Spring 2015

# Modernization of Ultrasonic Immersion Robot

Megan McDunn
*Montana Tech of the University of Montana*

Jayden Richter
*Montana Tech of the University of Montana*

Zach Yarus
*Montana Tech of the University of Montana*

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Montana Tech of the University of Montana

# Modernization of Ultrasonic Immersion Robot

by

Megan McDunn

General Engineering – Mechanical Option


Jayden Richter

Electrical Engineering


Zachary Yarus

General Engineering – Mechanical Option

Fall 2014 / Spring 2015

## Abstract

This senior design project utilized an ultrasonic immersion robot to collect ultrasonic data that was then used to generate three dimensional images. Ultrasonic waves provide a means to evaluate the interior of an object without damaging it. The robot, controlled by a LinuxCNC program, is used to collect data points over a pre-programed area and resolution. The data points consist of the x and y coordinates and ultrasonic amplitudes corresponding to depths. Matlab scripts were written that process the collected data and create images and videos depicting the surfaces and features of the scanned object.

During the course of two semesters the group members returned functionality to the robot system and the ultrasonic system and created the post image processing scripts. These systems were used successfully to create three dimensional images and videos of a key, a steel plate and an aluminum plate for presentation.

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# 1. Introduction

The focus of this project is to modernize an ultrasonic immersion robot. Ultrasonic imaging is a commonly used non-destructive examination (NDE) method. NDE is used to find flaws, cracks, and abnormalities in a specimen without damaging the material itself. The Ultrasonic testing method utilizes high frequency sound waves to conduct examinations. The high frequency sound waves reflect from flaws in predictable ways and produce distinctive echo patterns that can be displayed and recorded by portable ultrasonic flaw detectors.

The project objective is to produce three dimensional images with data acquired from the robot. The data is obtained by scanning the specimen with an ultrasonic transducer. Upon undertaking the project, two out of three primary sub-systems were mostly operational, and a third needed to be created. The first sub-system is the hardware and software of the robot. The software for controlling the robot is already fully developed, and the hardware just needed a few problems fixed and some minor maintenance. The second sub-system is a Sonic HR 1200+ ultrasonic flaw detector. The transducer for this device is attached at the end of the robot arm. It sends collected data through a serial port to the device, and the data is exported to the computer for post image processing. The last sub-system consists of post image processing code that creates an image from the collected data of the scanned specimen. From this image flaws can be detected. Figure 1 shows a flowchart of the entire system.
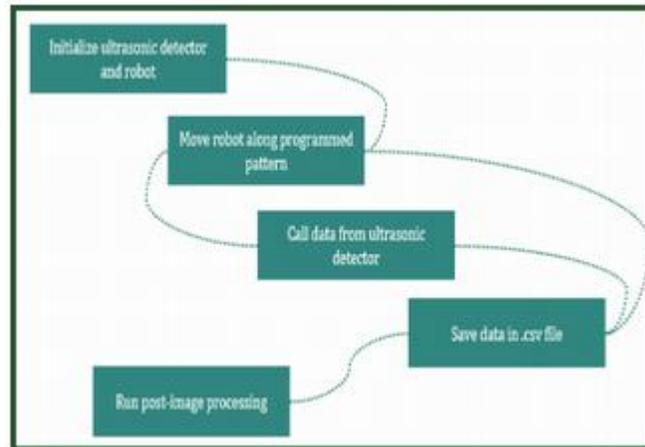
**Figure 1. Flow Chart of System**

## 2. Objectives

The first objective of the group was to familiarize ourselves with the physical components of the immersion robot, review non-destructive ultrasonic testing, and determine the best way to perform post image processing. The robot was in a state of disarray so the group planned on reorganizing the wiring and re-installing the outside panels. The desk with the computer and ultrasonic instrument also needed to be rearranged to increase practicality. Limit switches, an emergency stop and a power relay needed to be brought online to protect the robot. The functionality of the Olympus Sonic+ 1200HR ultrasonic instrument needed to be tested to be sure the transducer and display were working properly.

Manually inputting parameters on the ultrasonic instrument proved to be tedious and time consuming so the group planned to write a C code that would allow the user to retrieve and set the ultrasonic parameters from the computer. A way of retrieving the ultrasonic data from the instrument and compiling it in a separate file also needed to be created. The robot, the ultrasonic instrument and the post image processing needed to be joined through some kind of code.

Ultimately, the group wanted to verify the correct operation of each step and unify all three steps into a single process. This process would be simple and user friendly so students could perform their own scans and create three dimensional images from the collected data.

