Development of a low cost imaging system for a laser metal deposition process

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1 Abstract

The size of the melt pool created by the laser is one of the most important quality characteristic in a laser metal deposition process. This paper discusses the development of a low-cost vision system to automatically determine the size of the melt pool for in-process control.To cope with the intense infrared signal from the laser and melt pool, external ultraviolet illumination is paired with narrow bandpass filters on a usb microscope to achieve a clear image of the melt pool. The sensitivity of the melt pool to changes in system parameters and various substrate materials are also evaluated.

2 Introduction

Laser metal deposition is a type of additive manufacturing process in which a laser is used to create a melt pool to which additional material (typically metals) is added to build up a part. The material to be added can be transferred onto the substrate by powder injection,preplaced powder or by wirefeeding [1]. This process,in conjunction, with a computer numerical control (CNC) motion system ,enables us to build three dimensional parts which are functional in their intended purpose.The various main process parameters are incident laser beam diameter,process speed, material feed rate.The other factors involve gas flow rate,depth of focus and laser absorbtivity of substrate[2].

The size of the meltpool is one of the most important parameters in laser metal deposition. The melt pool size is highly dependant on the distance between the focussing lens and workpiece which inevitably changes during the laser metal deposition process.Hence, monitoring the size of the melt pool is an important part of the quality control process.Conventional image vision processing techniques use infrared filters along with a high speed shutter along with synchronising the laser with the shutter[4]. These propietary vision systems are relatively expensive to buy and maintain. Previous approaches to image the meltpool include [3]

1. Filtering out IR radiation along with pinhole concept
2. Dichroic filters with polarization lens

Both the previous approaches were unsuccessful due to the the inability of the lens to filter out the large amount of IR radiation emitted by the melt pool.We try to implement a low cost alternative solution to the conventional image processing process which enables us to determine the size of the melt pool and study the effect of various system parameters on the melt pool size.

3 Concept

During the laser deposition process, the laser heats up a finite area of the substrate and forms a meltpool.This meltpool radiates out energy of different wavelengths depending on the type of laser used,intensity,substrate material etc. According the black body radiation theory ,the wavelength of light emitted by the melt pool cannot be in the ultraviolet range. According to Aalderink et al,[5] the external illumination concept can be utilized if the signal to noise ration is of sufficient quality

$$S/N = I_S/I_N$$

where I_S is the irradiance of reflected illumination light that reaches the image sensor and I_N is the irradiance of the welding process that reaches the image sensor. We seek to eliminate the infrared radiation emanating from the melt pool entirely while providing our external illumination of different wavelength onto the melt pool.

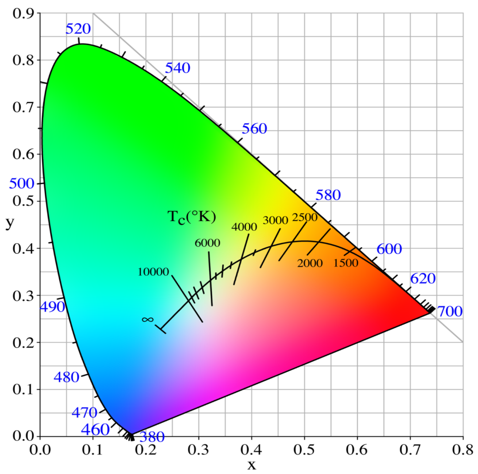


Figure 1: The CIE 1931 XYZ Color Space relates black body radiation color and temperature.Image courtesy of Wikimedia Commons

External illumination in the form of highly intense ultraviolet light ,when incident upon the meltpool should provide a clear image using special filters.

