture focusing method. These two types are discussed and their usage in weld inspections are studied. Various images were obtained from experiments involving an aluminum block with holes and industrial weld samples containing various defects were studied and analyzed.

3.3 "Development and Validation of a Full Matrix Capture solution", Patrick Tremblay, Daniel Richard, ZETEC, Canada.

Phased array technique has completely changed the process of ultrasonic non-destructive testing in the past decade. It is now widely adopted in the field of components in aerospace, oil & gas, heavy industry and power generation plants due to its high efficient inspections and precision. The Full Matrix Capture (FMC) technique is one of the important application of the phased array technology. It consists of the capture and storage of all possible A-Scans from every elements in the acoustic array. All of these raw information's are available to generate the data resulting for any given beam through off-line processing. This paper deals with the different challenges that were faced to achieve an efficient FMC data collection shows the data processing capabilities that the technique has to offer, also the different features of hardware and software that were used was discussed which highlighted the benefits of an enhanced performance on the FMC.

3.4 "Full-Matrix Capture with a Customizable Phased Array Instrument", Gavin Dao, Dominique Braconnier and Matt Gruber.

In recent years, the Full-Matrix Capture (FMC) techniques has gained headway in the field of Non Destructive Testing community for phased array applications. It is important to understand that FMC which acquires the ultrasonic signals, but further post processing of the acquired data is necessary with the help of software to generate an image for that particular application. With the help of a flexible software and excellent signal to noise ratio for each acquisition channel on a 64x64 or 128x128 phased array transducer with FMC helps in both industrial and also for further study of post processing techniques. This paper provided an example of imaging using the FMC technique with a 5MHz PA transducer having 128 elements and is post processed with the help of Total-Focus Method (TFM) algorithm.

3.5 "Fast total focusing method for ultrasonic imaging", Ewen Carcreff, Gavin Dao and Dominique Braconnier.

This paper deals with modern fast-imaging techniques using phased array probes for NDE evaluation. This method uses a large amount of summations in order to achieve focus at every pixel in the reconstructed image. Two methods that improve the speed of this summation was discussed and they are as follows GPU computation and Migration approach. GPU computing mainly uses large parallel computation whereas the migration approach uses the wavenumber domain and results in the improvement of image quality. The two methods were demonstrated along with experimental data captured from an aluminum block containing artificial defects.

3.6 "Fast total focusing method for ultrasonic imaging", Ewen Carcre, Gavin Dao and Dominique Braconnier.

SAFT and TFM are the most popular tools that are used widely in the field of ultrasonic non-destructive testing. They are used for the detection and characterization of any cracks or holes in an object. A large set of data is acquired with the help of a transducer array and are used for the reconstructing an image of the inspected object by summations. In this paper the standard technique and a migration approach is comparatively studied. With the help of experimental data, it was proved that the developed approach is faster had a better signal to noise ratio than the standard TFM. The migration method was very effective for near surface imaging where TFM used to fail, but the migration approach can only be adapted to layered objects whereas TFM can be used for complex geometries.

3.7 "Adaptive Ultrasonic Imaging with the Total Focusing Method for Inspection of Complex Components Immersed in Water", L. Le Jeune , S. Robert , P. Dumas, A. Membre and C. Prada.

This paper deals with an ultrasonic imaging method based on the phased array technology and TFM. The main objective was to image the surface by applying TFM algorithm in a water medium and to reconstruct the surface. A second TFM is taken inside the component. The TFM algorithm was optimized to decrease computation time and to reduce noises. The ultrasonic paths through the surface were found by the Fermat's principle along with an iterative algorithm and then TFM is applied which gives an internal image of the component. This paper shows different results of TFM in components of different geometries and result were obtained.

3.8 "Ultrasound Non-destructive Evaluation (NDE) Imaging with Transducer Arrays and Adaptive Processing", Minghui Li and Gordon Hayward.

This paper discusses the problems involved with ultrasonic NDE imaging with transducer arrays. Commonly evaluated materials in NDE applications, like stainless steel, concrete, and reinforced composites which are used in industries and other applications have heterogeneous internal structure. During the inspection of these materials by using ultrasound, the signals from the original defects are corrupted due to the echoes formed randomly and is scattered, even the defects that is larger than these random reflections are very hard to distinguish with the normal delay and sum operation. An adaptive beam-forming is used to the received data and the noises can be reduced. Beam-forming appropriately weights each element delayed data samples before the summation process.

These weights are obtained from the statistical analysis of the data samples. This weight and sum process is similar to applying a lateral spatial filter to the signals. It was shown that the noises were reduced by more than 30 dB and resolution was enhanced when adaptive beam-forming was applied. A steel block consisting of holes was used as a sample and the simulation results is demonstrated and found to be much better.

3.9 "Practical Application of Total Focusing for Sizing of Imperfections in Welded Joints", Michael Berke, Stefan Koralewski, Werner Roye, Laurent le Ber, Ulrich Kaps.

Sampling Phased Array which can also be called as TFM has be studied for about 10 years. This method uses FMC ultrasonic data that is transmitted and received from a large number of incidence points of the array probe. Due to this the resultant image is of very high resolution. Portable flaw detectors can be easily assembled that makes use of this signal processing method. In this paper this method was applied for imaging welded joints.

The main goal was to achieve a reproduced image of imperfections along with data evaluation of the obtained data by using an analysis software. The practical results that were obtained from the welded joints consisting of flaws using Phased Array was compared to Sampling Phased Array scans and an alternative to standard echo amplitude evaluation was discussed.

3.10 "Progress and Challenges of Ultrasonic Testing for Stress in Remanufacturing Laser Cladding Coating", Xiao-Ling Yan, Shi-Yun Dong, Bin-Shi Xu and Yong Cao.

This paper deals with the ultrasonic testing for stress that appears during the remanufacturing of laser cladding coating. It discusses about the active mechanisms that are involved in the non-destructive testing of laser claddings. The method used here is the relationship between the ultrasound velocity and stress on the surface of the laser cladding. A stress measurement system was made which compared the Rayleigh wave velocity and stress and was computed with a data acquisition and data processing device. The method of data acquisition and data processing was studied which was the time domain analysis and sampling of the ultrasound waves and was applied for the project.

<u>Conclusion:</u>

Thus from the above literature reviews, The various types of NDT testing methods was studied and the method chosen for this project was total focusing method and full matrix capture techniques since they gave better results when compared to other methods. The algorithm for the project was also created with the help of some literatures on matlab and full matrix capture technique.

4. Theory:

Phased array (PA) is an advanced technique of ultrasonic testing which is commonly used in industrial non-destructive testing and in the medical field. The most important application of this technique is to non-invasively examine internal organs such as heart (Medical Application) or to find deformities in manufactured items such as welds (Industrial Application). Single element probes can only emit a beam in fixed direction, but in order to test or analyze a large volume of material, a conventional probe must be used which allows the beam to sweep through the area of interest.

In phased array probes, the beam can be focused and swept without moving the probe by electronic means also it is controllable since they are made up of multiple small elements, and they can be pulsed individually by with the help of delay time. Thus the term phased stands for timing, and array refers to multiple elements. This technique of testing is based on the principles of wave physics. To test or interrogate a large volume of material, a conventional probe must be physically scanned (moved or turned) to sweep the beam through the area of interest. In contrast, the beam from a phased array probe can be focused and swept electronically without moving the probe.

The beam is controllable because a phased array probe is made up of multiple small elements, each of which can be pulsed individually at a computer-calculated timing. The term phased refers to the timing, and the term array refers to the multiple elements. Phased array ultrasonic testing is based on principles of wave physics, which also have applications in fields such as optics and electromagnetic antennae.

The high-frequency sound waves used for flaw detection and thickness gaging in ultrasonic nondestructive testing applications are generated and received by small probes called ultrasonic transducers. Transducers are the starting point for any ultrasonic test setup, and they come in a wide variety of frequencies, sizes, and case styles to meet inspection needs ranging from flaw detection in enormous multi-ton steel forgings to thickness measurement of paper-thin coatings.

4.1 Ultrasonic Transducers

A transducer is generally defined as any device that converts one form of energy into another. The subject of this paper is the ultrasonic transducers used for thickness gaging and conventional flaw detection. Phased array probes that utilize multiple elements to generate steered sound beams.

In ultrasonic NDT, transducers convert a pulse of electrical energy from the test instrument into mechanical energy in the form of elastic waves that travel through the test piece. Elastic waves reflecting from the test piece are, in turn, converted by the transducer into a pulse of electrical energy that can be processed and displayed by the test instrument. In effect, the transducer acts as an ultrasonic speaker and microphone, generating and receiving pulses of elastic waves at frequencies much higher than the range of human hearing.

Typically, the active element of an NDT transducer is a thin disk, square, or rectangle of piezoelectric ceramic or composite that converts electrical energy into mechanical energy, and vice versa. This element is sometimes informally called the crystal because, in the early days of ultrasonic NDT, elements were made from quartz crystals; however, ceramics such as lead metaniobate and lead zirconium titanate have long been used in most transducers. Recent years have seen increasing use of composite elements in which the traditional solid ceramic disk or plate is replaced by a micro-machined element in which tiny cylinders of piezoelectric ceramic are embedded in an epoxy matrix. Composite elements can provide increased bandwidth and improved sensitivity in many flaw detection applications.

When it is excited by an electrical pulse, this piezoelectric element generates elastic waves, and when it is vibrated by returning echoes it generates a voltage. The active element is protected from damage by a wearplate or acoustic lens and backed by a block of damping material that quiets the transducer after the elastic pulse has been generated. This ultrasonic subassembly is mounted in a case with appropriate electrical connections.

All common contact, angle beam, delay line, and immersion transducers utilize this basic design. The phased array probes used in imaging applications simply combine a number of individual transducer elements in a single assembly. Dual element transducers, commonly used in corrosion survey applications, differ in that they have separate transmitting and receiving elements separated by a sound barrier, no backing, and an integral delay line to steer and couple the elastic energy rather than a wearplate or lens. While the basic concept is simple, transducers are precision devices that require great care in design, material selection, and manufacturing to help ensure optimum and consistent performance.

The high-frequency vibrations that are the basis of ultrasonic NDT commonly occur as either longitudinal waves (particle motion parallel to wave direction) or shear waves (particle motion perpendicular to wave direction). All commonly used

NDT transducers generate longitudinal waves. Thickness gaging and straight beam flaw detection normally use longitudinal waves, which are the easiest to create and propagate well through typical engineering materials. Shear waves are used in most angle beam inspections of welds and similar structures. Angle beam assemblies use refractive mode conversion to turn the longitudinal waves generated by the transducer into shear waves, which have a shorter wavelength than comparable longitudinal waves and are thus more sensitive to large reflectors. Some immersion tests also utilize shear waves generated by mode conversion. Other modes, such as surface waves and plate waves, also exist as well as contact transducers that generate shear waves directly, but these are employed only in specialized tests.