# 3. The Robotic System and Post Image Processing

## 3.1. The Robotic System

The robotic system in the Non-Destructive Examination (NDE) lab consist of three primary components. These include the desktop computer, its operating system, and several programs, the five axes robot mounted atop the immersion tank, and an advanced lightweight digital ultrasonic flaw detector, the Sonic+ 1200HR, whose transducer is fixed at the end of the robotic arm. The robot and the ultrasonic instrument are integrated via cabling to the PC.

### 3.1.1. The Computer and Operating System

The desktop computer used in the NDE lab runs on a Linux operating system. For the purposes of this projects operations, the software in use includes a text editor and LinuxCNC, a program that executes commands in G code. Several C code stubs were written to calibrate robot kinetics, call the ultrasonic instrument for settings, setup the ultrasonic instrument, run the robot along a specific pattern, and call the ultrasonic instrument for data to be saved as a .csv file.

### 3.1.2.  The Robot

The robot in the NDE lab is a five axes design mounted atop an immersion tank

measuring 82 inches long by 30 inches wide by 17 inches deep.  The robot is integrated to the

computer via a serial port, and is primarily controlled through the LinuxCNC software.

The robot originally ran off of five individual power supplies.  These were Globtek, Inc.

Model RT-3S150-24 power supplies and were rated to rectify 115 V at 3.2 A AC to 24 V at 6.5

A DC.  Early into the start of the design project, one of the five individual stepper drives would

randomly fail due to power loss.  Because the power failure was inconsistent, it was concluded

that the five individual power supplies were beginning to fail most likely due to aged electrolytic

capacitors within the individual power supplies.

The five individual power supplies were replaced with a single, larger power supply that

is currently still installed.  This power supply, an Acopian Model U24Y2300, is rated to rectify

115 V at 10 A AC to 24 V at 23 A DC.  This supply was chosen because its rated capacity

exceeds even the most extreme cases of load due to multiple stepper motor operation, and has

ample capacity for future work and applications related to this project.

The five axes of the robot consists of three translational axes and two rotational axes.

The stepper motors for each axis are controlled by individual Geckodrive Model G210 Stepper

Drives.  These drivers control individual stepper motors, which are American Precision Rapidsyn

Division Model 23d-6204a, that induce the movements of each axes,.

### 3.1.3.  The Ultrasonic Instrument

The Sonic+ 1200HR used in the NDE lab is a hand held portable ultrasonic flaw detector.

The instrument is integrated to the computer via a serial port, and the transducer fixed to the

robot's arm is connected through a BNC cable. This detector uses a 15 MHz signal and is capable of depth sensitivities down to 0.005 in.

## 3.2. Post Image Processing

The post image processing is done on a separate computer running a Windows operating system using the program Matlab. For our use, three individual scripts were developed: "postProcessImagingPG.m", "displayPG.m", and "videoPG.m". Each script performs manipulations to the scanned data in order to produce the final images and videos.

In the m file "postProcessImagingPG.m", the .csv file from a performed scan is loaded into the work space, and assigned to the variable "thedata". This assignment is performed to create compatibility between the scripts and any .csv file loaded. The data's X and Y coordinates are then indexed for matrix assignment later. This is done by finding the resolution, or regular intervals, between points, and then applying the calculated offset and scaling to the coordinates. After allocating a matrix, amplitudes are assigned to X, Y, and Z coordinates to create a four dimensional data "cube". This script then calls either "displayPG.m" or "videoPG.m" based on the desired visual result.

The script "displayPG.m" manipulates the matrix in the workspace created by "postProcessImagingPG.m" to create a mean image of the data and perform planar scans through the three different dimensions of the data "cube". The script "videoPG.m" performs identical operations as "displayPG.m", but also saves frames of the figure created to an .avi video file.

# 4. Calculations

Calculations were performed to determine the final drive ratios of the X and Y axis to create a program that had units congruent to real world measurements. These values were calculated from ratios created by the screw drive mechanisms, gears, stepper motors, and stepper controllers. A formula was also developed to get an estimate of scan time duration based on the dimensions and resolution of the scan. This estimation proves useful in determining practical scan sizes and resolutions.