4 Experimental setup

The MicroLAMP (μ LAMP) consists of a 50 Watt(W) fiber coupled diode laser whose focussing lens is mounted on the vertical Z axis of a CNC system while the substrate is placed on the X-Y motion table. The focussing lens of laser is maintained at a constant standoff distance of 54 mm while the substrate is moved beneath the laser. The substrates were cleaned prior to deposition using isopropyl alcohol to remove any dirt or grease on the surface. The CNC table is driven by an Sanguino microcontroller connected to a computer via USB. The

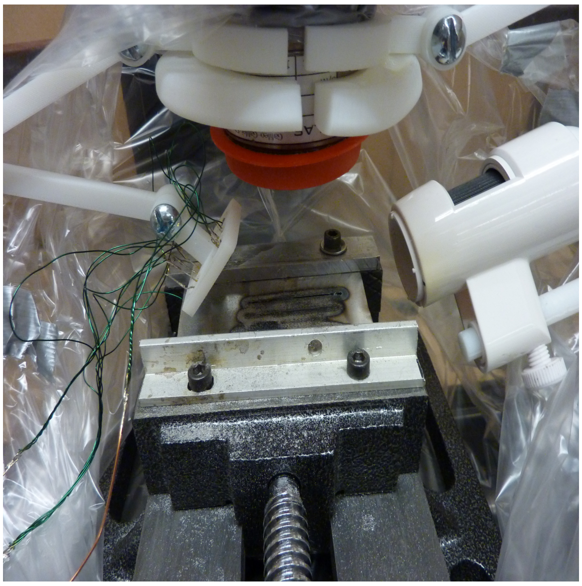


Figure 2: Experimental setup of Laser and vision system

substrate is secured in a vise and an inert atmosphere of argon gas is provided to prevent oxidation of the deposit on the substrate.

4.1 Image Processing setup

4.2 External illumination

An array of Ultraviolet(UV) light emitting diodes were focussed onto the melt pool area. The wavelength of ultraviolet light emitted is in a very specific range of 390-395 nm. The LED's are run at 90 % of their maximum capacity to avoid burning out and ensure longer operating life. Since the peak spectral response of the LED's are at 18 degrees emission angle , the UV array is tilted appropriately towards the substrate to ensure that the melt pool receives the highest spectral intensity of UV light. A fixture was designed and prototyped by a Fused deposition Modeller to hold the LED's along with the USB microscope.The total optical power output of the array is approximately 52.92 mW

5 Image acquisition setup

A Dinolite USB microscope with a CMOS sensor was selected with a maximum magnification of 200X . A CMOS sensor was preferred since it has high sensitivity in the ultraviolet range compared to CCD sensors. Hence the reflected UV radiation coming off the meltpool will be absorbed by the image sensor present in the microscope.The microscope was fitted with a narrow band pass filter which only allows UV light of wavelength 389-399 nm to pass through.A traditional Infra Red (IR) filter is used along with the narrow band pass filter to remove any unwanted IR from the image. The white LED illumination lights inbuilt within the microscope were removed due to interference with the image.The microscope and UV lights are mounted in a rapid prototyped fixture by a Dimension Fused Deposition Modeller. The fixture was designed as to allow various angular adjustements to the ultraviolet illumination and the microscope.

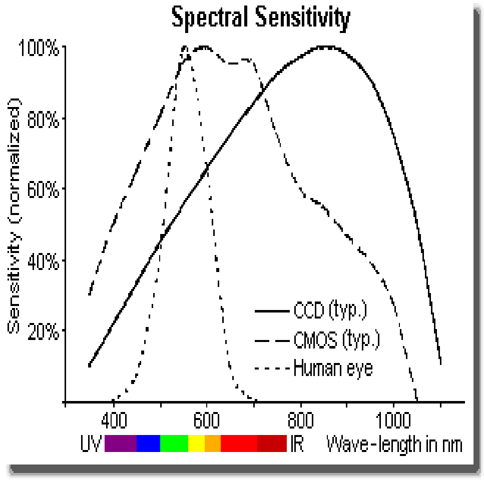


Figure 3: CMOS sensitivity to different wavelengths

6 Postprocessing

The raw image from the USB microscope is post processed using OpenCV image processing libraries in Python. The various post processing steps carried out include filtering,thresholding,smoothing. OpenCv software was used because of its ease of use in image processing and also because it was open source .Since the microscope is mounted at an angle to the meltpool perspective correction is applied to remove perspective error. The various post processes carried out include