In addition to the various design types, ultrasonic transducers are available in a wide variety of frequencies, sizes, and bandwidths to meet different application needs. Most ultrasonic testing is performed at frequencies between 1 MHz and 10 MHz, however commercially available transducers range in frequency from less than 50 KHz to greater than 200 MHz. (By comparison, the range of human hearing is from approximately 20 Hz to 20 KHz, decreasing as a person gets older.) Commonly used element sizes range from as small as 0.125 in. (3 mm) to 1.5 in. (38 mm). Bandwidth, or the span of frequencies contained in the spectrum generated by the transducer, may be either narrow or broad.

Higher frequencies permit detection of smaller flaws and measurement of thinner test pieces, but the sound energy won’t travel as far as at lower frequencies. Lower frequencies provide better penetration of thick test pieces, especially in materials like cast metals and plastics that transmit sound less efficiently, but they will be less sensitive to small flaws and may not measure thin sections.

- Large elements can permit quicker scanning of a test piece, but will reduce sensitivity to larger reflectors and may not couple well onto curved surfaces like pipes. Smaller elements will be more sensitive to larger reflectors and will couple better onto curved surfaces, but will not test large areas as quickly.
- Broadband transducers have good near surface resolution, enabling detection of flaws close to the surface and measuring thin parts.
- Narrowband transducers have better penetration and can generate stronger echoes from reflectors, but exhibit less axial resolution.

5. Principle of operation:

The phased array probe consists of an array of ultrasonic transducers which are few mm in size and each of them can be pulsed independently. By varying the time of pulsing a sequence or a pattern of constructive interference is generated which results in a beam at a particular angle, this means that the beam can be focused and steered with the help of electronics.

The beam is swept through the tissue or object which is being inspected and the data is collected for each element of the array and is put together to make a visual image which displays the interior part of the inspected object.

5.1. Full Matrix Capture:

Full Matric Capture (FMC) is a developing technique which uses a transmission / reception method that is implemented during the data acquisition stage. The beam formation is performed using a software hence there is no loss of information that is obtained from the individual elements. After the capture of data it is then streamed to a computer where the software applies a post-processing or an imaging algorithm.

The main advantage of FMC is that each element of the ultrasonic array is pulsed individually, and the resulting reflected signal is received by all elements. For maximum image resolution, higher number of elements has to be used. For example a 64 element ultrasonic transducer array will produce 64^2 or 4,096 raw data, which has to be further run by the imaging software. Hence this technique requires higher data storage but the final image will be of very good resolution.

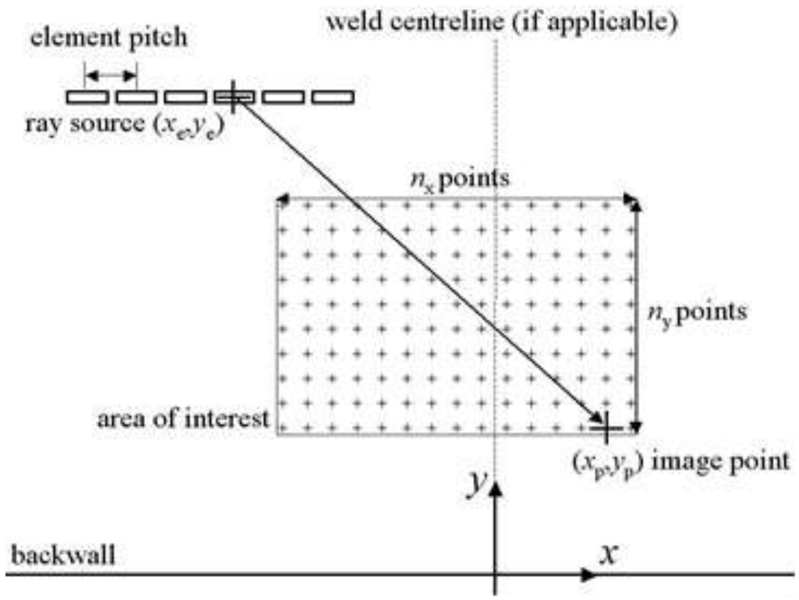

Fig. 1. General schematic diagram of TFM

TFM is one of the popular algorithm for imaging after the data is acquired by FMC. Since the data from the FMC is raw data, it has to be processed further and is done by TFM which applies delay laws to focus any point of the matrix. The TFM imaging provides better image resolution than any other standard imaging technique the spatial resolution is optimized at any depth, and a single FMC acquisition can be used to measure the surface and build an image inside the component. Its main drawback is the computation time it may require if the number of elements or focusing points is high.

Advantages of TFM over other methods,

- Better perspective.
- Improved vertical resolution.
- Improved lateral resolution.
- Improved flaw definition allows for better sizing.
- Reduced misinterpretation of geometry echoes vs. defects.

In addition to increased lateral and horizontal resolution, TFM permits increased characterization of non-point defects at different orientations.

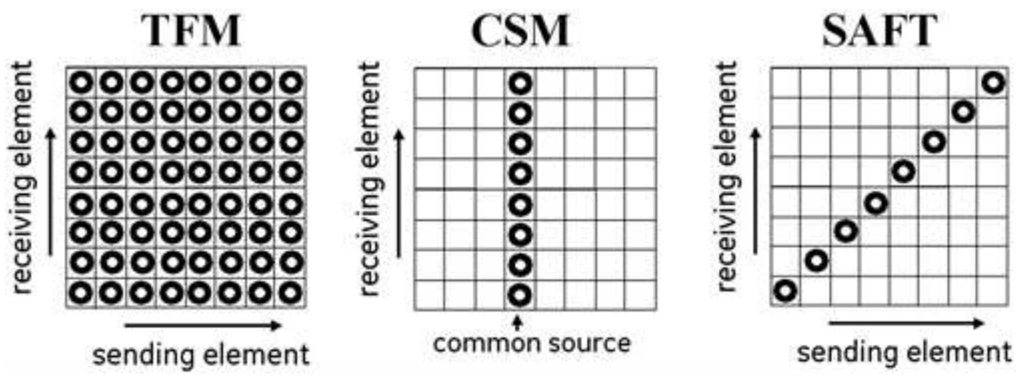

Fig.2 Send-receive combinations of the three imaging algorithms

The theoretical resolution of CSM and SAFT images are lower than those of TFM, partly because a greater amount of data are acquired thus lowering the effects of noise.

6. Algorithm and Trails:

The basic processing involved in the TFM technique can be calculated in any data analysis software. The program which I took into consideration was MatLab as image plotting from the resulting matrix is easier and it can also be easily edited for different types of arrays. The main step in the algorithm is to collect the data from the transducer array and to place it in the matrix, the matrix size is dependent on the transducer array that is used. For a 64 channel array, the resultant matrix will be 64x64 and will have 4096 data values which has to be further processed.

The image is formed from the matrix that is collected, for a 2-D image X and Y coordinates must be taken into account, this directly proportional to the distance between the flaw and the sensor. Hence by calculating the Euclidian distance between the points we can get the distance between the flaw and the sensor surface. The size of the flaw can be measured from the image as it is easy to differentiate between the pixels.

$$\text{Eij} = \sqrt{(Xij - Xp)^2 + (Yij - Yp)^2}$$

In the above equation,

Eij is the distance, Xij is the co-ordinate of the element in X-axis and Yij is the co-ordinate of the element in Y-axis.

Xp and Yp is the co-ordinates of the flaw or deformity that is present in the specimen.

To recreate this a specimen is assumed to be 10mm in dimension and with a flaw at its middle. Two matrices are created, one consisting of all the values of the X co-ordinates and another one containing the values of Y co-ordinates. A third zero matrix is created consisting of only one value which is the co-ordinate of the flaw.

The zeros indicates that the ultrasound has not been reflected and the value indicates that, an echo signal has been obtain from that co-ordinate. After the algorithm is created, it is tested for various flaws at different regions of the specimen and the array size is also changed.

6.1. Programs involved:

The following programs were executed in Matlab to get the resultant output matrices for different transducer arrays,

16x1 array:

```
a=[0.000,0.6250,1.2500,1.8750,2.5000,3.1250,3.7500,4.3750,5.0000,5.6250,6.2500,6.8750,7.5000,8.1250,8.7500,9.3750];

b=[0.000,0.6250,1.2500,1.8750,2.5000,3.1250,3.7500,4.3750,5.0000,5.6250,6.2500,6.8750,7.5000,8.1250,8.7500,9.3750];

A = repmat(a',1,16) ;

B = repmat(b,16,1);

O = zeros(length(A),length(B));

O(8,16)=2.5000;

c = 1:16;
```

```
d = 1:16;

E1 = (A(c,d)-O(8,16)).^2;

E2 = (B(c,d)-O(8,16)).^2;

G = E1+E2;

OutArray=sqrt(G);

T = zeros(length(A),length(B));

T = OutArray./1500000;

image(OutArray,'CDataMapping','scaled')

colormap hsv
```

32x1 Array:

```
Base = 0:0.3125:10;

A = repmat(Base',1,33) ;

B = repmat(Base,33,1);

O = zeros(length(A),length(B));

O(10,10)= 2;

F = zeros(length(A),length(B));

F(17,17)=8;

c = 1:32;

d = 1:32;

E1 = (A(c,d)-O(10,10)).^2;
```

```
E2 = (B(c,d)-O(10,10)).^2;

F1 = (A(c,d)-F(17,17)).^2;

F2 = (B(c,d)-F(17,17)).^2;

G = E1+E2;

H = F1+F2;

R = G.*H;

OutArray=sqrt(R);

T = zeros(length(A),length(B));

T = OutArray./1500000;

image(OutArray,'CDataMapping','scaled')

colormap hsv
```

64x1 array:

```
Base = 0:0.15625:10;

A = repmat(Base',1,65) ;

B = repmat(Base,65,1);

O = zeros(length(A),length(B));

O(33,33)= 5;

c = 1:64;

d = 1:64;

E1 = (A(c,d)-O(33,33)).^2;
```

```
E2 = (B(c,d)-O(33,33)).^2;

G = E1+E2;

OutArray=sqrt(G);

T = zeros(length(A),length(B));

T = OutArray./1500000;

image(OutArray,'CDataMapping','scaled')

colormap hsv
```

6.2. Matlab GUI:

Different arrays were designed and the outputs were obtained, next the user interface was developed and tested for the different sensors models in matlab. Various user interface options can be given with the help of the MatLab GUI developer. The options that are used for the current program include,

- Static Text – Tool used for displaying static text lines, which are mainly used for questioning the user.
- Edit Text – This tool is used for obtaining the different values from the user, it can have numbers as well as strings.
- Pop down menu – This tool is used for letting the user select an option from various pop down options.
- Button – This tool is mainly used for confirming a selection by the user.

- Radio – This is used for selecting an option from multiple choices that can be given to the user.

