3D Reconstruction of Surface Topography using Ultrasonic Transducer

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Abstract - ***Image reconstruction can be termed as the first stage of Computer Vision. The task of regenerating a 3D or a 2D image from a given target object involves the use of sensors. The type of sensor to use are design and requirement respective, since different type of sensors yield different types of outputs. In this study, we determine the surface topography by reconstructing a 3D image of a given target object using an Ultrasonic Transducer. This experimental process attempts to reconstruct a 3D image of the actual object using Ultrasonic sensors.***

***Key Words*: Sensors, Reconstruction of 3D Image , Ultrasonic Transducer .**

1. INTRODUCTION

A 3D Image is an image recreated from the actual object. This obtained image is rendered on a display screen on desired format so as to perform further operations. Every different sensing technology has its own characteristics and applications. Hence determining of the type of output required to perform further operations is very important in deciding the type of sensor to be used for image reconstruction. Today, image reconstruction can be seen as a widely used technology in stand alone or integrated applications ranging from designing to medical domains. 3D image construction involves the important tasks of capturing the shape, size, orientation and appearance of the actual object.

In this particular domain, we employ the use of Ultrasonic sensors to reconstruct the image of sample objects (a Wrench, a ₹5 Coin).For this purpose, we use a dedicated ultrasonic transducer that sweeps throughout a 2 dimensional plane. The transducer fires lines of pulses at a predefined rate and keeps receiving the signals reflected from the surface of the object. The Intensity at which the signals are reflected back are noted so as to trace the surface area of the target object. The output received is in the form of waveforms. These waveforms are then transformed into graphs so as to give detailed and localised map of the object's surface area. These computations can be made possible by the use of softwares like MATLAB and LabVIEW.

2. LITERATURE REVIEW

Surface reconstruction means that retrieving the data by scanning an object using a device such as laser scanner and constructing it using the computer to gain back the soft copy of data on that particular object. It is a reverse process and is very useful especially when that particular object original soft copy data is missing without doing any backup. Hence, by doing so, the data can be recollected and can be stored for future purposes. At the same time, the accuracy of the reconstructed result should be concerned because if the result is incorrect, hence it will not exactly same like the original shape of the object. While for surface representation, it means that the method used is able to represent the collected data in the form of shape which is roughly same as the original object. Lot of review or research papers mentioned that surface reconstruction based on the unorganized points was a challenging task, no matter it is in three dimensions of maybe even higher dimension (Zhao et al. 2001; do Rêgo and Araújo 2010; Dalmasso and Nerino 2004). This is due to it involves several processes such as curve net construction and surface fitting (Tsai et al. 2008). One of the problems for unorganized points is to obtain correct connectivity among the points (Yu 1999; Yang et al. 2004; Boudjemaï et al. 2003). Hence, accurate and precise results will be the main aim in designing an algorithm by choosing suitable methods to overcome the drawback of the problems.

Numerous methods have been proposed in reconstructing the surface of a model or objects because it involve in a lot of area such as medical, engineering, manufacturing and geoinformatics. After data collection is done, then will proceed by selecting suitable approaches to deal with the data. But before choosing the method to do the reconstruction, surface representation must be identified and considered. This is very important because the method used in designing the algorithm may have several limitations based on the data collected. If the data set is in unorganized type, then just used the collected data to build a coherent mesh structure which can display as same as the original shape of the object (Boudjemaïet al. 2005).

As mentioned by Júnior et al. (2004), (2007), the topology recovery is the main problems in surface reconstruction. So, the basis in developing the algorithm used in reconstructing the data must be able represent the topology and geometry by fitting the data correctly so that the surface produced will be similar as the original shape of the object.

As mentioned by Zhao et al. (2001), there are two type of surface representation, explicit and implicit. Some reviews mentioned that the surface reconstruction techniques can be categorized into surface interpolation or approximation (Yang et al. 2004; Wahab et al. 2005).But at the same time, parameterization and surface fitting are also considered as the stages involved in the surface reconstruction process as mentioned by Barhak and Fischer (2001). For parameterization stages, actually it is used to determine the topology, shape and boundary of the surface (Barhak and Fischer 2001) or assign parameter values to each point by making some assumptions (Hoffmann 2005).

