Development of a Melt Pool Tracking Vision System for Laser Deposition

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Abstract

This paper chronicles the development of a vision system for tracking melt pool morphology in the laser metal deposition process. This development is to augment an existing temperature feedback control system. Monitoring both the temperature and shape of the melt pool is necessary because of the effects of local geometry on the cooling rate at the melt pool. Temperature feedback alone cannot accommodate this effect without complex process planning. The vision system's hardware, software, and integration into the laser deposition system's controller is detailed in this paper. Preliminary testing and the effects on deposition quality is also discussed.

1 Introduction and Motivation

There are numerous structural components for air and vehicle frames, propulsion systems, and other industrial applications that are made from oversized forgings or from castings that have high raw material content. These components are complex in shape and can be made from expensive alloys. Current manufacturing processes for these components are costly and labor-intensive, exhibit long manufacturing lead times, and require complex tooling. The maturation of rapid manufacturing method will reduce lead time for part production and improve remanufacturing capabilities. Therefore, there is a strong need to directly produce and repair complicated functional parts to a known and repeatable condition. The following trends have already helped bring interest in the concept of rapid manufacturing:

- Smaller lot sizes / More segmented product offerings (mass customization)
- Shorter development cycles
- Shorter program/platform life
- Rising material costs
- Environmental pressures (governmental and social)
- Desire for part consolidation (DFM/DFA)

Despite these trends, no process currently exists which satisfies industrial needs in this changing marketplace. Only a few niche applications currently use rapid manufacturing techniques for production parts. This is possible due to two factors:

Tradition - The current industrial work force is trained and familiar with the traditional subtractive manufacturing methods.

Quality - Additive processes do not have the history behind them that the traditional subtractive processes do. Repeatability of both geometry and material characteristics for rapid manufacturing processes are still not well understood.

This work attempts to address an issue associated with quality concerns. Consistent volumetric addition via laser deposition requires some knowledge of the current state of the melt pool. Real-time tracking of melt pool temperature is impossible through contact measurement and difficult via non-contact methods. This work presents an alternative approach which attempts to use the melt pool size rather than temperature to control the process.

2 Background

Since its appearance, rapid prototyping technology has been of interest to various industries that are looking for a process to produce a part directly from a CAD model in a short time. Among them, direct metal deposition process is one of the few process which directly manufactures a fully dense metal part without intermediate steps. In this process, metallic powder is injected into a laser generated heat spot where the material is melted and forms a melt pool which quickly solidifies into metal layers [3, 4, 9]. Parts are built to completion layer by layer, from bottom to top. This process is similar to other rapid prototyping technologies in its approach to fabricate a solid component by layer additive methods.

Funded by the National Science Foundation and Air Force Research Laboratory, the Missouri University of Science & Technology (MS&T) has developed the Laser Aided Manufacturing Process (LAMP) [5–8, 10–14]. The system, illustrated in figure 1, combines both deposition and machining in a single setup. This eliminates part re-setup which is a significant advantage over processes which require post-processing in separate machinery. Any production part will have a specification for both its geometric and mechanical properties. Microstructural characteristics are a major factor in determining the performance of a material. Solidification microstructure is a function of the temperature gradient in both space and time [2, 15]. The part geometry determines the heat conduction properties of the structure as it is being built, so it has an effect on the thermal history of the part, and thus the solidification microstructure. Constant conditions are necessary for consistent processing. Consistent conditions require some kind of feedback, thus the impetus for this work.

3 Imaging Design Concepts

The primary challenge for image capture in this project is the reflection of the laser beam off of the shiny surface of the melt pool. Three successive concepts were tested for dealing with this issue. The first two are attempts at selecting what portion of the spectrum of light coming from

Figure 1: The LAMP process during a repair operation - The laser cladding head is shown on the right. A touch probe head is currently held in the machining spindle. A repaired H13 tool steel die component is held in the vise.

the melt pool reach the CCD sensor. The third design looks at a single wavelength of light that is well outside the expected response of the melt pool. The sensor used for this study is a 1.3 megapixel CCD from the commonly available Microsoft VX1000 webcam.

3.1 Filtering and Selective Reflection

The first imaging concept tested was a simple filtering design. The filter stack consists of a piece of heat proof glass to remove IR and a short pass filter to cut off wavelengths longer than 700nm. A 300μm pinhole lens was used rather than the webcam's included optics as a way to further cut down on the signal reaching the CCD. Figure 2(a) shows the configuration of this design.