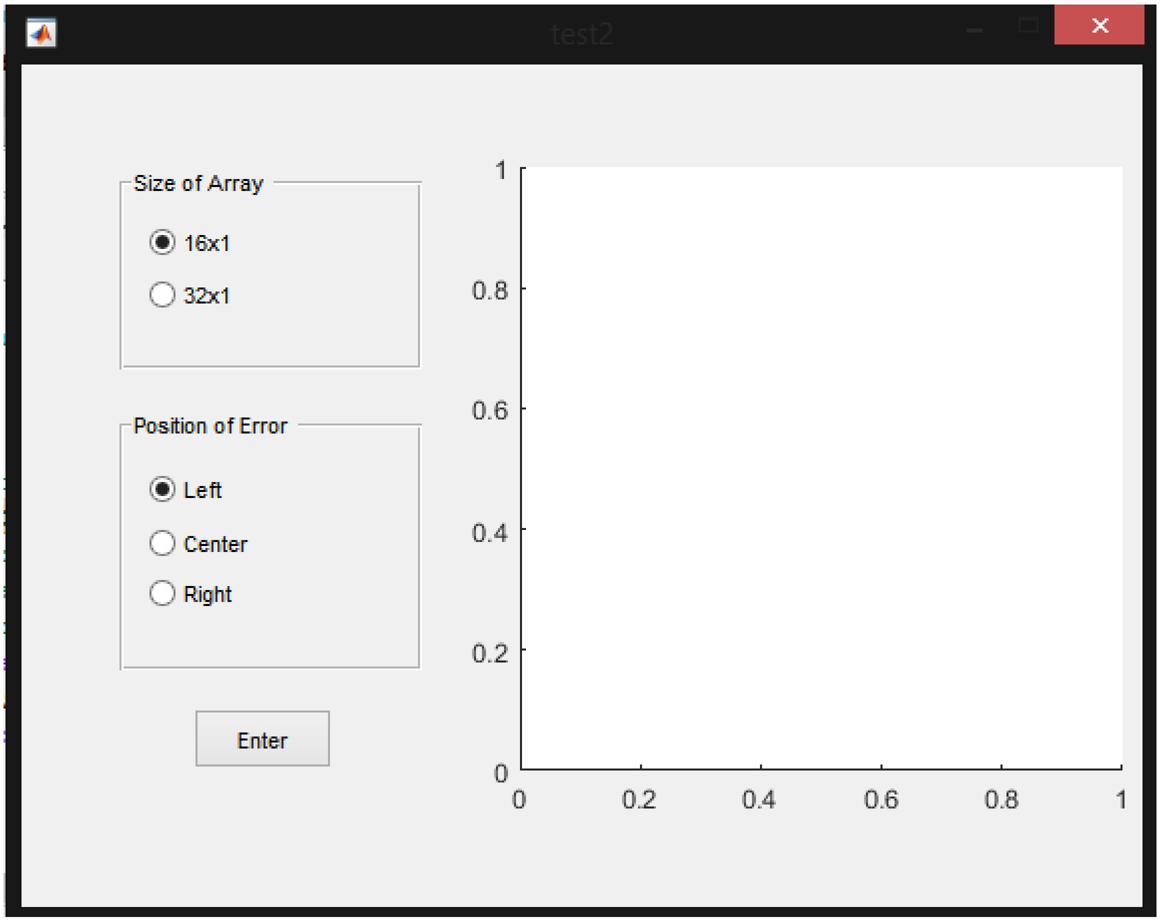

Fig. Basic GUI created using radio and button options.

Various trails were performed with the help the GUI, it included mainly with the position of the flaw and the area where it occurred. This was done for 16x1 and 32x1 array sequences. The size of the test object was considered to be 10mm in length and breadth, therefore each pixel at the output represented 0.6250mm for 16x1 array and 0.3125mm for the 32x1 array. With the help of the output image the size and position of the flaw can be easily measured and calculated. The following trails were performed and the position and size was calculated.

Trail 1:

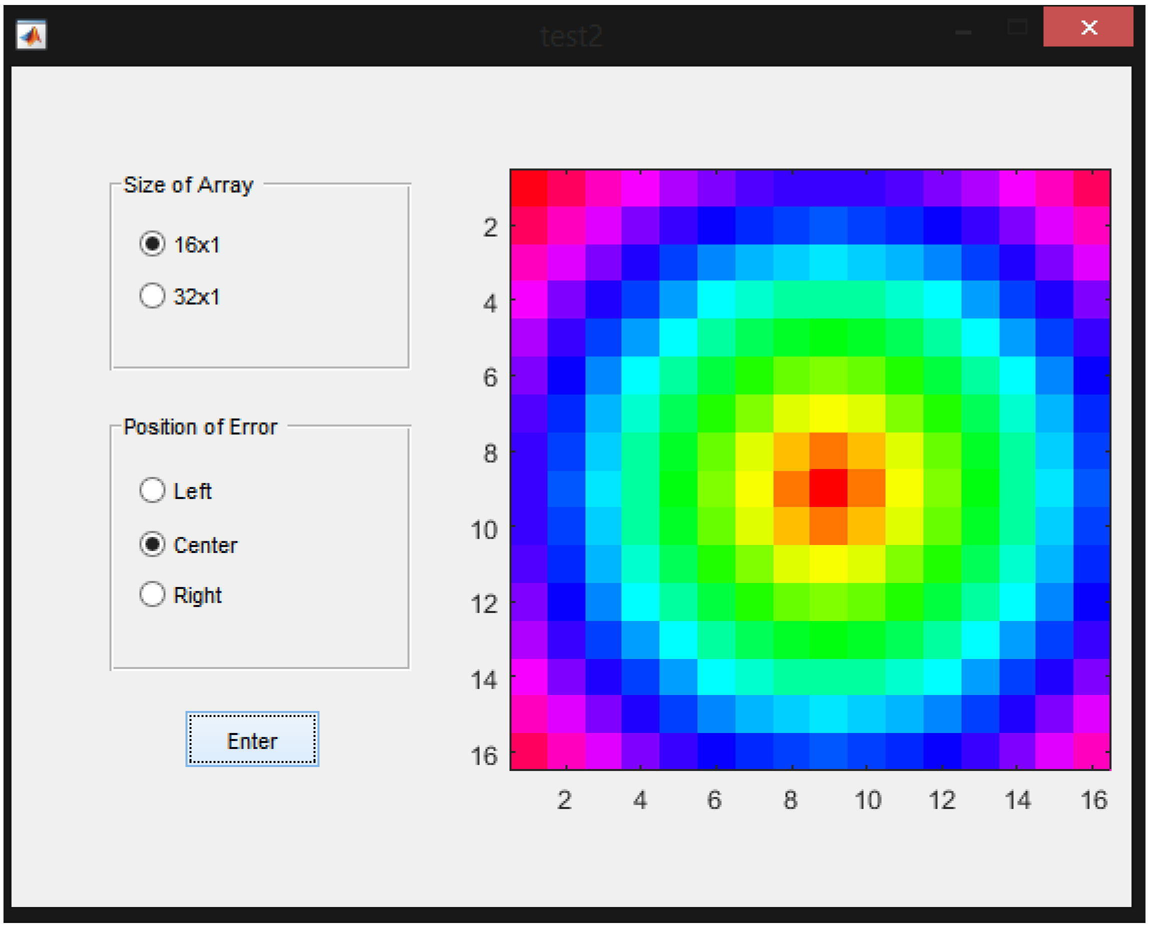

Fig. Trail 1 – 16x1 array flaw at center position.

From the output image it's clear that the flaw is at the center of the sample, and it occurs around at the 9x9 matrix value, therefore it can be assessed that the flaw is located at 9 x 0.6250 = 5.625mm from the edges of the given sample and extends a bit outwards and lies between the 8x8 to10x10. The effective size of the flaw is calculated and was found to be 6.250 – 5.000 = 1.250mm.

Trail 2:

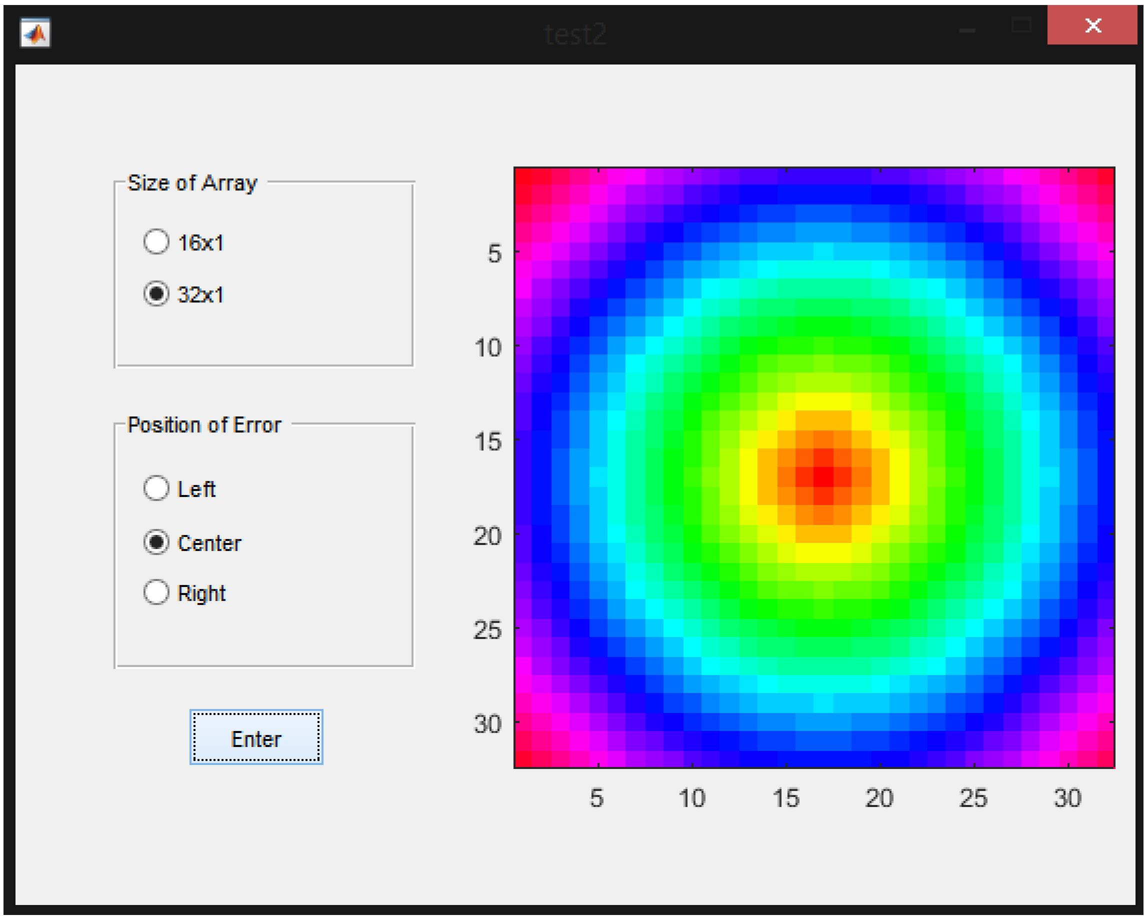

Fig. Trail 2 – 32x1 array flaw at center position.