1. Obtaining the image-The output from the usb microscope is video.A frame is grabbed from the video to do image processing
2. Converting the image to grayscale-The intensity values of light are observed in a grayscale image
3. Smoothing the image-To remove noise in the image
4. Thresholding the image-This is done to effectively differentiate the melt pool from the background.
5. Contour fitting and ellipse fitting-Since the melt pool obtained is not always circular,an ellipse is fitted to the melt pool contour to obtain an average measurement of the melt pool size
6. Measuring melt pool size

The necessary camera intrinsic matrix and distortion coefficients are determined using inbuilt calibration functions in OpenCv which enables us to obtain the best melt pool size approximation and minimize radial,tangential distortions [6].Since the microscope is not mounted coaxially with the laser,it is necessary for us to obtain a bird's eye view of the melt pool to avoid error.

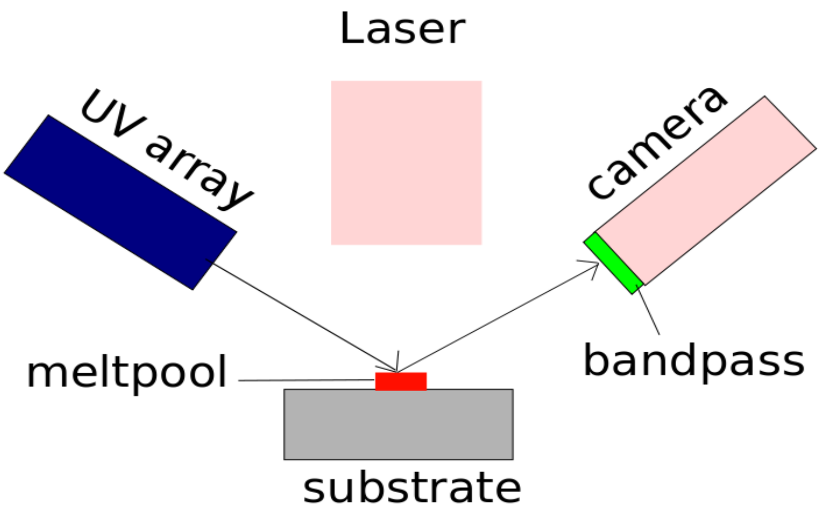


Figure 4: UV array and microscope setup

7 Results

The following image processing algorithm was developed using OpenCv image processing library.The raw image obtained from the vision system is subjected to the above image processing to obtain the melt pool size. Other parameters such as circularity can be easily ascertained from the data. The overall cost of the system , which includes cost of the usb microscope, filters and LED's is approximately 400 dollars excluding the cost of fixturing which is relatively inexpensive compared to commercial systems available in the market today.

