

# Minimal Waste Galvanometer Field Correction for Additive Manufacturing

**B.A. KING<sup>1</sup>, G.R. BENNETT<sup>2</sup>, A.E.W. RENNIE<sup>1</sup>**

<sup>1</sup> Engineering Department, Lancaster University, Lancaster, UK

<sup>2</sup> Euriscus Ltd, Ormskirk, UK

[b.a.king@lancaster.ac.uk](mailto:b.a.king@lancaster.ac.uk), [graham.bennett@euriscus.co.uk](mailto:graham.bennett@euriscus.co.uk), [a.rennie@lancaster.ac.uk](mailto:a.rennie@lancaster.ac.uk)

## ABSTRACT

The process of generating field correction data for galvanometer scanners in additive manufacturing is costly, inefficient and wasteful. In this paper a method is presented to retrieve the field correction data using patterns scanned on thermal paper and use a MATLAB image process algorithm to analyse and achieve the correct field size, absolute focus and ascertain the field correction file. On execution of the image processing algorithm, the generated field correction file was applied and test patterns repeated delivering a perfect output.

**KEYWORDS:** Galvanometer scanner; Laser based additive manufacturing; Field correction; Image processing

## 1. INTRODUCTION

The majority of laser based Additive Manufacturing (AM) methods utilise galvanometer scanning system, including stereolithography, selective laser sintering and selective laser melting and others, to direct the overhead mounted laser onto a position on the bed of the machine, offering high accuracy and resolution, and extremely rapid response to a step input, for laser beam positioning[1]. Galvanometers operate using two servo driven mirrors the rotation of which drives laser beam movement in one direction, used in combination with an optic lens for focusing, Figure 1.

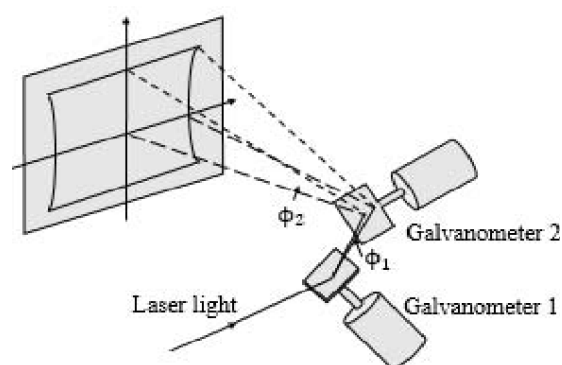
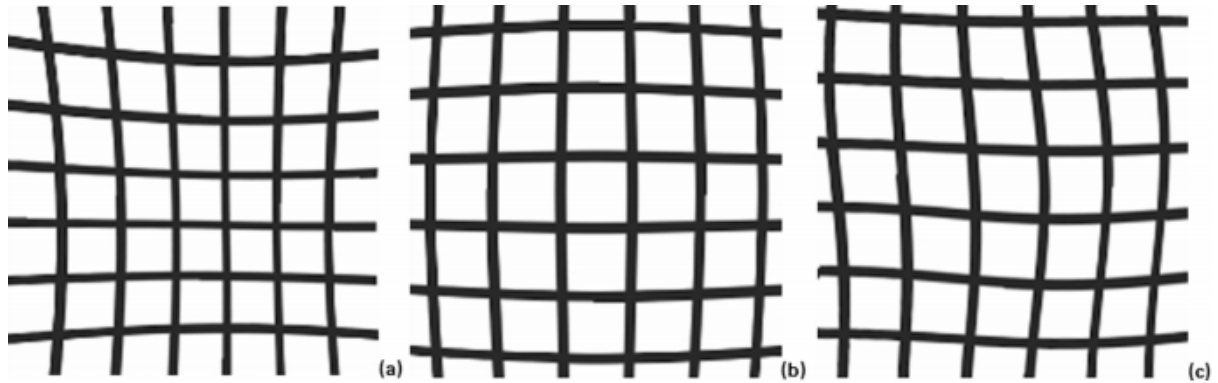


Figure 1: Galvanometer Scanner Diagram

Galvanometers are imperfect systems, due to mechanical construction errors and the inherent non-linear relationship between the angle of rotation of the mirror and position of the laser beam [2], the pillow, barrel and pillow-barrel distortion effects seen in Figure 2 are commonly seen in a grid patterns executed by galvanometer scanners with no field correction. To overcome the effects of field distortion manufactures of laser scanners [3] [4] allow for the inclusion of a field correction file which contains the actual coordinates of scanned points in

comparison for their target position, this information is interpreted by the scanner controller and used dynamically adjust the position of the opto-mechanical elements to ensure perfect positioning and focus. Additionally there are other field specific concerns relating to the position of the focusing lens that require correction including achieving perfect laser focus in the central region, adequate field size for the laser based AM machine.