## 4.1. Final Drive Ratios

### 4.1.1. X Axis

$$\frac{4\ rotations}{1\ inch} \times \frac{14\ teeth}{30\ teeth} \times \frac{200\ steps}{1\ rotation} \times \frac{10\ \mu steps}{1\ step} \times \frac{1\ inch}{25.4\ mm} = 146.982\frac{\mu steps}{mm}$$

### 4.1.2. Y Axis

$$\frac{4\ rotations}{1\ inch} \times \frac{200\ steps}{1\ rotation} \times \frac{10\ \mu steps}{1\ step} \times \frac{1\ inch}{25.4\ mm} = 314.961\frac{\mu steps}{mm}$$

## 4.2. Approximate Scan Time

$$Approximate\ Scan\ Time\ (hours) = \frac{\frac{X\ Size\ (in)}{X\ Resolution\ (in)} \times \frac{Y\ Size\ (in)}{Y\ Resolution\ (in)}}{3600}$$

# 5. Engineering Process

## 5.1. What Worked

Each group member became familiar with the software controlling the systems; these include the Linux OS, C code and G code. Each member also learned to control the robot manually and to write G codes that the LinuxCNC could read to automate a scan.

The ultrasonic instrument and transducer were tested with varying specimens to verify normal functioning. Two test plates were made with holes drilled through them and into the sides to test the ultrasonic system. The ultrasonic system, moved around the tank by the manually-controlled robot, was able to detect the thicknesses of the test plates and locate the drilled holes. Holes drilled into the side, "invisible" from the top surface of the plate, were also detected. A built-in tool in the instrument called the Gate was used to confirm the thickness of the plates to measurements taken by hand.

The speeds of the motor controllers, Gecko G210 stepper drives, were found for each translational axes. The final drive ratio was determined and reinitialized so the LinuxCNC operated in the same units as the real world. Before our project, the LinuxCNC moved the robot arm at erroneous increments. This caused the robot to overshoot and undershoot desired locations, greatly skewing scan accuracy. The robot arm is now able to make precise movements on each translational axes.

The original faulty power supplies were replaced by a single larger power supply that will better suit the needs of current and future work. The old power supplies were failing due to aged capacitors within them. The new power supply provides a higher rated capacity and can easily handle the load of multiple stepper motors running at once.

The systems that still need to be replaced or repaired have been identified. These systems include the limit switches, the gimbal and swivel axes of the robot arm, and the outside panels. Mechanical maintenance also needs to be performed, specifically the lubrication of the screw drive mechanisms.

Ultrasound calibration and parameter retrieval codes were written in C to remotely ask for the current parameters and to input parameters from the computer. The parameter retrieval code would report the range, gain, and material velocity. The calibration C file would be updated with the specific parameters, saved, then recompiled and ran in the terminal window and the instrument would have its parameters redefined.

A user-defined M code file was created called M103 that appended the x and y position from the scan and the amplitude data and depths from the ultrasonic instrument and saved it to a data file called thedata.csv. This code was very important because it links the robot and the ultrasonic instrument and allowed the group to run scans while collecting data. The group soon discovered the storage time required was about one second per point regardless of the set dwell time. This revealed another potential obstacle for future work.

The post image processing was done using Matlab Scripts. The three scripts were called postProcessImagingPG.m, displayPG.m and videoPG.m. The postProcessImagingPG.m script is used to import the data into Matlab and turn it into a four dimensional data "cube". The displayPG.m script is used to analyze the processed data and present a figure with four subplots; a mean top image, a scan through the top, a scan through the side, and a scan through the end of the image. The videoPG.m is used to create an .avi video file of the figure created by the displayPG.m script.

Many scans were completed with an assortment of objects and the data processed. The best results obtained were scans of a brass key, a steel plate and a welded aluminum plate. The brass key scan was 3in x 1.5in and had a resolution of 0.02in/step making a total scan of 11,250 data points. Figure 2 shows a side by side comparison of a photograph brass key and the mean image created by the post image processing.
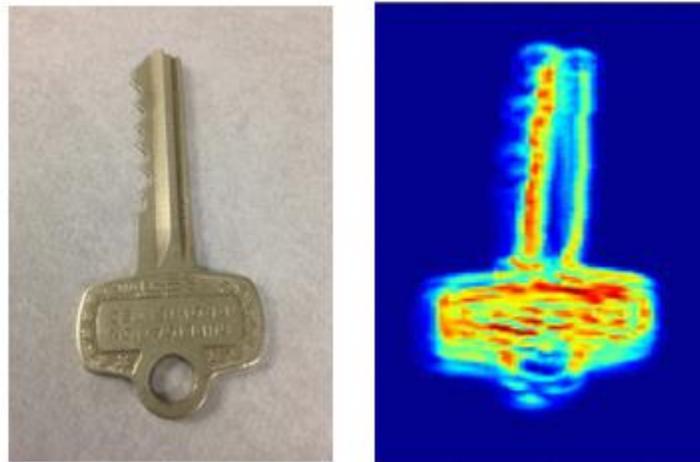