As general for surface reconstruction process flows, after the data collection is completed, the next step is to represent the topology of the data and is continued by pre-processing steps such as compression and simplification. Depending on the type of data and after completing these steps, it will proceed to construct the data by fitting it to get as same as the shape of the object. Optimization may involve in the fitting process where it will deal with the iterative steps in producing accurate and better results. Next step, sometimes involve some beautification works on the result produced such as adding in data points to overcome some holes produced by the algorithm. The last steps will be the visualization by validating the results produced using third party software. Processing time taken to produce an accurate and optimal result without affect the quality of the surface are the main focus and aim in designing surface reconstruction framework.

3. DESCRIPTION OF COMPONENTS

3.1 MATLAB

MATLAB permits matrix manipulations, plotting of functions and knowledge, implementation of algorithms, etc with programs written in alternative languages, together with C, C++, Python, etc. It includes high-level commands for two-dimensional and three-dimensional knowledge image, image process, animation, and presentation graphics.

3.2 LabVIEW

LabVIEW offers a graphical programming approach that helps you visualize each side of your application, as well as hardware configuration, activity knowledge, and debugging. This visual image makes it straightforward to integrate activity hardware from any trafficker, represent advanced logic on the diagram, develop knowledge analysis algorithms, and style custom engineering user interfaces.

3.3 DSP (Digital signal processing)

Digital signal process (DSP) is that the method of analyzing and modifying an indication to optimize or improve its potency or performance. It involves applying varied mathematical and procedure algorithms to analog and digital signals to provide an indication that of upper quality than the initial signal.

3.4 ULTRASONIC TRANSDUCER

Ultrasonic transducers are a type of acoustic sensor divided into three broad categories: transmitters, receivers and transceivers. Transmitters convert electrical signals into ultrasound, receivers convert ultrasound into electrical signals, and transceivers will each transmit and receive ultrasound. For example, by measuring the time between sending a signal and receiving an echo the distance of an object is calculated.

3.5 OSCILLOSCOPE

An oscilloscope, is a type of electronic test instrument that that permits observation of varied signal voltages, typically as a two-dimensional plot of 1or a lot of signals as a operate of your time. Other signals (such as sound or vibration) can be displayed as voltages. Oscilloscopes are used to observe the modification of an electrical signal over time, such that voltage and time describe a form that is continuously graphed against a label scale.The observed waveform will be analyzed for such properties as amplitude, frequency, rise time, time interval, distortion et al.Modern digital instruments might calculate and show these properties directly.

3.6 ULTRASONIC PULSE RECEIVER

Precise Ultrasonic Pulser Receivers are the building blocks for ultrasonic tests in research and laboratory-based applications like flaw detection, thickness gauging, material characterization tasks and transducer beam profiling. Its receivers include conventional units, high frequency versions, plug in cards, computer -controlled models and supporting accessories like pulser-preamp, remote pulsers, high speed A/D motor,controller boards and A-B-C scan software. These Pulser-Receivers are of high frequencies.

4. REQUIREMENT ANALYSIS

- MATLAB 9.2
- Labview 2018
- Ultrasonic Transducer
  - Transducer with the type of ISS immersion manufactured by the GE Company
- Oscilloscope
  - Agilent's DSOX2024A, 200 MHz bandwidth, and a 10 MHz, Φ0.5 inch
- Ultrasonic Pulse Receiver
  - UPR of the type: 5072PR with the brand of OLYMPUS
- Computer
  - Basic Computer with computational capabilities.
  - Min Req:
    - Pentium Processor or above
    - 2gb Ram
    - 100gb Storage Space
- Step increment motor
- Ultrasonic Frequency
  - 10 MHz frequency

5. PROCEDURE

The process of sensing begins with the Ultrasonic transducer moving along the x-y axis in a predetermined stepwise motion in order to scan the targeted object. The ultrasonic transducer includes modules of a transmitter as well as receiver. The transmitter handles the responsibility of sending the ultrasonic signals while the receiver handles the task of receiving the signals reflected back from the object surface at each step. The step increment motor provides the transducer with the necessary distance between each step. An Ultrasonic pulse receiver receives the analog signals from the ultrasonic transducer and converts them into digital signals. This digital signals is then used to perform computations and thereby obtain the required output, which is also simultaneously monitored using an oscilloscope. The computations performed on the signal are done using MATLAB and LabView.

