

DIGITAL MANUFACTURING SYSTEM DESIGN FOR LARGE AREA MICROSTRUCTURE BASED ON DLP PROJECTOR

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ABSTRACT

There are numerous industrial applications that require the capability of fabrication micro-scale features in large areas, e.g. the fabrication of human kidney with small features such as blood vessels, or adding micro-scale surface textures on a large area. By using a digital micro-mirror device (DMD), the digital light procession (DLP) based projector can generate the mask images used for stereolithography apparatus (SLA), which can help to achieve much higher efficiency and lower cost. Due to the limitation of the resolution of the DMD mirrors, for large area part, we cannot get a high resolution from each projected pixel. We modify the optical systems of the projector and make the projected image focused on a smaller area. Then in order to achieve a large area fabrication, we use another two axes to extend the building area. Also some image processing work has been done to make the projected images more uniform. A testbed has been developed to verify this additive manufacturing process.

Keywords: *Additive Manufacturing (AM), Mask Images Projection Stereolithography, Micro-scale fabrication, DLP Projector*

1. INTRODUCTION

In recent years, more and more 3D micro size parts need to be fabricated for different kinds of usage, like mechanical, chemical, medical and some industrial use. Reverse engineering has been fast developed in the last several decades [1]-[3]. Also, layer-based additive manufacturing processes such as Stereolithography Apparatus (SLA), Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM) machine have been developed for rapid prototyping and fast manufacturing in recent years[4]-[7]. Compared with traditional SLA process, a new mask images projection (MIP) process using DMD based projector to generate the mask image has much more advantages. Instead of the line scanning system driven by stages in the SLA systems, a DMD is used in the projector to generate the mask image for one layer each exposure time. It has much higher efficiency and lower cost than the traditional SLA process [7]-[10].

As shown in Figure 1, the general MIP system has a DMD based projector as the light source, a series of lens to control the light, a Z stage to move the curing platform up and down and a tank containing the liquid photo-curable resin.

To build a given 3D model by the MIP process, the first step is slicing the CAD model by a set of horizontal planes. Second, each thin slice is converted into a 2D mask image. Then the layered images was sent to the DMD based projectors and projected out one layer by one layer. During the space between each layer's projections, we use the Z stage to move the platform up and down to make the cured part be finished layer by layer, as shown in Figure 2.

Due to the limitations of the number of micro mirror on each DMD chip, there are some limitations for the MIP process. When we want to build a large part by the MIP process, the resolution for each pixel becomes low and we cannot get a smaller feature than the resolution size. To solve this problem, first, we change the optical system of the projector and make the projected images focused on a very small area, which helps us get a much higher resolution for each pixel. Second, we add two movement axes on X and Y direction with the optical system and building platform separately, which helps us get an extended building area. Then we can get a big building area which is composed by lots of small pieces. Both small features and big area parts can be built by this multi-scale MIP system.

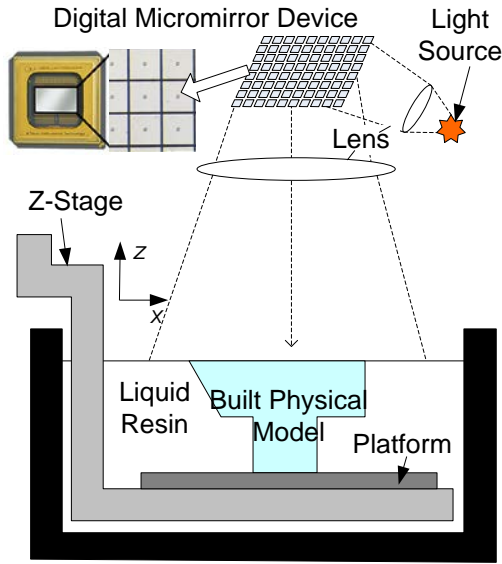


Figure 1 : MIP System

The reminder of this paper is organized as follows. The principle of multi-scale MIP system is presented in section 2. The optical system design is presented in section 3. The experimental hardware setup for performing physical experiments is discussed in section 4. In section 5, the image brightness compensation is discussed. Some test cases are shown in section 6. Finally conclusions with future work are presented in section 7.