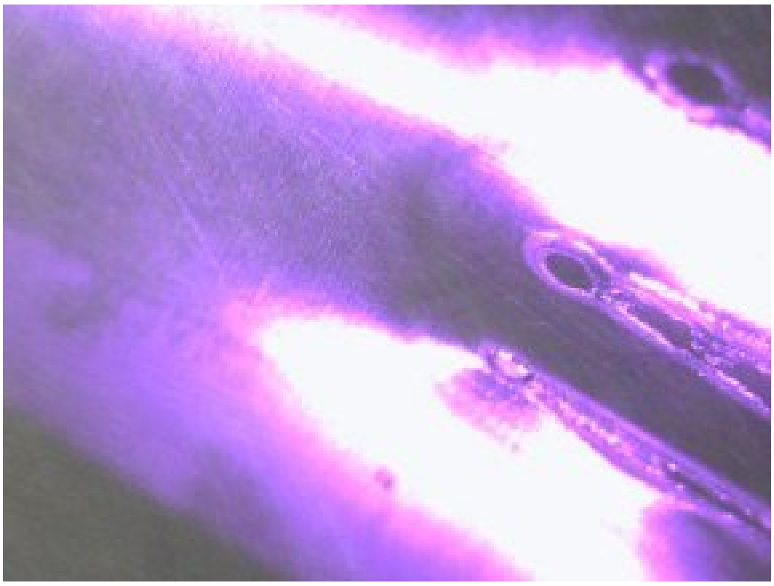
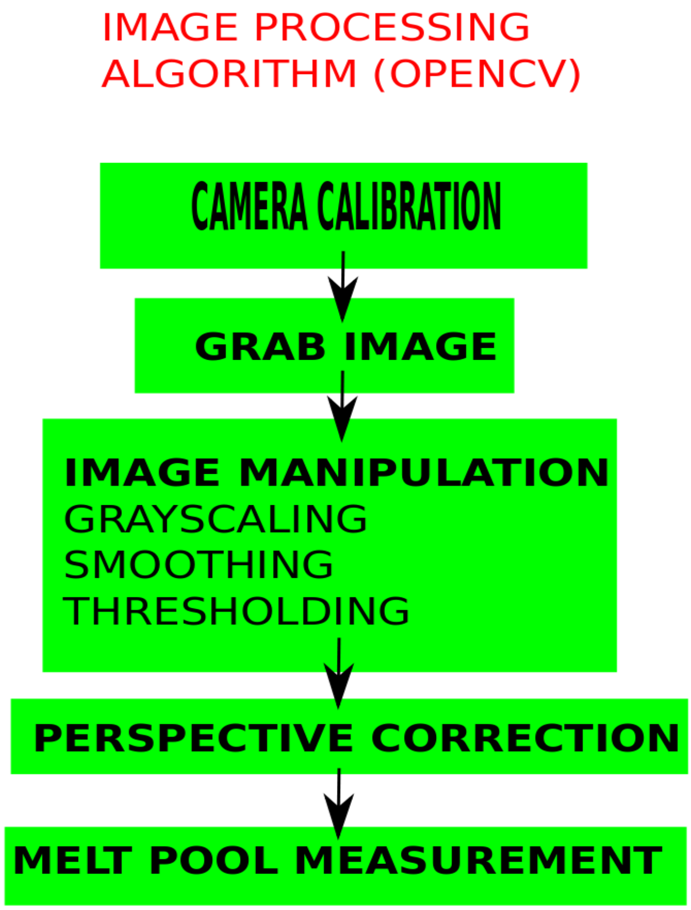


Figure 5: Raw image obtained from camera



8 Conclusion and Future Work

The vision system is currently capable of acquiring images of the melt pool and processing it to acquire useful data,specifically melt pool size. Due to equipment problems we were unable to obtain sufficient real world data from the vision system.Future work involves integrating the imaging system with the mini laser deposition system so that in process changes are detected and corrected to obtain repeatable and good quality deposits.

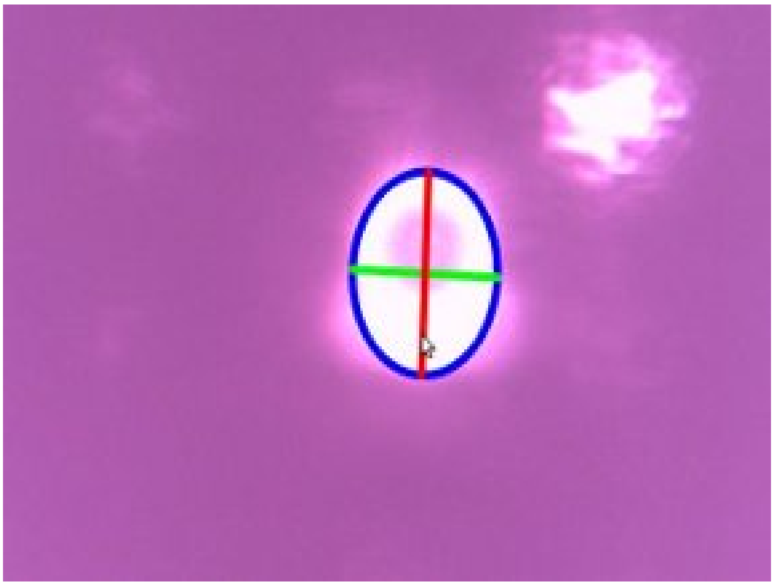


Figure 6: ellipse fitted onto melt pool

9 Acknowledgement

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