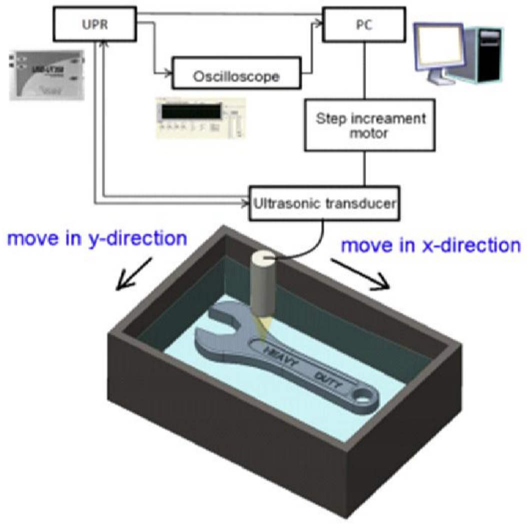

Figure 1: Basic Architecture of the scanner.

6.PROPOSED METHODOLOGY

6.1. *DATA FLOW DIAGRAM*

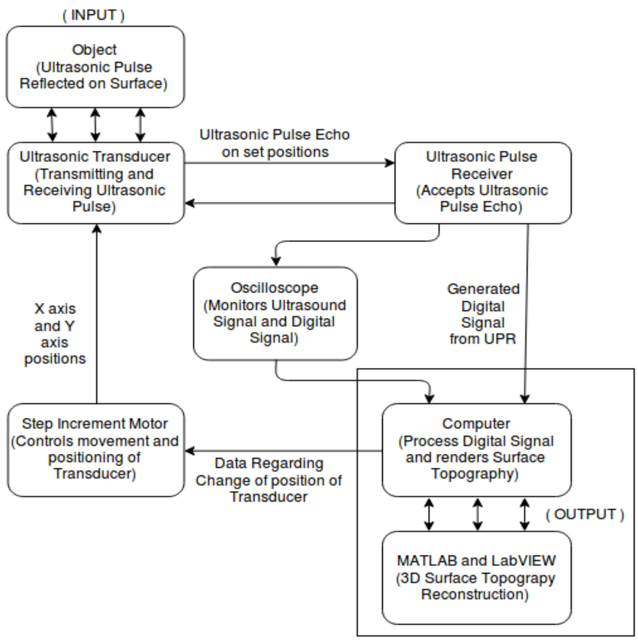

FIGURE 2: Data flow diagram

6.2.ULTRASOUND WAVES

During ultrasonic testing, waves of low amplitude are propagated through such a material so as to measure either or both the time travel and any change occuring in the intensity over a set distance. Principles of pulse echo are utilized to calculate the ultrasonic transit time/ultrasonic reflection time through any body to be measured. Reflections at boundaries of different materials are caused as ultrasonic signal travels through interface of different impedance which depends on speed of sound as well as density. To generate ultrasonic pulse-echo, we need a single ultrasonic transducer with both - transmitter and receiver. Echo generated by the ultrasonic transducer travels through the components and is refracted at the boundaries between various medium and reflected at the surface again. The reflections of ultrasonic waves gives valuable details regarding the surface or regarding the contact situations. The reflected signals however gives information regarding integrity of geometry of the tested object. This study focuses on use of these ultrasounds to digitize surface image for special signal processing, which can be completely partially shaded. The attempt of ultrasonic scanning for specialization of surface images and recalibrations is the motive behind this study.