**Figure 2:** Field distortion a) pillow effect, b) barrel effect c) combination of barrel and pillow distortion

Conventionally calibration of AM machines is performed by producing test parts and subsequently analysing geometric dimensions and other part properties to ascertain the correctness of the process parameter in question [5][6]. This is costly and inefficient and wasteful with respect to the unnecessary use of materials, lengthy, due to the duration of manufacturing and inaccurate as the parts can often be distorted due to unstable environment and erroneous process parameters, making it difficult to understand the effects of the field correction alone. Accordingly a method which eliminates the need to produce parts to ascertain the field correction file and achieve perfect focus and field size was developed.

## 2. METHODOLOGY

Thermally reactive paper [7] was identified as a method of recording the position of the laser beam, when the laser is directed on to the paper it colours due to a reaction between the Bisphenol-A and the thermal radiation from the laser. Neutral focus and field size were calibrated using different varieties of thermal paper [8][9], followed by creation of the positional dynamic correction file.

To generate the field correction file the suggested method is imaging a grid executed by the galvanometer, where the intersection of grid lines is an error measurement for the correction file. Image processing can then be used to ascertain the coordinates of the intersection of the grid line, which in turn can be used to create the field correction file.

### 2.1 Experimental Setup

A Coherent Diamond C70 laser [10] operating at 25 kHz was used in combination with a Raylase AxialScan 30 galvanometer operated by a SP-ICE3 controller card, to mark the thermal paper. All elements were mounted in a custom Rig, Figure 3. The laser scanner system was mounted on adjustable platform which can be between 250-750mm above the bed of the machine, to simulate the framework of a range of laser based AM machines. Data was transferred from an external PC to the SP-ICE3 controller card via an Ethernet connection,

which controls both the position of elements in the scanner and the PWM signal to the laser. The remaining features including the power supplies, laser chiller and safety features were all managed by an Allan Bradley SLC 500 PLC.

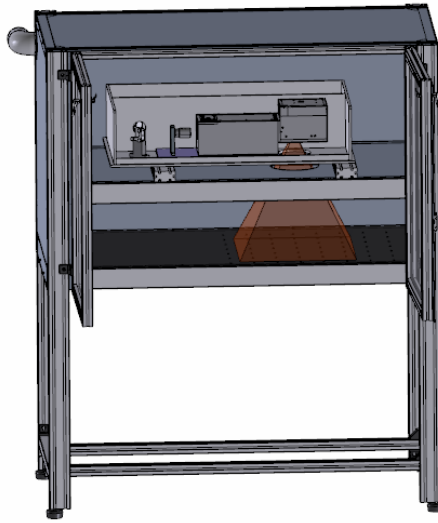


Figure 3: CAD rendering of the laser scanner test rig

## 2.2 Field Size

AM systems have a specified bed cross section, it is essential that the entirety of the bed is used for efficiency, consequently, the majority of laser scanner systems for AM include a method of mechanically adjusting the position of the gantry upon which the dynamic focus lens is mounted to achieve the correct field size. Initially one vector which spanned the length and of the build bed, through the central point, as shown in Figure 4, one vector was chosen instead of two due to the “pillow” field distortion. The length of the vector was measured, found to be 356mm, compared to a target field size of 500mm and the position of the lens gantry was altered accordingly, the vector was re-executed and measured to the correct value

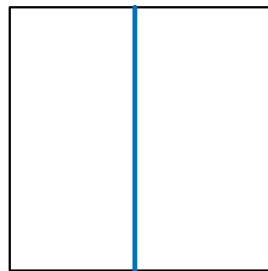


Figure 4: Scanned vector to determine field size

## 2.3 Focus

The neutral focus of the scanner can be adjusted by setting the starting position of the lens mounted on its gantry. The initial position of the lens can range from -50 to 50%, where -100% would be the furthest position the lens can go on the gantry towards the laser and 100% is the closest towards the scanner. The limit is capped to +-50% as the lens still has to account for dynamic focusing whilst the scanner is in operation.