**Figure 2**.**Comparison of Photographic and Ultrasonic Key Images**

Specific details of the key can be recognized such as the teeth, grooves and keychain hole. This scan took around three hours to complete. Figure 3 shows a comparison of the 2in x 2in steel plate with holes drilled through it with the mean image created by the post image processing. The scan was 2.5in x 2.5in with a resolution of 0.02in/step. The scan totaled 15,625 data points and took about 4.5 hours to complete.
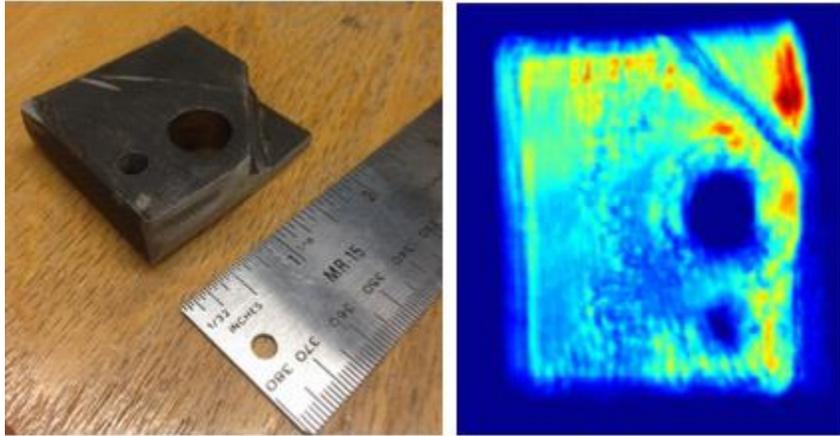
**Figure 3. Comparison of Photographic and Ultrasonic Steel Plate Images**

The two holes drilled through the plate are clearly visible as well as the welded on corner. A hole drilled into the side of the plate can be seen in the ultrasonic image near the top left corner. The hole appears as a yellow blob and demonstrates this system has potential to detect concealed discontinuities invisible from the top surface. The system would have to be finely tuned in order to confidently find discontinuities that are unknown to the user. A scan was taken of a 5in x 7in aluminum plate with two holes and a weld running along lengthwise. The scan was 5in x 7in with a resolution of 0.05 in/step. The total amount of points was 14,000 and the scan took nearly four hours to complete. Figure 4 shows a comparison of a photograph of the plate to the mean ultrasonic image.
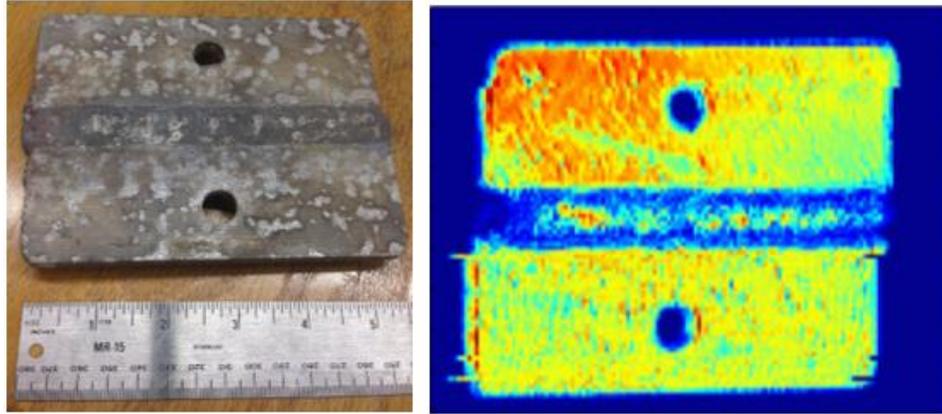
**Figure 4. Comparison of Photographic and Ultrasonic Aluminum Plate Images**

## 5.2.   What Did Not Work

The group never got around to reorganizing the physical components of the robot system so the system is still relatively unorganized. Side panels were never re-installed so power supplies, wires and gearing are exposed. The desk was also not rearranged. The limit switches were never brought online. The reason being the group did not have enough time to learn how the limit switches communicate with the computer via serial port.