6.3. *FOCUS AND RESOLUTION OF ULTRASONIC TRANSDUCER FOR SCANNING*

A Parallel Beam of ultrasound generated from an ultrasonic transducer offers very poor resolution. Hence, the resolution of ultrasonic transducer need to b increased by focusing; i.e, reducing the diameter of the emitted ultrasound wave. In the transducer, the plate on the front forms a concave lens, providing initial convergence for the signal. Focus of ultrasound can be adjusted by setting the diameter 'd' using the formula:

$$d = \frac{1.028\ lw\ cw}{f\ D}$$

Where, lw = focal length in water (Eg:1 inch), cw = speed of sound in water (1481 m/sec), f = ultrasonic frequency (10 Mhz) and D = diameter of transducer element (0.5 inch). In the example considered before, diameter 'd' is 0.3mm. Also, as we consider the magnitude of the reflected signal, as an average of 5 wave peak values, we can increase the scanning resolution by reducing the moving step size.

6.4. *SURFACE TOPOGRAPHY RECONSTRUCTION*

When an ultrasound pulse makes impact with the contact between two different materials, it is partially transmitted and partially reflected as well. There are miniscule variations in the values of amplitudes of such reflection signals when the incident pulse hits the surface profile of a 3D object. If the scanning pitches, viz, dx and dy, are as small as required, an analytical difference in data for reflected signals (Using MATLAB) can be used to generate an approximate 3D image of the target, depending on the scanning resolution. The proportion of amplitudes of signal of ultrasound waves reflected depends upon acoustic impedance of object in contact. This Reflection Coefficient, 'R' is defined as:

$$R = \frac{z1 - z2}{z1 + z2}$$

Where, z = acoustic impedance and subscripts referring to two sides of interface. Acoustic impedance is the product of wave's speed and the density of material.
In practice, reflection coefficient differs between 0 and 1.
In this study , we will scan two targets;
An adjustable wrench and a 5⍰ coin. The amplitudes of signals reflected from the water/coin interfaces are collected and 3D images of the topography are constructed.

6.5. *PROCEDURAL DESIGN*

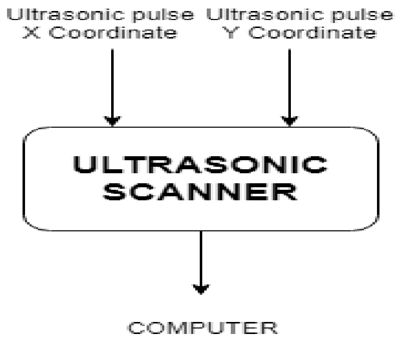

Figure 3: Level 0 Design of Ultrasonic Scanner

Module : Ultrasonic Surface Topography Scanner.

Inputs : Ultrasonic Pulse.

Outputs : Display Graph, Surface Topography Renders.

7. TESTING

7.1: Test targets and experimental apparatus

(a) (b)

Figure 4: Photographs of the three targets used in the experiment

(a)the floating word, 'DUTY', on a wrench
(b) a 5 rupee coin

The above figures ie. a and b are the photographs of the targets used in this study: a wrench and a coin of 5 rupees which are to be scanned. The world on the handle of the wrench, 'DUTY' is scanned using ultrasound and the reflected signals were collected for post signal processing.

Below is the figure that shows the concept of spatial resolution and the step movement of the transducer over the scanned region. The spet movement for the transducer used in this study is 0.1mm, which produces thousands of data points within the scanned area.

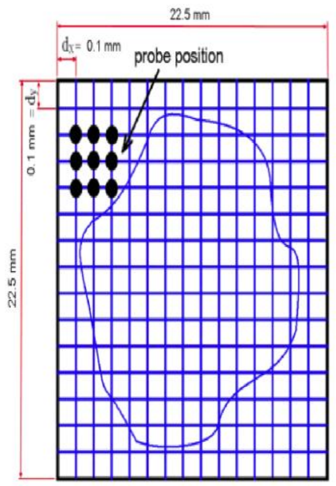

Figure 5. The spatial resolution and stepped movement of the transducer.

The UPR and the transducer were controlled by a prearranged content program, written in LabVIEW. The software configures the emitted pulses, receives the signals and so processes the reflected ultrasonic data to indicate the 3D topography of the surface. The software configures the emitted pulses, receives the signals and so processes the reflected ultrasonic data to indicate the 3D topography of the surface. The ultrasonic transducer was mounted in a water tub and the scanning process is automatic.