In this trail a 32x1 array was used as the transducer by using the same flaw as used in the previous trail, the resultant image shows that the flaw is located at the center of the given sample. The flaw occurs between 15x15 to 20x20 and is located at 16x16, the effective size of the flaw can be measured as 6.125 – 4.6875 =

1.4375mm. This shows that with the increased no. of transducer array, the precision of the system improves.

Trail 3:

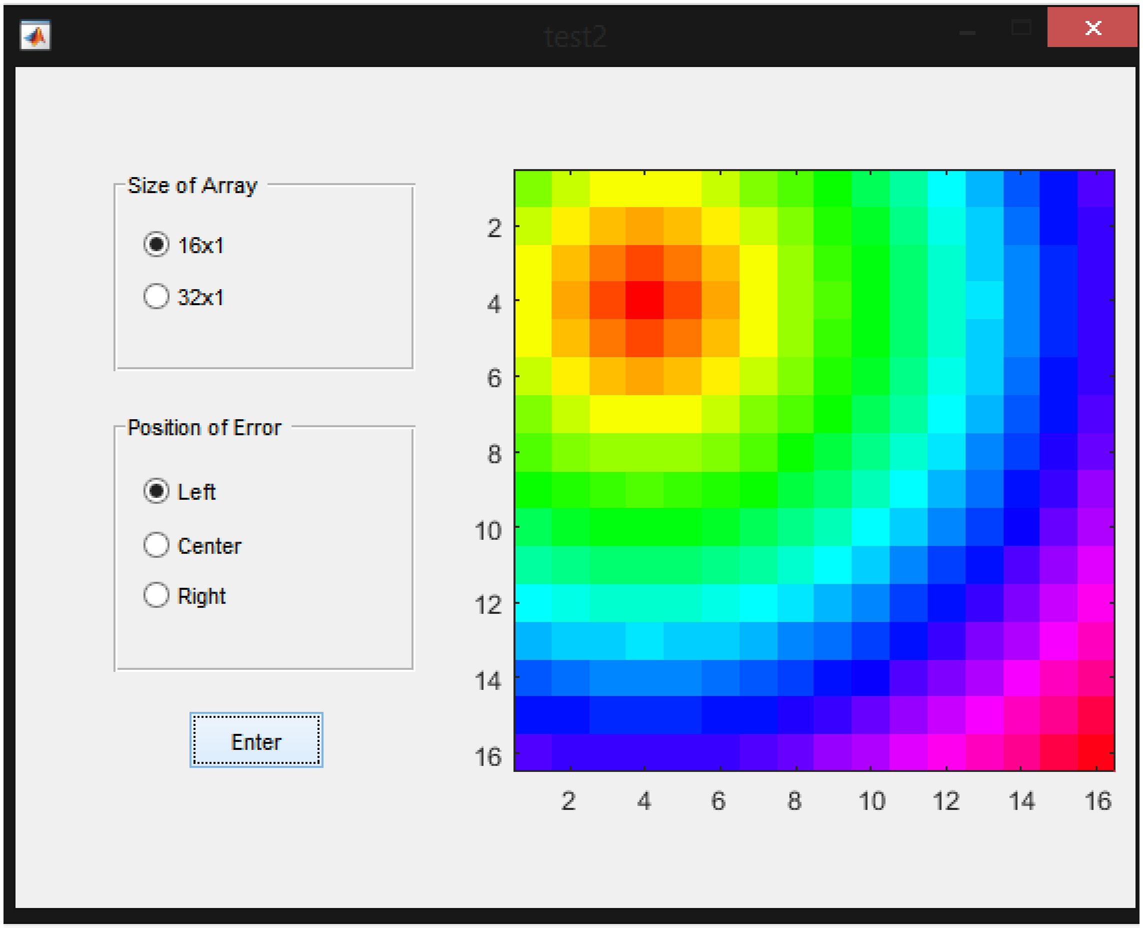

Fig. Trail 3 – 16x1 array flaw at left position.

Similar trails were done by having flaws at different positions, at the left and at the right side of the sample. It was done with 16x1 array as well as 32x1 array and the results were obtained as below, The flaw is located between 2x2 and 6x6 matrix, it occurs at 4x4 which is 2.5mm from the top and left side of the sample, the effective size of the flaw is 3.75 – 2.5 = 1.25mm in size. The same is done using a 16x1 array and the resultant image is as follows, like the previous result the accuracy of 32x1 over 16x1 arrays is greater.

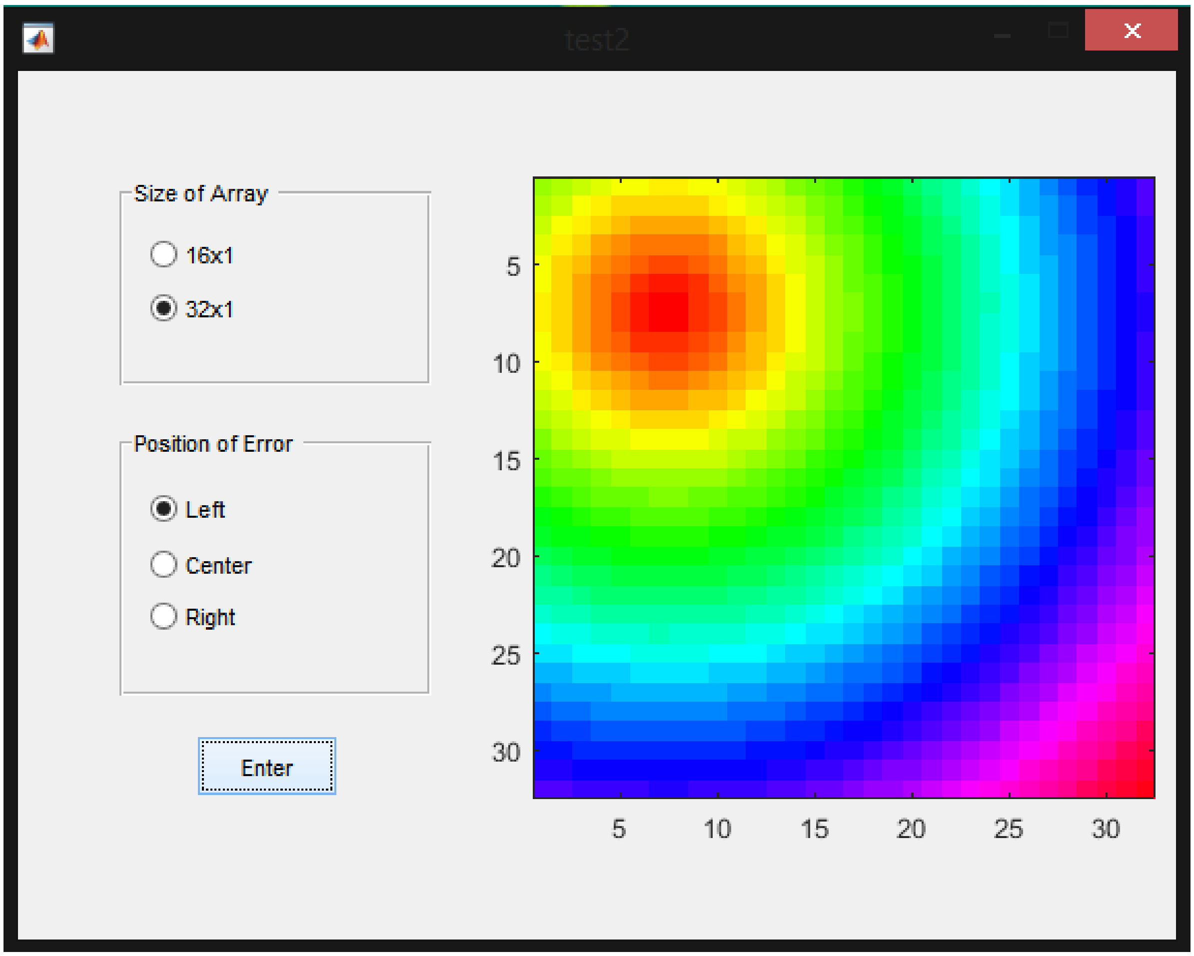

Fig. Trail 3 – 32x1 array flaw at left position.

From the figure it is possible to see that the flaw is located at the left side of the sample, it is between 5x5 to 10x10 and the flaw is located at 2.5mm from the top and left edges of the sample. The size of the flaw can be calculated and was obtained to be 3.125 – 1.5625 = 1.5625mm. From the same trail which was performed using the 16x1 array gave the size to be 1.25mm whereas this trail gives the size of 1.5625mm. This again proves that with increasing number of array size, the accuracy increases.

