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Laser Ultrasound Spectroscopy Scanning for 3D Printed Parts

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Abstract

One of the challenges of additive manufacturing is quality control due to the possibility of unseen flaws in the final product. The current methods of inspection are lacking in detail, too slow for practical use, or unable to validate internal structure. This report examines the use of laser ultrasound spectroscopy in layer by layer scans of 3D printed parts as they are created. The result is fast and detailed quality control. An additional advantage of this method is the ability to cancel a print as soon as a defect is detected, therefore saving materials and time. This technique, though simple in concept, has been a challenge to implement. I discuss tweaking the 3D printer configuration, and finding the optimal settings for laser scanning small parts made of ABS plastic, as well as the limits of how small of a detail the laser can detect. These settings include the frequency of the ultrasonic transducer, the speed of the laser, and the distance from the laser to the part.

Introduction

Current methods of inspecting additive manufactured parts are expensive and ineffective. There are external probing methods, such as Coordinate Measuring Machines, that can only find external properties of a part. There are internal probing methods, such as X-ray scanning that is hazardous and expensive in both time and money, or CT scanning that cannot detect cracks and gets less sensitive as the part gets bigger. None of these systems are used for in situ inspection. The in situ methods that do exist currently rely on photographic systems to take images of a 3-D print layer by layer and compare it to the CAD model of the print job. This method cannot inspect the internal properties of a part, or the dynamic properties of a part.

In contrast, we are developing an in situ method using Acoustic Wavenumber Spectroscopy (AWS). This will allow for inspection of the part as it is made so that any defects can be detected early so that materials and time can be saved. It can also be used to verify the structural integrity of a print so that 3D printed parts can be used in practical applications, as opposed to just prototyping.

In addition to these benefits, this method is also fast and relatively cheap. It uses an ultrasonic transducer to provide an excitation of the part. A laser Doppler vibrometer is then used to measure the response of the part with a raster scan. This allows us to identify defects based on different wavelength responses.

The goal of my investigation was to find the optimal settings for using the ABS scanner, and to find out how small a flaw I could identify. I was able to find these settings, which are detailed in the conclusions. I was also able to find the ratio for the smallest level of detail possible on a scan. This ratio is controlled by the size of the scan area. The smaller the area, the better the possible detail, in a ratio of $15mm^2$ to 1/32mm.

This report describes the methods and challenges in tuning the settings for the AWS system, the results achieved, how this work impacts mission, and what work must be done in the future to further refine this technique.

Progress

The Challenges of the 3D Printer

The first and biggest challenge was getting the 3D printer to work properly. The z-axis was badly off-kilter and the lead screw had to be manually turned so that the left and right sides were at the same level. The machine then had to be zeroed so that the print surface was level. The extra covering on the glass plate that was designed to make the print stick better did not work, and it ripped in the center. I also had to find the optimal parameters for printing in ABS, because the printer was very picky and it would destroy a print on its own due to a lack of adhesion between the plastic and the print bed on the first layer. These parameters are things such as the temperature of the heated print bed, the temperature of the extruder, and the best combination of glue and tape on the print bed. Unfortunately, these parameters seem to change with every model, and while I found an average to start with that helped minimize the problem, it is still imperfect as the first layer does not always adhere to the print bed. This made it difficult to create a ‘control print’ with no defects to compare to one with defects. It would often take several tries to achieve this ‘control print.’

The Challenges of the Software

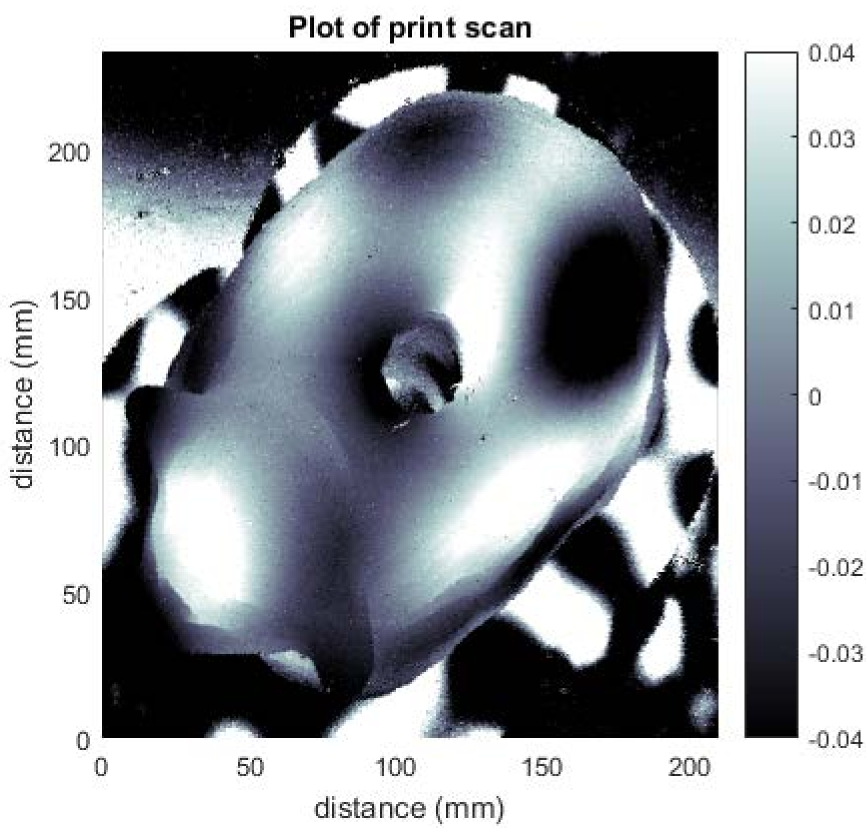
The second greatest difficulty of this project was the software for the AWS system. For most of my time at this internship it was severely broken. At the time of this writing, the code is the greatest weakness of this project. It needs to be made more user friendly with greater control over the values for the speed of a scan and the pixel spacing. The limitations that I hit were the fault of the software, the most significant of which are the memory leaks. While trying to find the limits of this method, the scans would fail faster and faster until I was forced to close the program. When I opened the program again, it was able to perform a full scan. This means the program has to be closed after every scan, otherwise it cannot handle a second scan reliably.