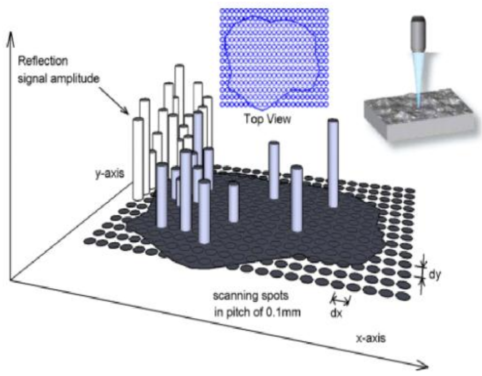

Figure 6: A schematic diagram of the ultrasonic scanning process for 3D surface reconstruction.

The above diagram shows a schematic diagram of the scanning equipment setup. It includes the wrench that was used as a target. A focusing transducer was immersed within the water bath and positioned so the wave was focused on the wrench surface. The transducer was connected to an x-y positioning stage, so it may well be scanned across the assigned region. The dimensions and the resolution of the scan were selected according to the surface geometry and the degree of accuracy required.
The principal equipment include an ultrasonic pulse receiver (UPR), an oscilloscope, a transducer. The UPR provides a voltage pulse, which excites the transducer to produce an ultrasonic pulse. The transducer is connected to an x-y positioning stage, so it could be scanned across the targeted region. The signals received through the transducer are fed to the digital oscilloscope and are mathematically correlated to determine their amplitude changes.

The transducer was moved vertically, in order to focus the ultrasonic signal onto the interface and to determine the maximum reflected signal amplitude. The transducer was moved back and forth in the x and y directions n order to scan the given surface region. The reflected data was collected for the entire region of interest. When the scanning process was complete and the data were captured, the tens of thousands of digital readings for the amplitude of the reflected signals were arranged as a matrix, according to their x-y coordinates. This matrix was then used to plot the target image, using the 'surface' function in MATLAB.

8. RESULT

The surface topography of the wrench:

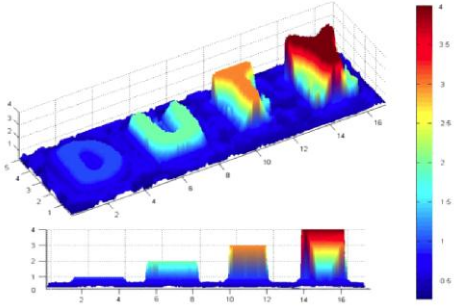

Figure 7. The rearrangement image with the increasing height of the four characters, 'DUTY'.

Above figure shows 3D image of the floating world 'DUTY', on the wrench in the order of increasing heights. The real height of the floating word was about 1.0 mm, all of the reflected digital amplitudes were proportionally recalibrated to range between 0 mm and 1.0 mm. In the final image, the 3D surface topography of the word, 'DUTY', is clearly seen and it is similar to the real shape. The image resolution will be increased by decreasing the step size movement of the transducer.

2. The image of the profile of 5 Rupee coin:

Figure 8. The construction of a 3D surface of the profile of 5 Rupee coin, using the ultrasonic scanning method.

Above figure shows the 3D surface image of the profile of 5 Rupee coin, obtained using the ultrasonic scanning method. The signals that were collected were arranged in a matrix according to the (x,y) coordinates of the transducer.

9. DISCUSSION

This experiment is predicated on the amplitude of the ultrasonic reflection signal to reconstruct the surface topography of the object. Under the premise assumption that the travel distance is extremely short and also the sound velocity is extremely quick, the reflection amplitude is approaching to be linearly proportional to the distance between imaged material surface and transducer aperture. Therefore, this experiment is to verify whether or not the assumption is appropriate and also the reconstruction results is about to the real object surface. The experimental results demonstrate that a single ultrasonic probe will be used not solely to detect flaws within the interior of objects, however conjointly to portray the 3D topography of target surfaces. correct processing of the reflected ultrasonic pulses enable the peaks and valleys of the scanned surface to be pictured. A transducer is moved across the designated area and emits a targeted ultrasonic pulse that impinges on the target surface. The reflected signals are collected and also the digital signals are re calibrated to match the depth of the surface topography and to plot the 3D surface image.

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