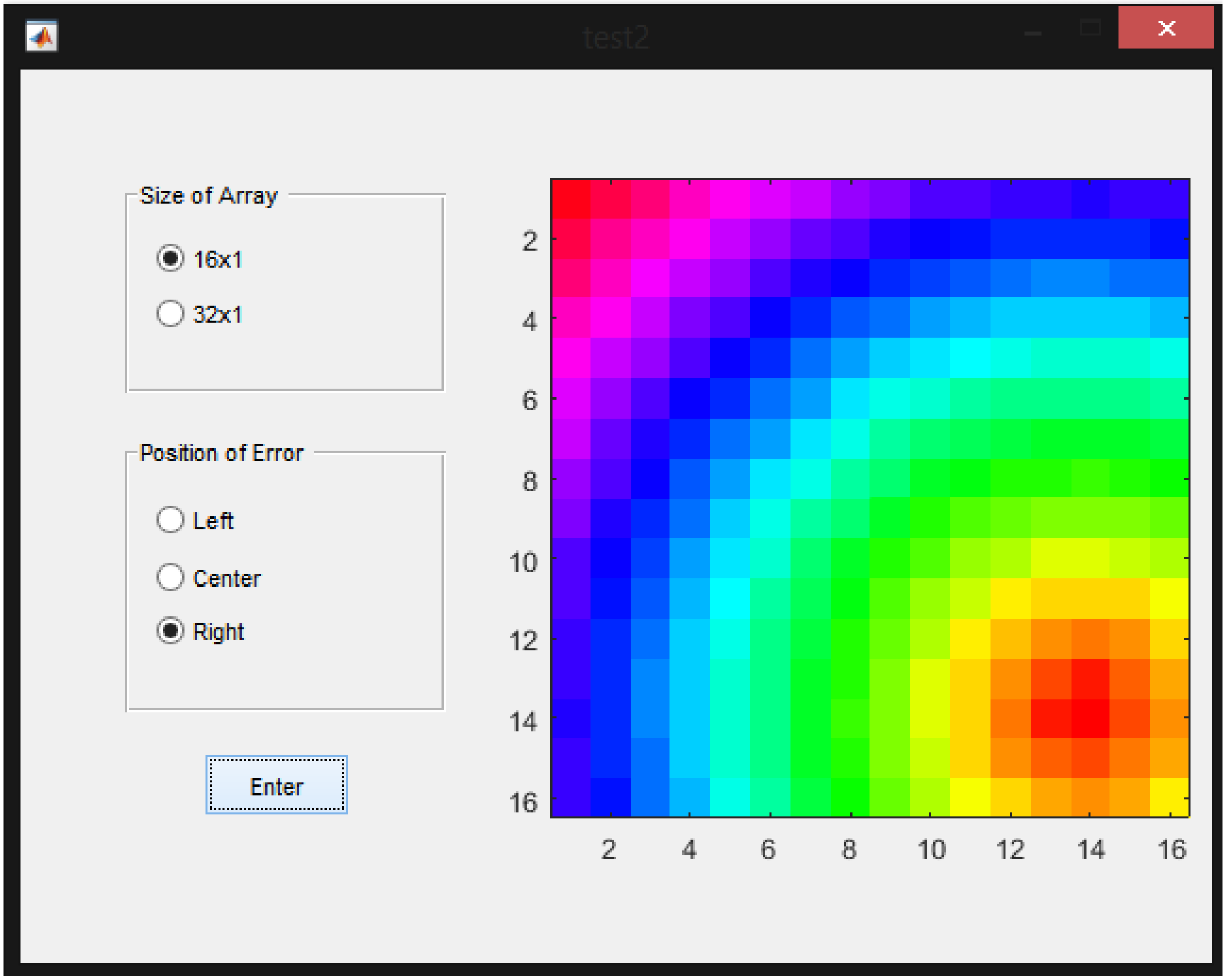

Fig. Trail 3 – 16x1 array flaw at right position.

From the figure it is possible to see that the flaw is located at the right side of the sample, it is between 12x12 to 15x15 and the flaw is located at 8.75mm from the top and left edges of the sample. The size of the flaw can be calculated and was obtained to be 9.375 – 7.5 = 1.875mm. This trail is performed again using the 32x1 with similar conditions for the flaw and the sample size.

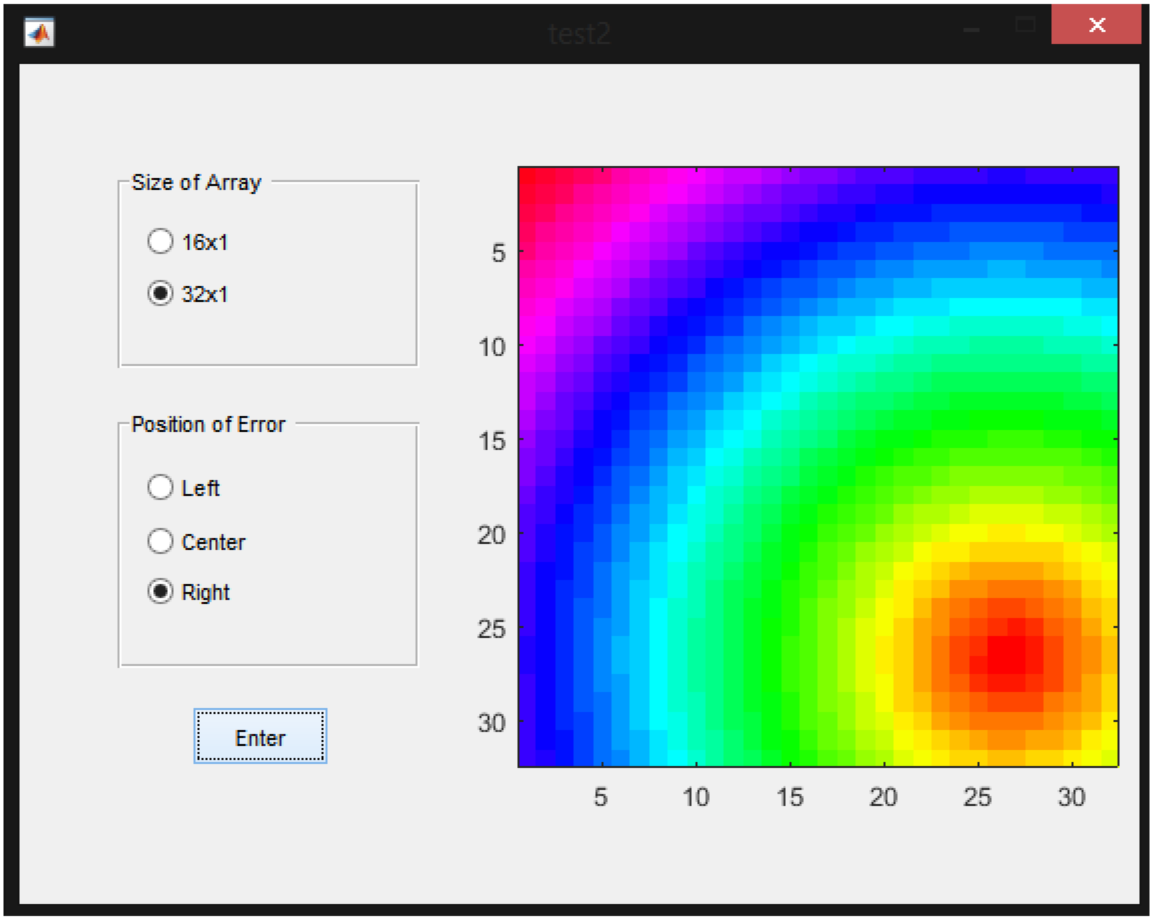

Fig. Trail 3 – 32x1 array flaw at right position.

From the figure it is possible to see that the flaw is located at the right side of the sample, it is between 25x25 to 28x28 and the flaw is located at 8.125mm from the top and left edges of the sample. The size of the flaw can be calculated and was obtained to be 8.75 – 7.8125 = 1.5675mm. From the same trail which was performed using the 16x1 array gave the size to be 1.8725mm and its location was found to be at 8.725mm from the top and left edges of the given sample whereas this trail gives the size to be 1.5675mm and its position to be at 8.725mm.

<u>Trail 4:</u>

This trail included two flaws near to each other, it was done using both the 16x1 array and the 32x1 array. The distance between them could be calculated by measuring the no. of pixels between the outer pixel of both the flaws. This trail used two different locations for the flaws in the 16x1 and 32x1 arrays and the resulting image was captured and all the distances were calculated as the previous trails but the distance between the two flaws was calculated in this trail.

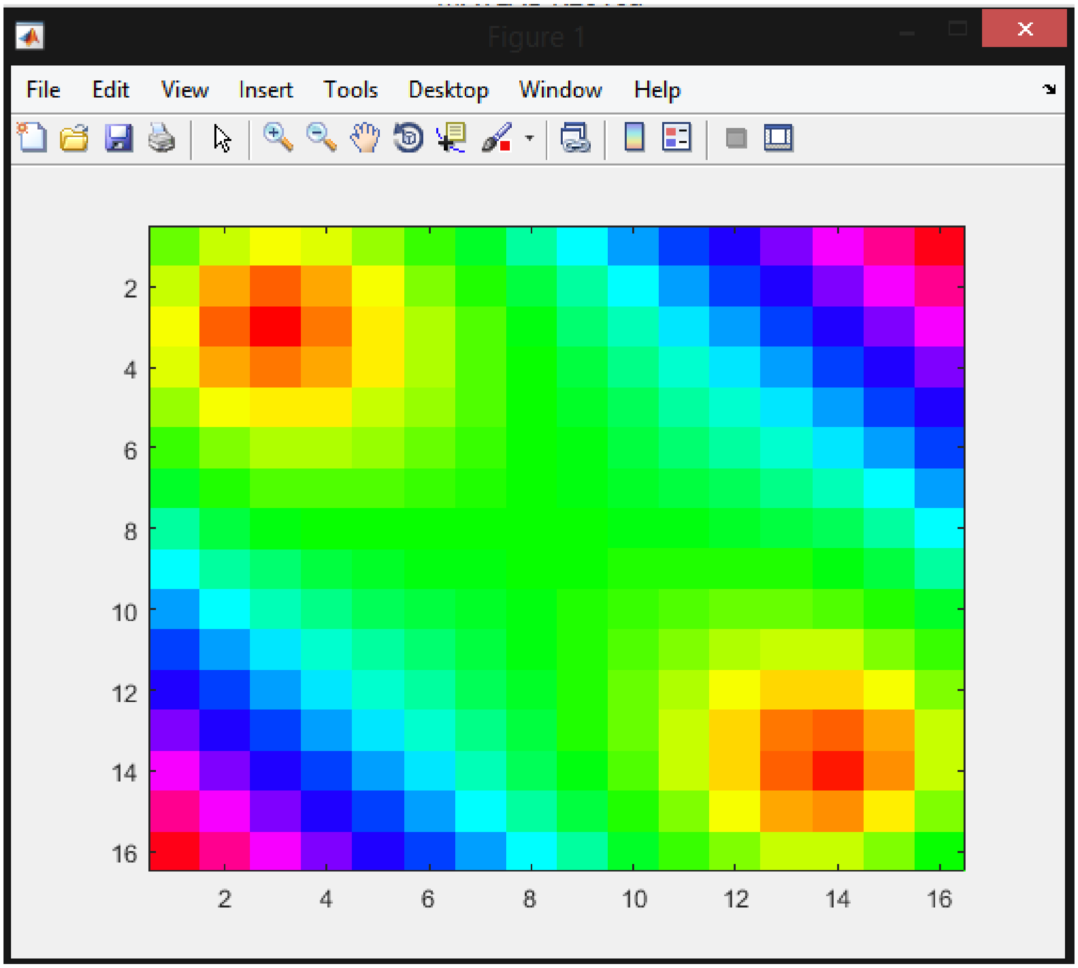

Fig. Trail 4 – 16x1 array, two flaws (farther)

The 16x1 array has two flaws at 3x3 and 14x14 and the first flaw is spread between 2x2 and 4x4, the second flaw is spread between 11x11 and 14x13. The position of the first flaw is 1.875mm from the top and left edges of the sample and the second flaw is 8.75 mm from the top and left edges of the sample. The distance between the two flaws is 7mm.