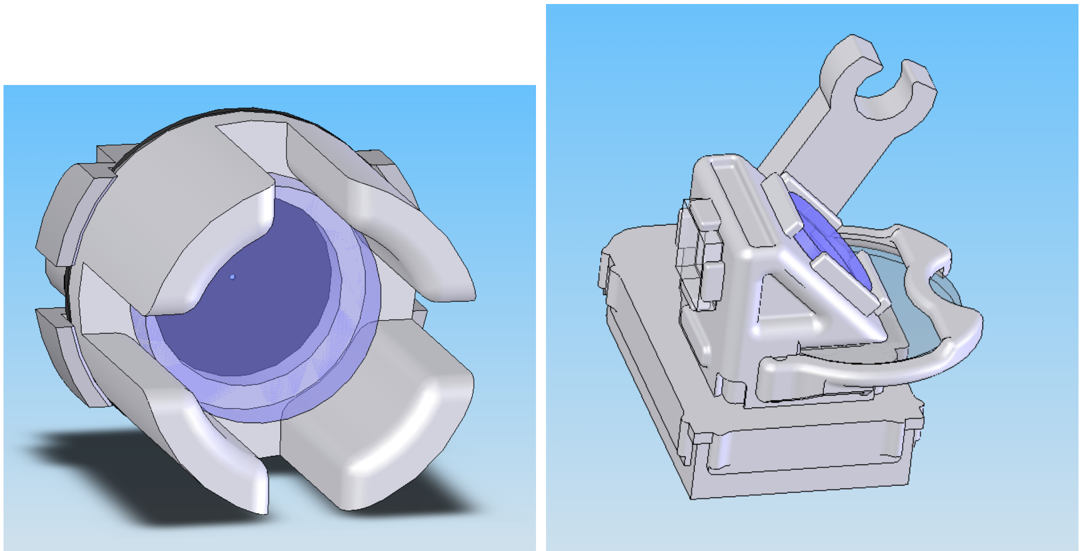
The second concept, illustrated in Figure 2(b), uses a more aggressive approach to remove the laser reflection from the image. A piece of heat proof glass cuts out some the IR. Then a cold mirror reflects visible light through a green dichroic filter and a polarized glass disc.

Both the first and the second designs resulted in image acquisition such as the image shown in Figure 3. Measurement techniques for the captured images are discussed below in Section 4. The melt pool is concealed by the bright bloom in the center of the picture. The second bright spot in the upper right of the image is the reflection of the melt pool on the copper nozzle tip. This is obviously not a good solution for imaging the melt pool, so a third option was devised.

3.2 Illumination

To avoid the imaging problems associated with the previous two designs, the third imaging concept seeks to eliminate all of the thermal radiation from the melt pool. According to black body radiation theory, as illustrated in Figure 4, the melt pool should never radiate light in the UV range. Thus, that is where this design concentrates.

To image the melt pool using light in the UV range, a narrow bandpass filter was used to cut the camera's range down to 389nm to 399nm. Since this is outside the range of visible light as well the melt pool's thermal response, an external illumination is needed. Three UV (390nm - 395nm)



(a) Pinhole lens holder and filter attachment for the simple filtering concept.

(b) Assembly of the reflective design showing the heat resistant glass (clear), the cold mirrior (dark blue), and the polarized glass (gray).

Figure 2: Solidworks 2008 assemblies of the first two concepts.

LEDs were used. Figure 5 shows the configuration of the Illumination design. Unfortunately, this design has not yet been tested as of the time of this writing.

4 Image Processing and System Integration

Image processing for this project is done using the Python bindings for Intel's open source computer vision library, OpenCV. This library provides the functionality to both capture images through the VX1000's video4linux driver interface and do the necessary operations to locate and measure the melt pool within the image.

Capturing a clear image of the melt pool during laser deposition can be difficult due to the powder obscuring the image. Others have attempted to solve this issue with a fuzzy thresholding algorithm [1]. However, if the input is a video stream, simply taking the median value of each pixel from a set of frames will effectively erase fast moving objects from the image. This is similar to a trick used in image processing to erase tourist from a photo by using this operation on a set of stills taken over the span of a few minutes.