The originally projected image concept was never created. Due to problems manipulating the data in Matlab, the sought-after three dimensional image was not created. Technically, a three dimensional image was created, with the color changes depicting changes in amplitude. The group wanted a computer generated solid object that could be rotated and manipulated, such as removing layers in order to find voids. Traditional three dimensional plot commands were inadequate with regards to manipulating the data as desired. An alternative method was used that involved indexing the x and y coordinates from the data file and assigning amplitudes to depths for each x and y coordinate. This data cube could then be examined with planar scans through the object.

The system was not unified into a single, push-a-button-and-go process. The computer in the lab with the robot did not have Matlab to perform the post image processing. The data needed to be brought to another computer via flash drive and the post image processing ran from there. No way to build an image from data being collected in real time was looked into. Due to the nature of having to manually adjust the range and the gain on the ultrasonic instrument before each scan, a simple push-a-button system was hardly possible.

### 5.3.  What Would We Change

The only significant change the group would make if continuing the project would be to enlist a dedicated CSCI student with a higher level of understanding in several programming languages. This would allow other group members to allocate more time to design goals related to their degrees.

## 6.  Future Work

More time needs to be spend narrowing down specific range settings. If the range is set too high, the ultrasonic waves reflect off the front and back surfaces several times over causing confusion when analyzing the data. The .m files could be revised to increase efficiency and image clarity. A method could be created to minimize "noise" and only include actual amplitude values from appropriate surfaces. The bottom of the tank, the transducer itself, and reflections of the front and back walls cause noise that decrease image clarity. Some investigation could go into speed velocities for alloys and heterogeneous materials. This project focused on homogenous metals in an attempt to reduce complications and obtain good results.

Unifying the three systems is still a possibility and would significantly reduce the time it currently takes to run scans and process the data. However, manually manipulating the ultrasonic instrument may always be required to initially set up a scan.

This project was never negatively affected by not having operational limit switches, but the robot could be manually-controlled or programmed to run off its rails causing significant damage. Limit switches should be a priority if this project is resumed in the future.

The transducer does not point straight down and the tank floor is not level. This causes significant range problems when the material being scanned is very thin or if the material is very long. Collected data is significantly affected by these problems.

Decreasing the data collection time would be worth looking into. Currently the collection time is about one second per point and his held up by the saving time of the ultrasonic instrument. This adds up radically when taking tens of thousands of data points.

## 7. Student Contributions

### 7.1. Megan McDunn

Megan joined this project because she had previous experience with ultrasonic testing techniques and she was interested in developing codes to run scans and process scan data. Megan was responsible for drafting weekly reports, the project Gantt chart, and she was the primary author of presentations. Her weekly meeting attendance was satisfactory and she was instrumental in developing and running UT scan scripts and post image processing code.

### 7.2. Jayden Richter

Jayden was asked to work on the project for his background knowledge of electrical hardware and basic programming capabilities. He attended nearly all weekly and other group meetings, and also spent much individual time updating electrical systems and checking UT scan progress. His greatest contribution was the development of post image processing software along with other C scripts used in the UT scans.

### 7.3. Zachary Yarus

Zach joined this group having previous experience working with nondestructive ultrasonic techniques in a welding nondestructive evaluation class. He maintained satisfactory meeting attendance and put in extra hours in the lab. More or less, he was in-charge of running scans and distributing the collected data to the other group members. Also, he contributed in creating reports and presentations and was the primary author of the User Manual.

## 8. Conclusion

Overall, several of the original design goals were met. These included reinstating robotic and ultrasonic systems to operating condition and developing code to create images from data acquired during scans. Three dimensional images and videos were created of several different objects of varying material and structure. While the three sub-systems were not linked together into a simple process, all parts function independently.

The members of the group encountered and tackled many of the challenges faced in the real world. These realities included deadlines, time management, and prioritization of tasks and also encompassed many factors of teamwork such as collaboration and dividing and conquering.

Lastly, the group had to overcome the harsh realities of dealing with inevitable failures and developing compromises.

   Future projects working after this group will have clear documentation and instructions to pick up where the project was left off. These documents are archived in hard copies and also saved in digital form for long term storage, preservation, and reference.

**Appendix A: User Manual for Initializing an Immersion UT Scan and Performing Post Image Processing**

**Appendix B: Ultrasonic Instrument Setting Retrieval Code**

**Appendix C: Ultrasonic Instrument Calibration Code**

**Appendix D: Generic_Scan_Orig.ngc File**

**Appendix E: Matlab Scripts for Post Image Processing**