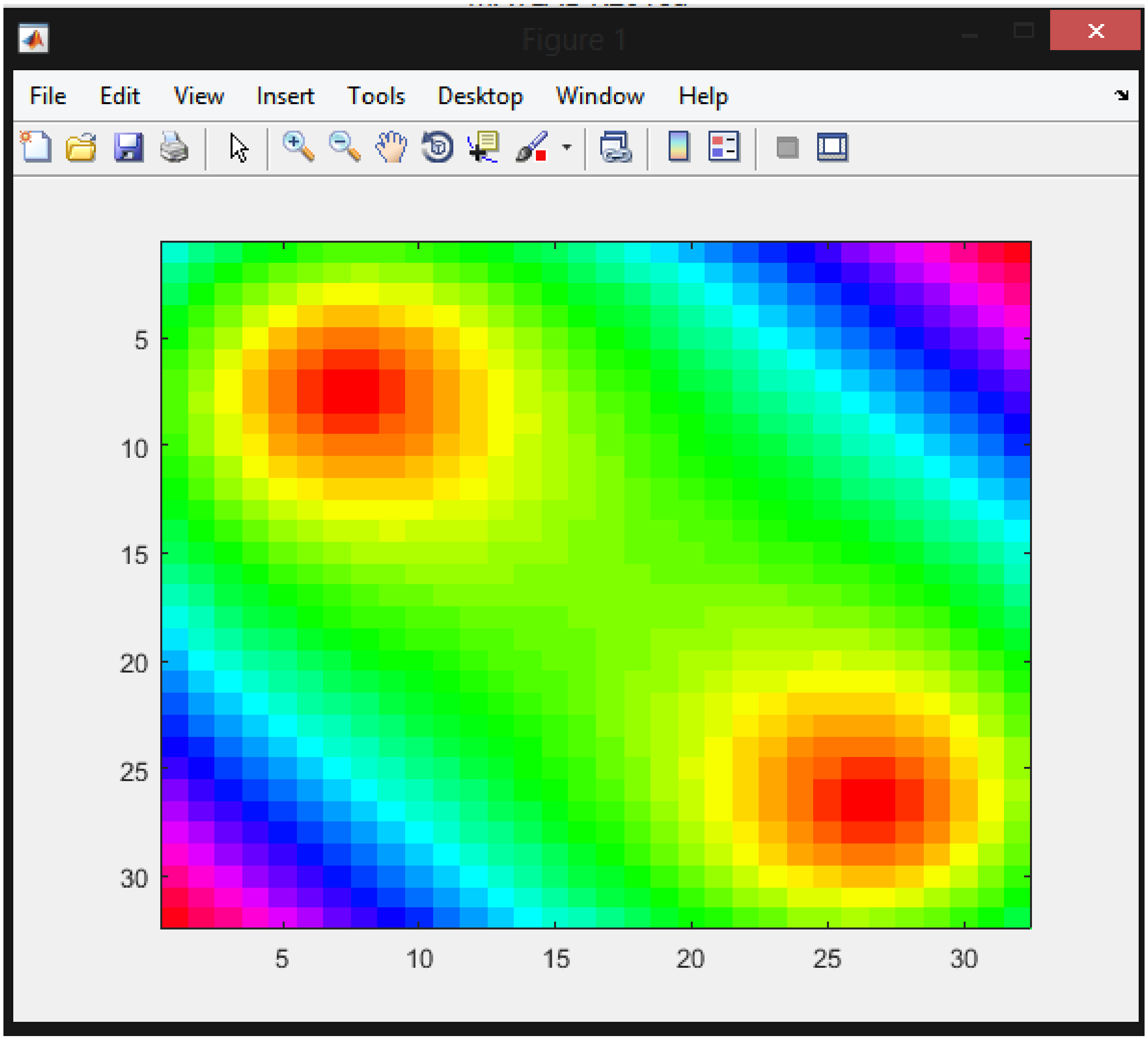

Fig. Trail 4 – 32x1 array, two flaws (farther)

The second trail was done using a 32x1 array with two flaws, from the fig. we can see that the first flaw is between 6x6 and 8x8 and the second flaw is between 26x26 and 28x28. The effective size of the flaw is 4 pixels wide each therefore its size is 0.3125x4 = 1.25mm. The distance between these two flaws is 20 pixels which is 20x0.3125 = 6.25mm. Creating two flaws on matlab was done with the help of “ **.*** ” operation between two different array that had flaws at a single position and overlapping them to create two flaws on a single sample.

Trail 5:

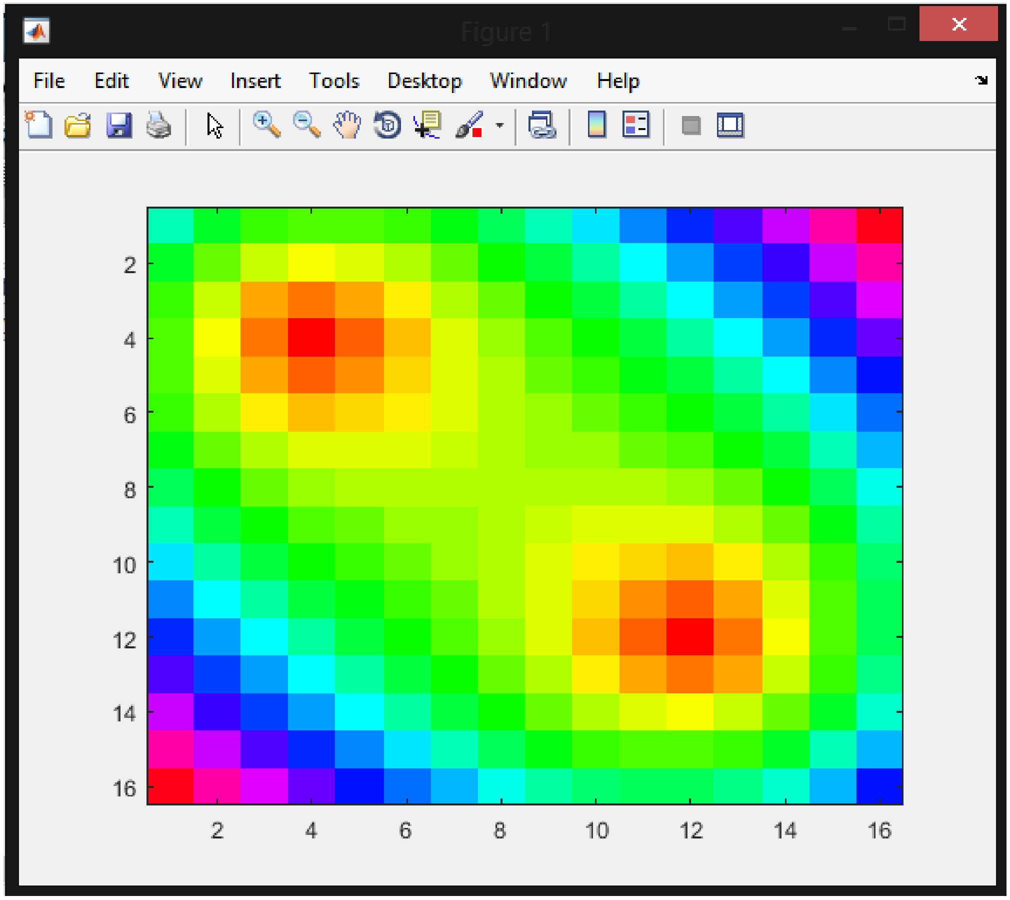

Fig. Trail 5 – 16x1 array, two flaws (closer)

Trail 5 was performed similar to trail 4 where there are two flaws but they were made to be closer to each other and their distance and size was calculated. The flaw is located at 4x4 and is spread around 3x3 to 5x5, therefore the position of the flaw was found to be 2.5mm from the top and left edges of the sample. The second flaw is located at 12x12 and is spread between 11x11 to 13x13, the position of the flaw was calculated to be 7.5mm from the top and left edges of the sample. The distance between the two flaw is 7.5mm – 2.5mm = 5mm. Therefore the two flaws which was closer to each other was analysed in this trail with the help of the 16x1 array model.

The next trail is performed similar to the 16x1 array, from the figure it is easy to identify the two flaws that are located in the given sample. The first flaw is located between 7x7 to 11x11 and is 2.8125mm from the left and top edges of the sample. The second flaw is between 21x21 and 25x25 and is 7.1875mm from the left and top edges of the sample.

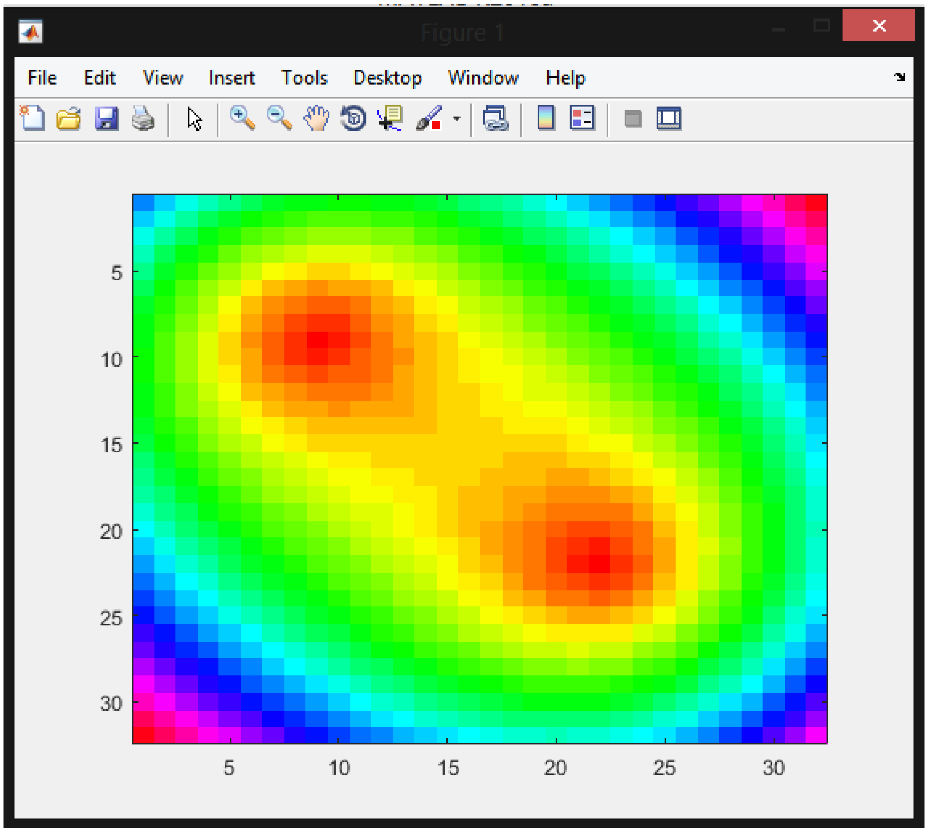

Fig. Trail 5 – 32x1 array, two flaws (closer)

These were the trails that were performed on matlab on the digital signal processing of acoustic arrays, further trails can be done by changing the location of the flaws and adding more flaws to the given sample, these results were then compared to the results that were obtained from an experiment conducted on a real time non-destructive system and was studied.