Results

I did have success in finding the limitations in the scope of the project in its current form. The level of detail in a scan is at a proportion of 15mm^2 to 1/32mm. This is the size of the scan area in relation to the highest possible level I was able to reach. This scan that reached this level of detail is shown in Figure 1.

This scan is of the top view of a sheep bead [1]. The colorbar on the right represents the wavenumber, which in this instance is the spatial frequency of an ultrasound wave in one cycle per meter. The gradient near the top is the print bed, and the sharp black and white whorls around the sheep is the wide first layer of the print. You can clearly see the hole in the center of its body and its head. You can also see some of the print layers on its head and around the edges of its body.

Figure 1: Scan of a sheep bead print



As for the ideal settings, I found that the best possible frequency for ABS plastic is 80.5 KHz. The current method for setting the pixel spacing in this software is less than ideal. In order to have a scan at a higher detail than ½ mm, I had to increase the value for the distance between the laser and the part. By doing this, I was able to make the relative distance greater because the laser thinks that it is farther away than it is, therefore it compensates for the distance by adding more detail. Doubling the distance halves the pixel spacing.

Future Work

Ideally, the best way to implement this technology would be a way to turn the code into a plugin for the 3D printing software. Integrating these two parts together would streamline the process of inspecting parts. This could allow the two software modules to communicate so that the inspection process could be entirely autonomous, with the print pausing after every layer so that the part can be scanned, then continuing after the scan for that layer has finished.

Another possible path to take this technology would be to turn the scans into a 3D model that one could compare to the g-code model generated by the 3D printing software. This could allow for a faster method of visually inspecting a part’s external properties. This would be most useful in applications where the internal structure of a part is not as critical as the external structure.

As for inspection of a part while it is being printed, algorithms could be developed to check the scans for defects by comparing the results of a scan to what is expected from the wavenumber. This could make it so that there is little to no need for human intervention to inspect parts.

Impact on Laboratory or National Missions

In situ inspection of additive manufactured parts can allow metal printed parts to be used for more than just prototyping because as an inspection method it allows a higher level of accuracy and peace of mind for the structural stability of a part. This provides a greater range of freedom for designing complicated parts, because things that would not be possible to make using traditional machining methods would now be available for design and use.

The AWS inspection method in general allows for a much faster inspection of parts with the least amount of equipment and contact with the part.

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Conclusions

In my research I have found that the software that has been developed for this project is where most of the limitations seem to stem from. I did not find limits to the hardware itself. The cleanest method to fix the software would probably be to remake it from scratch in a coding language that has better memory handling.

I found that the highest level of detail possible with the current software is a proportion of $15mm^2$ scan area to 1/32mm relative pixel spacing. This means that for every square millimeter of scan area, there are 480 pixels worth of information. With the proper plotting of these scans, it means that in theory it is possible to detect a flaw as small as 2 square micrometers.

References

[1] Sheep Bead Model: https://www.thingiverse.com/thing:491013

Appendix

Participants

- Eric Flynn – mentor
- EliseAnne C. Koskelo – previous work with the systems
- Nick Stull - helped with the code and understanding the systems

Scientific Facilities

I used a 3D printing lab in the National Security Education Center (NSEC) as part of my project activities.

Notable Outcomes

Brennan, G. (Aug, 2017) Laser Ultrasound Spectroscopy Scanning for 3D Printed Parts. Internal presentation.

Figures

Figure 1: Scan of a 15mm^2 sheep bead print at 1/32mm pixel spacing.