To assess the focus the laser beam was positioned at the centre of the build area, with a sheet of ZAP-IT laser calibration paper [ZP] laid underneath, the laser was switched on for 0.5s, at a pulse width of 1 us, the neutral lens position was then altered by 5%, the thermal sheet can be seen in Figure 5, from visual inspection the ideal neutral focus was determined to be between 30% and 40%, the experiment was then repeated varying the lens position by 1% between these two values. The ideal lens position was determined to be 37%.



Figure 5: Effects of varying the neutral position of the lens by 5% from 45% to -30%

## 2.4 Field Distortion

To calibrate field distortion a 9x9 grid pattern was scanned on the thermal paper, the initial output is shown in Figure 6, where the characteristic galvanometer pillow distortion can be seen in the centre extremis of the X axis. A loss of focus can be seen as the pattern deviates from centre, in the far corners the beam is so unfocussed that it does not mark the paper at all. The sheet was scanned using a flatbed photo scanner, the resultant image was a JPEG file of 900x900dpi.

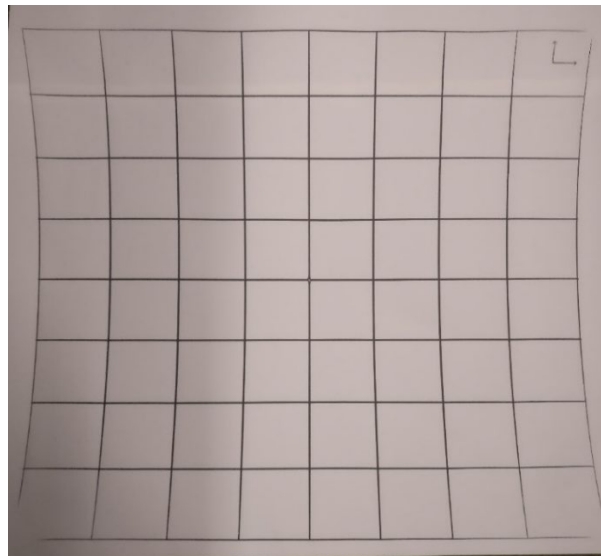


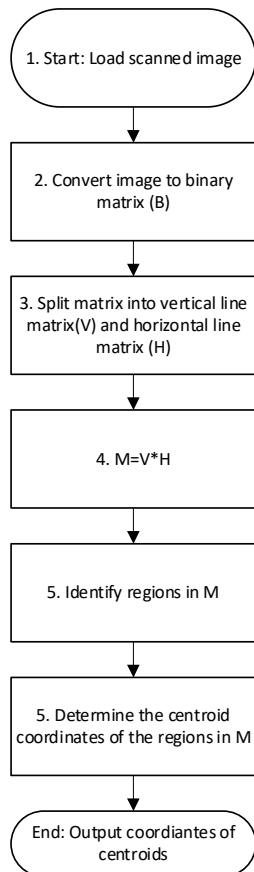
Figure 6: Scanned grid with no field correction

The scanned image is processed using the MATLAB algorithm detailed in the flowchart in Figure 7, it operates as follows

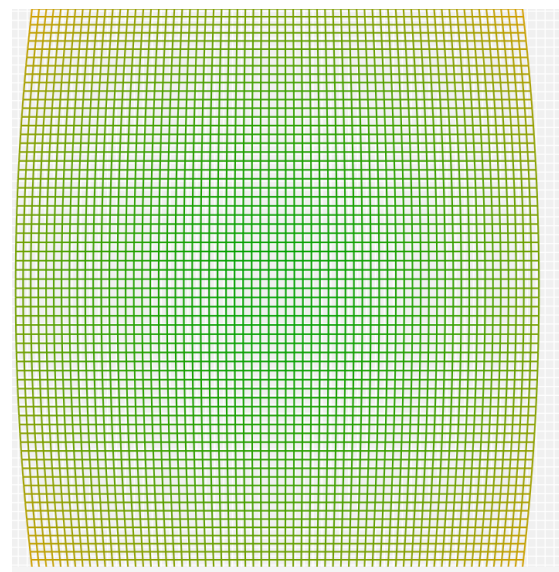
1. Read the image in to the work space;
2. Convert the image to a two dimensional binary matrix of dimensions equal to the number of pixels in the image, a one represents a dark pixel and a zero represents a light pixel. Dark and light pixels are determined at a threshold hue value of 85%;
3. The binary matrix is then split in to two matrices containing only the horizontal and vertical marked gridlines, by identifying consistent chains of dark pixels across the entire row or column respectively
4. Multiplying the horizontal and vertical pixel matrices leads to a clusters of dark pixels
5. The regions are identified using the boundaries function

- The location of the centre region is determined using the centroids function, this is accepted to be the location of the grid intersection.