Trail 6:

Flaws on the x and y axis of the sample,

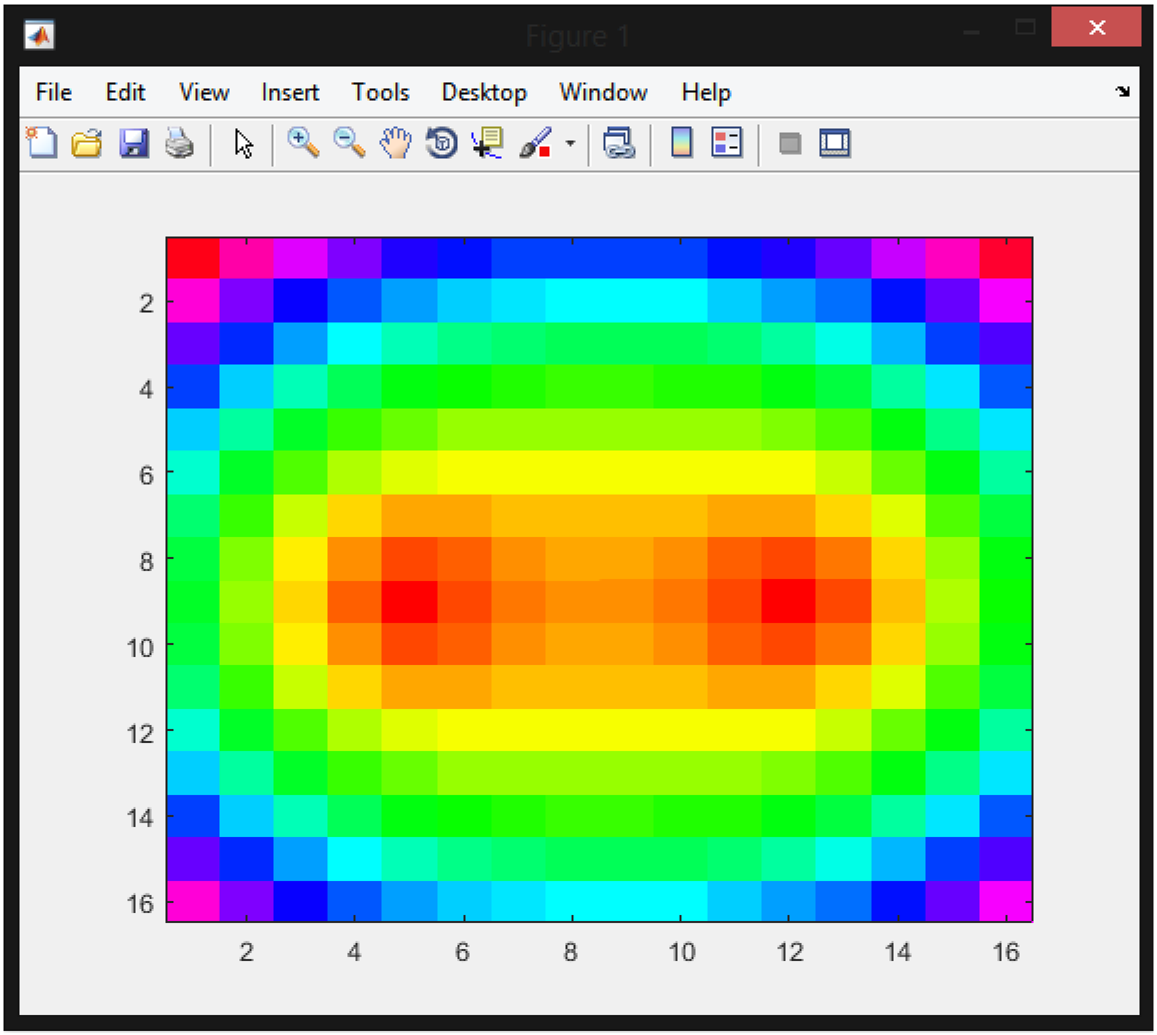

Fig. Trail 6 – 16x1 array, two flaws (x-axis)

This trail was to find the least distance at which the two flaws detected becomes one, the first flaw was found at 9x5 and the second flaw at 9x12. Their positions were found to be 5.625mm and 6.25mm and the difference between then was 0.625mm. The size of the first one flaw is 2.5mm and second one is 1.7mm and at the least minimum distance it is about 0.8mm. This was done on a 64x1 array on the y axis.

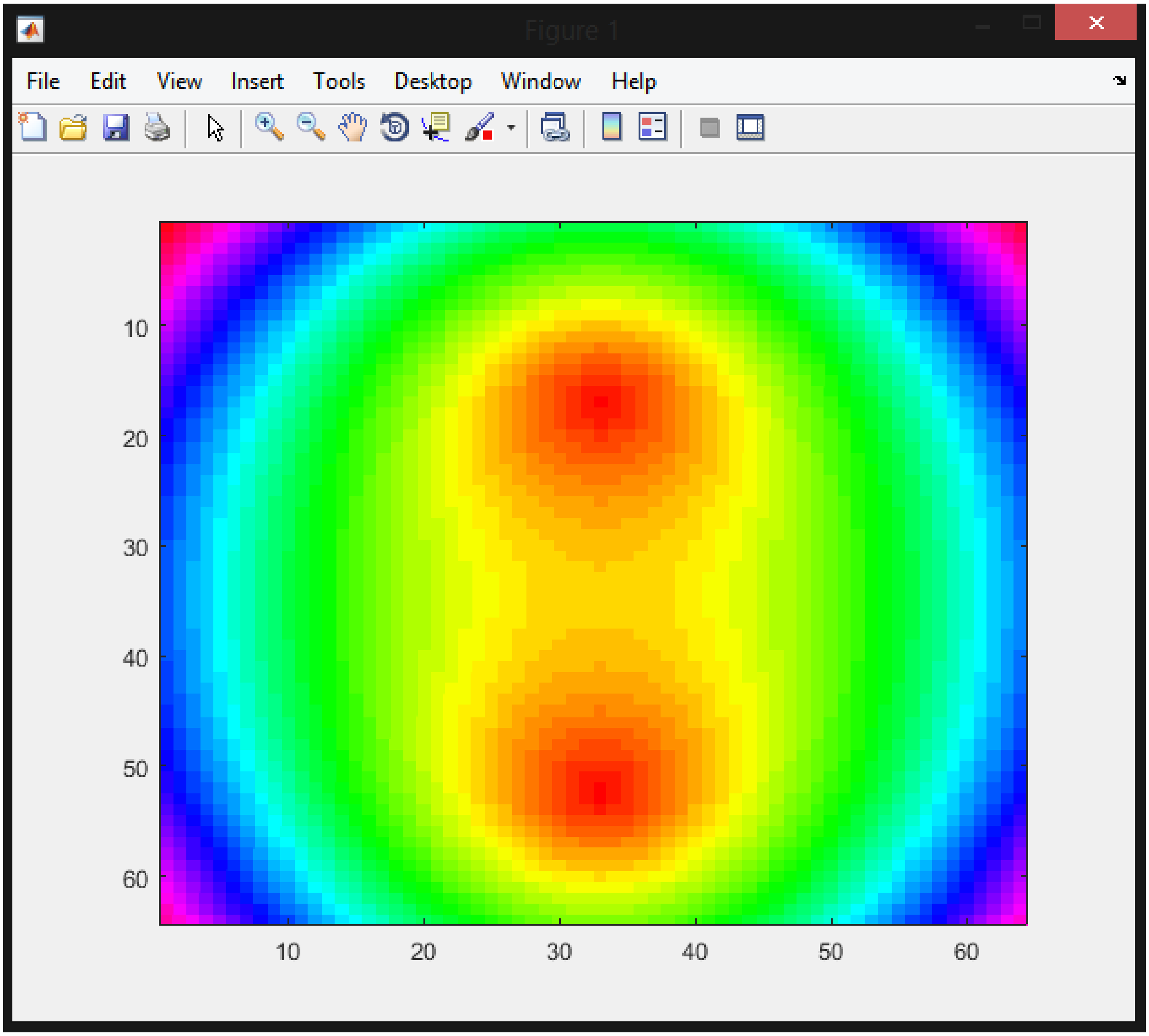

Fig. Trail 6 – 64x1 array, two flaws (y-axis)

Similar results were obtained as the 16x1 array, the position of the at which the two flaws merged was 40x40 and the minimum was found to be 80%.

7. Experimental Setup:

The experimental setup for the NDT system consists of an ultrasonic sensor which is 16x1 array and is used to transmit and receive signals from the sample. It has an amplifier system which is used to increase the power of the obtained signals and is then fed into a multichannel ADC system that converts the analog signals into digital signals, these signals are then processed in a microcontroller and is sent to a desktop with the help of a usb port. The block diagram of the the experimental setups is as follows,

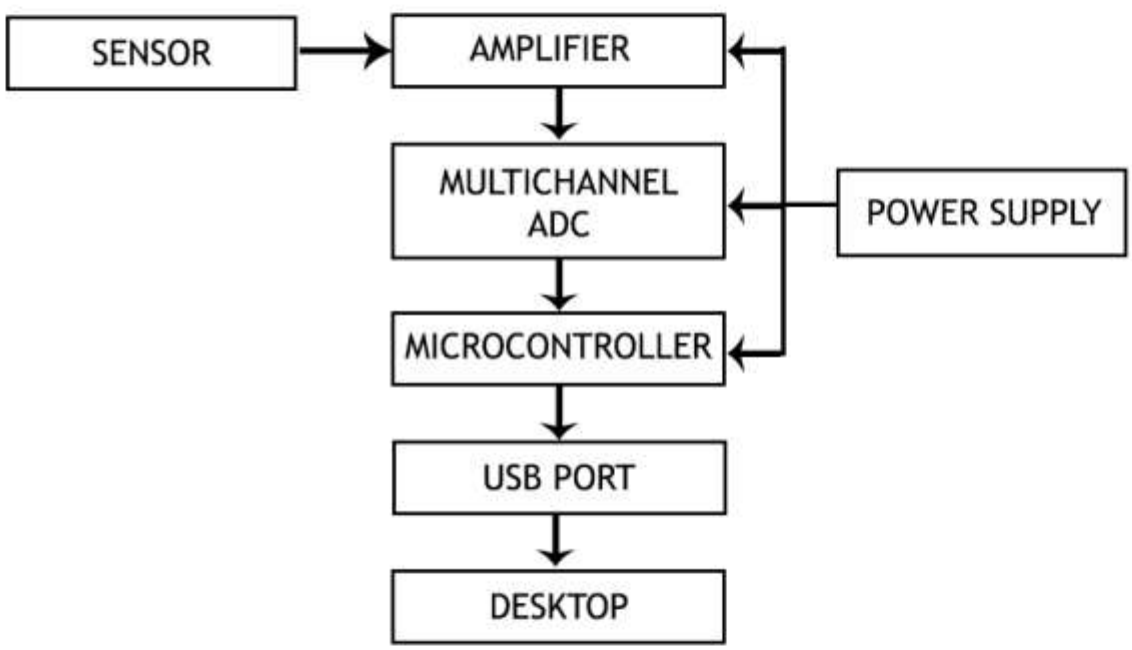

Fig. Block diagram of working model

The components included in the block diagram are explained below,

Sensor:

The sensor used here is a 16x1 ultrasonic transducer array manufactured by Olympus. The sensor is used to produce the ultrasounds and it receives back the reflected waves. The data acquired is in analog and its strength is weak, hence the received signals has to be amplified for further process.