To measure the melt pool, a best fit ellipse is fit to a binary image, with the major and minor axes of the ellipse being the information of interest. The orientation of the camera is then used to do a perspective correction. Ideally, multiple cameras will capture simultaneous images from different angles to achieve a good approximation of the melt pool shape. This information is then passed to the LAMP system's National Instruments Real-Time controller via a serial USB connection.

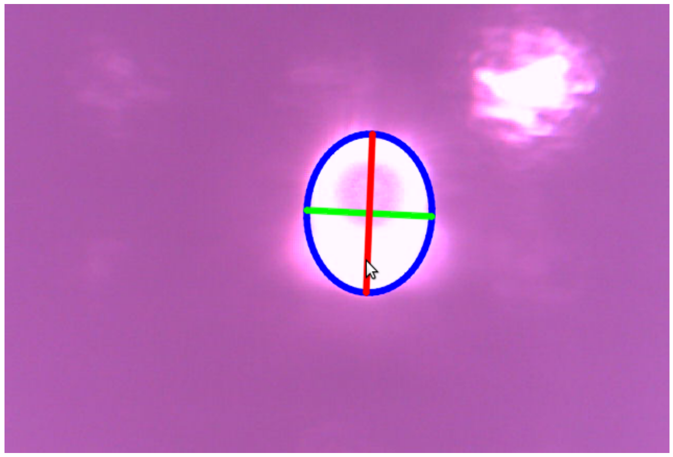


Figure 3: This is a sample result from the imaging system. The blue ellipse is a best fit ellipse over what it thinks is the melt pool. The red and green lines are the major and minor axes, respectively.

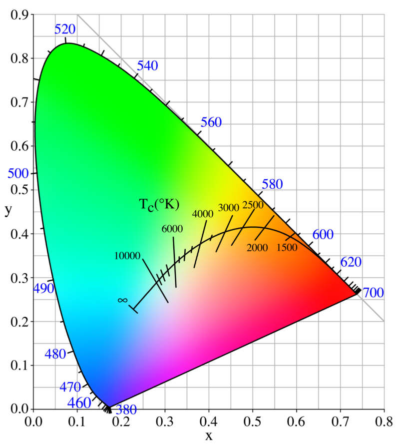


Figure 4: The CIE 1931 XYZ Color Space relates black body radiation color and temperature. (Image courtesy of Wikimedia Commons)

5 Discussion and Conclusion

During this work, all of the structural components for the concept imaging designs were fabricated from ABS plastic on a Dimension FDM machine. When testing these designs, it became apparent that the white ABS plastic did very little to block the intense near-IR and IR radiation coming from the melt pool. In fact, the image was completely saturated even when the melt pool was not in the camera's field of view. This problem was remedied by shielding the camera with Aluminum.

A system for measuring melt pool geometry is a necessary component for a robust laser deposition process. This work represents steps taken to implement such a system. Unfortunately, equipment problems in LAMP lab at MS&T prevented the completion of this project in time for inclusion into this paper.

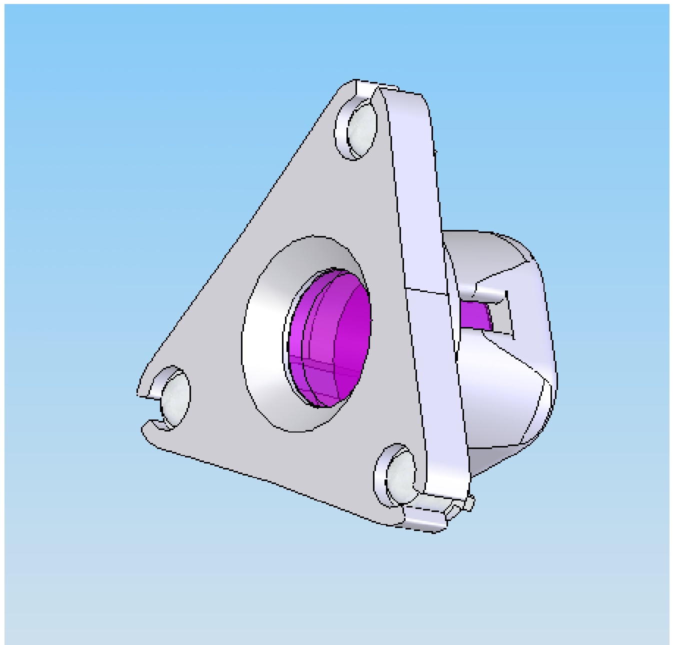


Figure 5: Configuration of the UV Illumination design

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