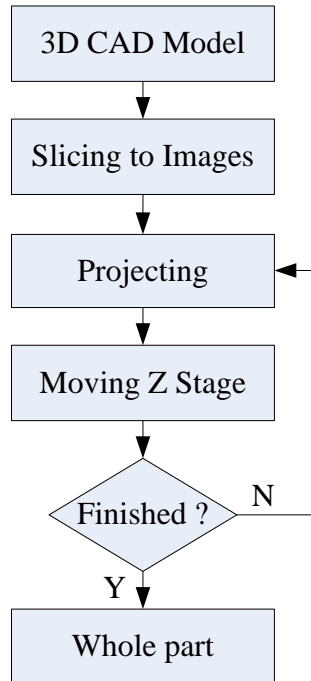


Figure 2 : Overview of MIP Process

2. PRINCIPLE OF MULTI-SCALE MIP SYSTEM

Multi-scale MIP system can be used in lots of industrials, medical applications, which need to build some large area parts with very small features, like some sensors, human kidney model, and so on. For this kind of parts, first, we also need to slice the CAD model into contours of each layer. Then, for each layer of the part, we can separate it into lots of pieces and generate the images for each piece. Then by projecting these images one by one on the same layer, we can get the whole layer built for the part. Figure 3(1) shows on layer of a “CROSS” part, the red lines are the contour. Then the whole contour is separated by the grids. Taking the A, B, C three portions as examples, the corresponding images are Figure 3(2) to Figure 3(4).

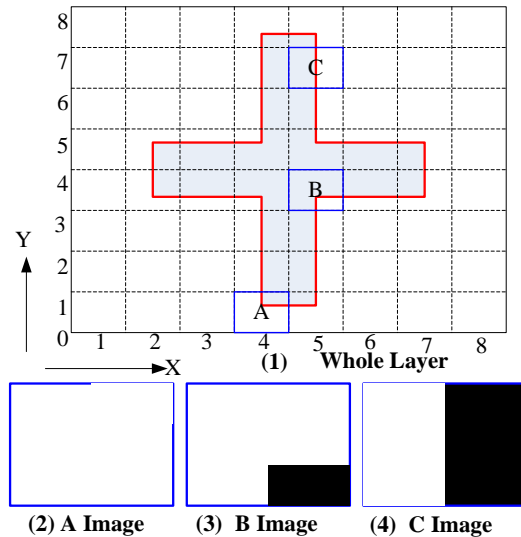


Figure 3 : One Layer Image Separation

The multi-scale MIP system has two additional X and Y axes to extend the building area. The same as most layer-based manufacturing systems, the part is also built layer by layer. During one layer’s building period, we need to repeat the process of projection and Z stage movement together with the XY axes movement. First we move the projection image to the built position and project the image of this portion. Second, we move the Z stage to separate the built part and the constrained film. Third, move the additional X and Y axes to make the projection image at the position of next portion. After all the portions of this layer are built, we move the Z stage for one layer’s thickness and begin to build the next layer.

3. THE OPTICAL SYSTEM DESIGN

3.1 The Projectors and Optics.

Right now, there are lots of commercial DMD based projectors we can take from the shelf. Most of them have a control system called digital light procession (DLP). As shown in Figure 4, there are light source, series of optics and a DLP system inside the projector.

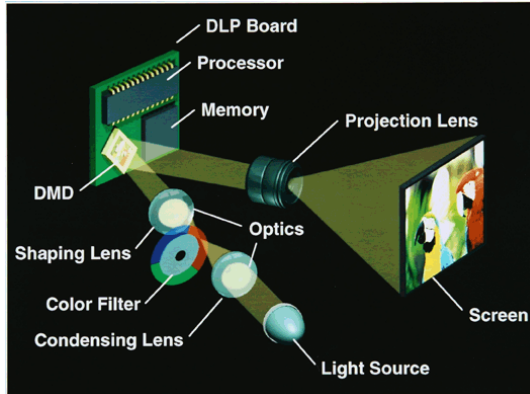


Figure 4 : Structure of DLP Projector

The projector we are using is from Acer Company and the model number is H5360, which has a biggest resolution of 1280*720. But the resolution we use in this system is 1024*768, which is a standard for most of the projectors we can get. The ratio is 4:3 on X and Y directions.

But for our purpose, we don't need the whole light from the projector lamp, because it's too strong and we cannot control the very short exposure time accurately. So we remove the projection lens and add a series of other optics to collect the lights reflected from the DMD mirrors and focus them, which shows in Figure 5. The resin we use in our test cases is blue light curable, so we add one blue filter in the light path. One collimating lens is used to make the lights collimated before the 45 degree reflecting mirror. The 45 degree mirror and the objective lens are fixed on the X stage, so the final will not change when the light is collimated. One 10X objective lens is used to focus the collimated lights to the bottom of the platform and helps us get a very small focused image of the projected one.

Just outside the projector, we add one electrical shutter first to control open and close status of the light. The shutter is an electrical shutter from JML OPTICAL Co. The blue light filter is a band pass filter with 410nm CWL and 10 FWHM (Model No. FB410-10), from Thorlabs Co. The collimated lens is a coated convex lens with focus length of 150mm

(AC254-150-A-ML), also from Thorlabs Co. The objective lens is a 10X microscope lens manufactured by Olympus and distributed by Thorlabs Co. The 45 degree mirror is an Aluminum coated mirror.