The location of the centroids are saved in a .csv file and loaded into the multi-point editor provided by Raylase. The points are then used to generate the field correction file in the .fc3 format, visualisation of the effect of the generated field correction file for the grid in Figure 6 is shown in Figure 8, and the average deviation from set grid point to the measured grid point was 0.34mm, while the maximum deviation was 5mm.



**Figure 7:** Flowchart for image processing grid point identification



**Figure 8:** Visual rendering of the correction file

### 3. RESULTS & ANALYSIS

After adjusting focusing field size and applying the generated correction file the grid in Figure 9 was scanned, the dimension of the grid is 500x500mm as expected and consistent focus can be seen throughout the grid lines. Upon visual inspection the pillow distortion seen in Figure 6 has been corrected. The Grid in Figure 9 was scanned and processed using the algorithm described in section 2.4, in this instance the deviation from the centroid was an average of 0.02mm, with a maximum deviation of 0.14mm, compared to 0.35 and 5mm in the grid with no field correction in Figure 6. For further verification the 16 grid points, in Figure 9 were manually measured using callipers and were found to match the computed points within 0.1mm which can be accounted for measurement error.

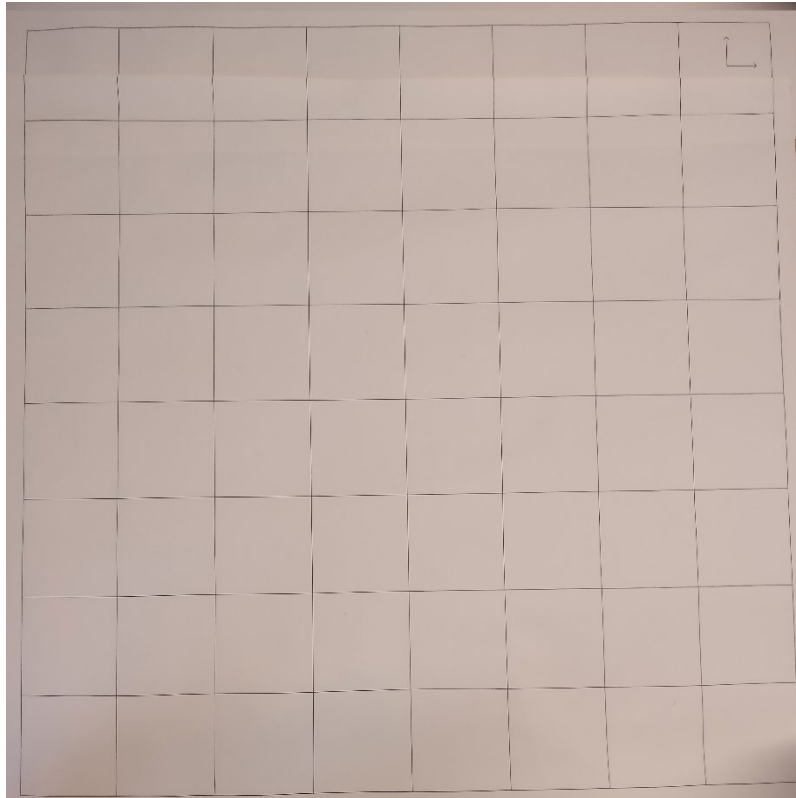


Figure 9: Scanned grid after field correction

#### **4. CONCLUSION**

In this paper a minimal waste method of correcting field parameters in laser based AM machines has been derived, a method has been presented for collecting laser positional data without using thermal paper, which is cheaper and faster to analyse than build materials. Focusing and field size were adjusted using measurements, and field correction file data was generated using image processing, the method was verified using a combination of physical measurements and re-testing the image processing algorithm.

The method presented offers AM users the opportunity to generate field correction data without using build material, which is both costly and wasteful. Using thermal paper increases the efficiency and simplicity of the calibration process allowing for immediate analysis of relevant parameters in comparison with post-construction analysis in the current accepted calibration.

Possible future work includes sourcing a supplier of thermal paper that can match the dimension of any build bed. Additionally a method of photographing the scanned images whilst still in the AM machine would offer full automation of the calibration process.

#### **ACKNOWLEDGEMENTS**

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