Amplifier:

Signals from each segment of the transducer array has to be amplified, so for an 16x1 array transducer 16 amplifiers are required. The amplification of the signals from the transducer is done and then sent into a multichannel ADC system.

Multichannel ADC:

The ADC is used to convert the analog signals into digitalized format so that it can be used for processing in a microcontroller. It consists of 16 ADCs and IDT-72V263 RAM. The signals can be stored in RAM and is processed in a microcontroller.

Microcontroller:

The microcontroller used in this system is ATmega128, the features of this are as follows, The high-performance, low-power Microchip 8-bit AVR RISC-based microcontroller combines 128KB of programmable flash memory, 4KB SRAM, a 4KB EEPROM, an 8-channel 10-bit A/D converter, and a JTAG interface for on-chip debugging. The device supports throughput of 16 MIPS at 16

MHz and operates between 4.5-5.5 volts. By executing instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed.

USB Port:

The USB port links the system to a computer, It is a standard cable port and is connected using a cable.

Desktop:

A standard computer is used for viewing the created image matrix from the sensor, it should have good amount of RAM to work efficiently.

Power Supply:

The power supply used is a standard +12V and 1.5A, it is achieved with the help of step down transformer and is supplies the power to the amplifiers, ADC and the microcontroller.

8. Financial Management and Resource Efficiency

8.1. Theme of project:

Digital signal processing of an acoustic array is very useful in the field of non-destructive testing of various medical instruments and other industrial applications. Total Focusing Method (TFM) is used to detect the deformities and it requires the data acquisition of time domain signals by using an ultrasonic array. The main aim of my project is to study the data that is acquired from the sensors and process it using a software and to create an image based on the acquired data.

The data acquisition process is done with the help of software's as it usually involves very large amount of processing to obtain the desired amount of data for various position of the acoustic array. A 16x1 or 32x1 acoustic array is studied and the data acquisition along with its processing is discussed and performed with the help of Mat-Lab software. Then the array is used to detect deformities such as holes in any medical apparatus and machines. The resulting image from the software is studied and it displays the deformities of the given sample.

8.2. SWOT Analysis:

Strengths:

- Data acquisition process is very easier compared to other methods of non-destructive testing.
- The software used is very compatible and standard, hence it can be easily adapted by anyone with basic knowledge of the software.

- Larger arrays can be easily stimulated with the help of the software, through hardware it is difficult to produce results for higher array size.
- Compared to hardware alternative, software simulations are cheaper. The entire hardware required for data processing can be reduced with the help of matlab.
- Since the hardware required is significantly reduced, manpower required to run the project in a larger environment is also reduced.
- This project is not only targeted at the biomedical field, it can be applied in numerous fields where non-destructive testing is required.
- The software has regular updates, hence it is possible to make use of the latest updates for higher performances.

Weaknesses:

- The main weakness of the project is that the software used is not an open source software, the licences has to be purchased every year which is not suitable for long term uses.
- The project is dependent on fast computers to perform the data processing and imaging.
- The field has been well developed, latest technologies use powerful microprocessors to perform the data processing which is lower cost when compared to matlab software.
- Usage of matlab software to perform the imaging and data processing is new in the field of NDT.
- Programming in the software is a difficult task, each simulations has to be programmed separately and precisely.

- The softwares are regularly updated with newer features, hence the current programming has to be changed to make it suitable for the newer versions of the software.

Opportunities:

- This is an entirely new field in non-destructive testing, hence there are lots of emerging technologies using softwares.
- Open source softwares can use this emerging field by improving certain features in their software which gives an edge over licenced softwares like matlab.
- This will open higher amount of employment for fresher students who are knowledgeable with softwares like matlab.
- This also can provide opportunities for cross platform projects for further improved systems.
- It creates numerous employment opportunities in various fields as the project can be applied in various fields.

Threats:

- Compatibility is the main idea behind the project, if the current non-destructive testing companies are able to make their equipment's into a compatible piece then the project will be less efficient when compared to the newer compatible models.
- Technologies that use the latest microprocessors is also a threat to the project, the processing time of the software is higher when compared to microprocessors. Hence the system becomes less efficient in the market.

- Softwares that are cable of maximising the computing time is also a threat to the current project, since the entire programming has to redone on a newer software.

9. Social Responsibility

Digital signal processing of an acoustic array is very useful in the field of non-destructive testing of various medical instruments and other industrial applications. Total Focusing Method (TFM) is used to detect the deformities and it requires the data acquisition of time domain signals by using an ultrasonic array. The main aim of my project is to study the data that is acquired from the sensors and process it using a software and to create an image based on the acquired data.

Thus this project emphasize on the use data analysis software's for the processing of data that is acquired from the full matrix capture method (FMC) and total focusing method (TFM). A specimen with flaws could be easily simulated with the help of Matlab and it was processed with the help of various pre-made functions that was available on the software, different flaws present in different regions of the specimen could also be designed and visualized with the help of the software. Further steps include the reception of data from a working transducer array and processing that information for detection of flaws in real time applications.

9.1. Occupational safety:

The main occupational safety concerned with the project is electrical shock from the working equipment. Each and every electrical component that is used has to be insulated and secured properly and usage of safety apparatuses is important. The main working component is ultrasound waves hence it does not affect much compared to other methods of non-destructive testing.

9.1.1. Identification and analysis of workplace hazards, which the research object can create for people.

The main workplace hazards which arises from this project for people using the system is the electrical shock hazards that may occur due to poor wiring and insulation. Therefore all the connections has to be thoroughly inspected and checked before the operation of the system.

9.1.2. Identification and analysis of workplace hazards, which may influence a researcher during the research process.

Most of the time spent during the research process by the researcher is coding and working on a computer, for experimental results working with the ultrasound transducer and a medium is necessary. Care has to be taken while working and safe equipment had to be always worn by the researcher for safety precautions. Also the data which is used for research is important, it has to be safely stored in a secured database.

9.1.3. Protection methods to mitigate the potential damage.

The main precaution taken for this project has to be with the electrical shock hazard that arises from the various electrical components used. Safety checks has to be done periodically to avoid any potential damage from the shock and other electrical factors associated with the system.

Another important factor is the working conditions of the computer used, it has to be equipped with anti-virus and soft wares which protect the necessary data that is used for the analysis and research work. There is not harmful effects of ultrasound waves, since the frequency used for this project is very low.

9.2. Environmental safety

This project does not have any kind hazardous emissions or components that affect the environment. Care has to be taken during the disposal of the waste products which includes wiring and other electrical components used during the experimental trails.

9.2.1. Impact analysis of research object on environment.

Electrical wastes are the only problem associated with the project on environment, hence the waste products that arise during the project trails has to be safely disposed.

9.2.2. Impact analysis of research process on environment.

There is not much impact by the research process on the environment as it mostly done by a software on a computer.

9.2.3. Protection methods to mitigate the potential damage.

The electrical wastes had to be disposed accordingly to prevent its potential damage on the environment.

9.3. Safety in emergency

Emergency cases occur when there is short circuits in the system, the working voltage is about 12V hence there is no risk of shock from electrical leaks in the outer parts of the system. However the power supply part consists of a step down transformer which steps down the voltage from 220V to 12V, this part has to be isolated properly so that there is no short circuits and electrical hazards.

9.3.1. Identification and analysis of emergency situations, which the research object can create.

The main emergency situation that arises is fire due to short circuits and electrical shock by physical contact. Proper isolation of the power supply unit and insulation of the wires can prevent these emergency situations.

9.3.2. Identification and analysis of emergency situations, which may occur during the research process.

During the research process, data loss can occur which is a huge situation as all the collected data is important for the project.

9.3.3. Protection methods to mitigate the potential damage.

Good wiring and isolation units can prevent the potential damage that arises from electrical shocks and fires. Proper backups and antivirus and antimalware softwares has to be installed to protect the data during the research process. In case of fire accidents it is necessary to install and use fire extinguishers also to have first aid at the lab.

9.4. Workplace design:

The workplace should be neat and dry, as a moist working place can cause problems to the electrical components of the project. Good computers is necessary for smooth data processing of the data which is acquired from the working of the system. The workplace should have soundproof coverings to prevent the intervention of noises which will affect the efficiency of the system.

10. Conclusion:

Thus this project emphasize on the use data analysis software's for the processing of data that is acquired from the full matrix capture method (FMC) and total focusing method (TFM). A specimen with flaws could be easily simulated with the help of Matlab and it was processed with the help of various pre-made functions that was available on the software, different flaws present in different regions of the specimen could also be designed and visualized with the help of the software. Further steps include the reception of data from a working transducer array and processing that information for detection of flaws in real time applications

Further improvements of this project include the use of three dimensional arrays which can be used to find the depth of the flaws and also improve the image matrix by using higher order of matrix arrays.

11. References:

1. "Full Matrix Capture and the Total Focusing Imaging Algorithm using Laser Induced Ultrasonic Phased Arrays", Theodosia Stratoudaki, Matt Clark and Paul D. Wilcox.AIP Conference Proceedings 1806, 020022 (2017).
2. "Demonstration of Application of Total Focusing Method in the Inspection of Steel Welds", Matthias Jobst and George D. Connolly.ECNDT 2010 Session: Ultrasonic Testing 2010.
3. "Full-Matrix Capture with a Customizable Phased Array Instrument", Gavin Dao, Dominique Braconnier and Matt Gruber. AIP Conference Proceedings 1650, 1001 (2015).
4. "Adaptive Ultrasonic Imaging with the Total Focusing Method for Inspection of Complex Components Immersed in Water", L. Le Jeune , S. Robert , P. Dumas, A. Membre and C. Prada. AIP Conference Proceedings 1650, 1037 (2015).
5. "Ultrasound Non-destructive Evaluation (NDE) Imaging with Transducer Arrays and Adaptive Processing", Minghui Li and Gordon Hayward. AIP Conference Proceedings 1806, 140002 (2017).
6. "Practical Application of Total Focusing for Sizing of Imperfections in Welded Joints", Michael Berke, Stefan Koralewski, Werner Roye, Laurent

le Ber, Ulrich Kaps. Proc. 19th World Conf. on Non-Destr. Test., Munich, 2016.

7. “Progress and Challenges of Ultrasonic Testing for Stress in Remanufacturing Laser Cladding Coating”, Xiao-Ling Yan, Shi-Yun Dong, Bin-Shi Xu and Yong Cao. PMCID:pmc5848990.