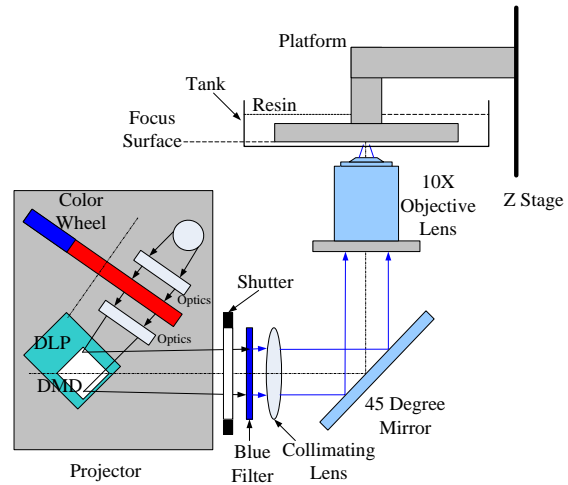


Figure 5 : The Projector and Optics System

3.2 The Focus Adjustment of the Projectors.

After we setup the optical system and the movement system, we have to adjust the position of the lenses to make the projected focused on the building platform. There is much challenge to focus the projected image to a very small area. The final size of the projected image is about 1mm*1mm, which is too small for human eyes to judge the focus status. So we use a micro-scope to capture the projected image on the top surface of the tank. There are two steps to focus the micro size projector. First is adjusting the position of the collimated lens and get a collimated light. Then adjust the position of the objective lens and get a small focused image on the building platform.

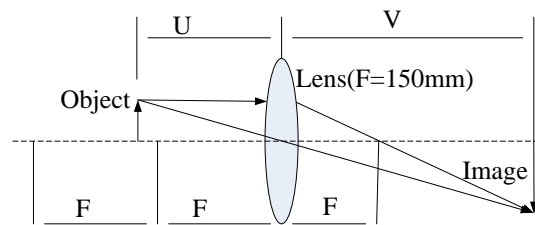


Figure 6 : Convex Formation ($f < u < 2f$)

First, we need to adjust the collimating lens to get collimated light from the projector. We assume that the DMD chip inside the projector is a point light source. Also we know the focus length of the collimating lens. From the convex lens formation formula, we can get the relationship between the focus F, object distance u and the image distance v, as shown in equation 1. For $f < u < 2f$, there will be a

magnified real image on the other side, as shown in Figure 6.

$$\frac{1}{F} = \frac{1}{U} + \frac{1}{V} \quad (1)$$

In order to get the collimated light from the lens, we should put the lens at the position with a distance equal to its focus distance F. But when it is at the focus position, there will be no image formatted on the other side. So we put the screen at a much farther position, and adjust the position of the lens to make the image focused on the screen. Then we measure the distance between the lens and the screen and compute the right distance from the lens to the DMD chip, as U in the equation 1. And then we linearly move the lens (U-F) distance by a precise linear stage to make the lens at its focus position. Then we can get the collimated light from the projector.

After the reflection of the 45-degree mirror, the light will go into the objective lens. We can adjust the objective lens to get the image focus on the top surface of the tank. The focused image is so small that we cannot see it clear manually, so we use a microscope with 200X magnitude to capture the image.

4. THE MOVING STAGE SETUP

There are three stages in our system. One is used for the platform moving up and down defined as Z stage. We use another two stages in our system to expand the working area. By moving the 45 degree mirror and the objective lens in X direction, we can extend the building area in X direction. The platform and resin tank are both fixed on the Y stage. By moving the Y stage, we can get the extending distance on Y direction.

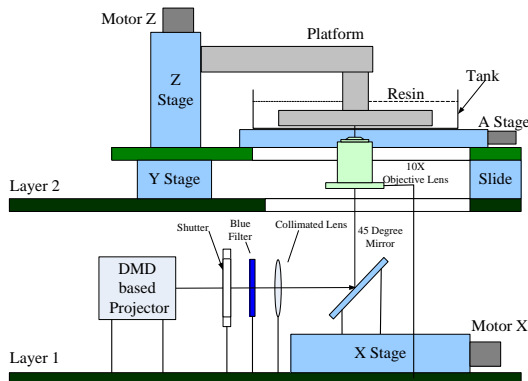


Figure 7 : The XYZA movement system

We also add one stage in the direction of X, which is mounted together with Z stage both on the

Y stage. This linear stage can help us get and relative movement between the tank and platform, which is very helpful to reduce the peeling force, defined as a stage in Figure 7.

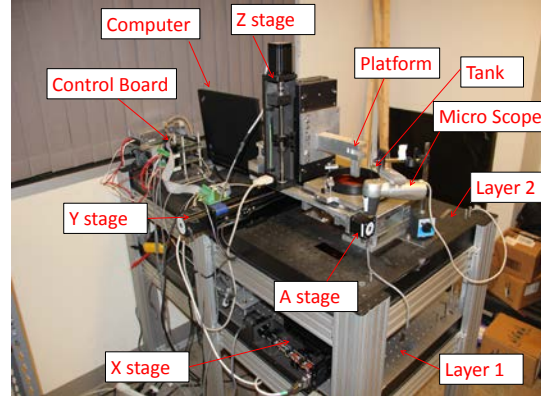


Figure 8 : Hardware system setup

The X stage is from Pacific Precision Labs, Inc. and the model No. is ST-SL04-PR-P100, which has a 2.54mm pitch screw. We use a step motor (1.8°/step) to drive it and the resolution for one step is 12.7um. The Y stage is a stepper driven stage from Velmex Com., which has the same motor and resolution with the X stage. The Z stage has a smaller pitch screw, 1mm, so we can get a 5um resolution from the same stepper motor. The whole setup is showed in Figure 8.

5. PROJECTED IMAGE PROCESSING

After we get the focused image on the top of the tank, we find that the brightness of the image we captured is not uniform. The brightness of the image at different positions of the image is different. This non-uniformity is from the projector itself. We tried several projectors which are the same model, and they have almost the same brightness distribution, as shown in Figure 9, which uses a white image projected.

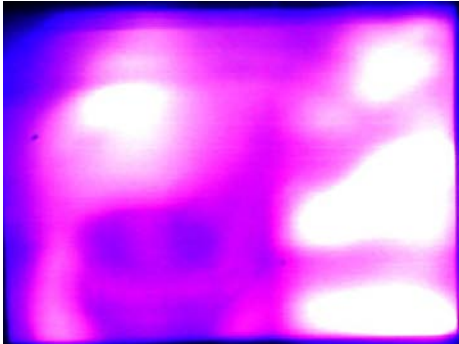
Different light brightness defines different energy density, which affects the curing of the resin. With the commonly used conversion formula from the RGB color to brightness, we can get the brightness value for each pixel in this area. Equation 2 shows the conversion equation, where G is the gray scale value, and R, G, B are the color values for red, green and blue in the image.

$$G = 0.299 \times R + 0.587 \times G + 0.114 \times B \quad (2)$$

After we get the brightness distribution, the image will be cut into smaller grids with 10*10 pixels size. Then we get the average gray of each grid, which can be mapped to the brightness

distribution of the whole image. For each region of the image, we can get its gray value.

(1) Captured Image



(2) Average Gray-scale Image



Figure 9 : The non-uniform image

As shown in Figure 9(1), the captured image's brightness is non-uniform. The Figure 9(2) is the brightness of the image presented in 10*10 grids. The method we are using to solve the non-uniformity of the projected image is using gray scale of the image to do compensation. For the higher bright portion, we set the gray value lower.

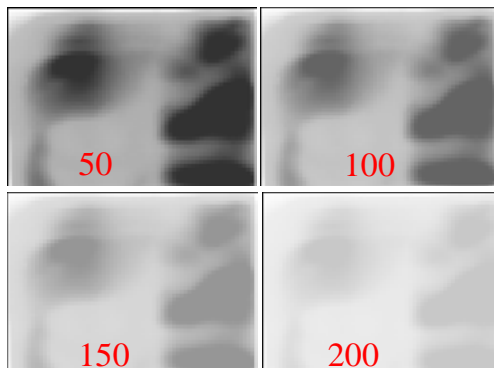


Figure 10 : The compensated images

One important parameter in this process is the smallest gray value for the brightest portion in the image. We tried from 10 to 250 as the smallest gray value in the image and captured these projected

images again. When the bottom gray value is 100, we can get the most uniform image. The compensated images with different bottom gray values are shown in Figure 10 and the corresponding captured images are shown in Figure 11. The numbers in the images are the bottom gray value of the compensation.

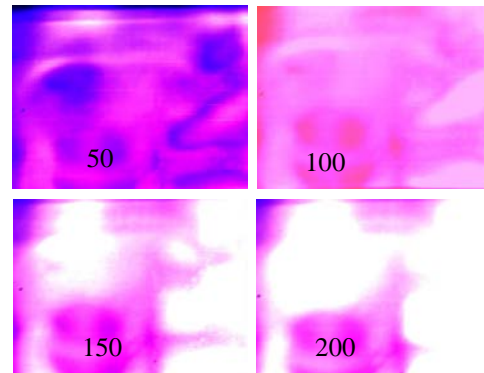


Figure 11 : The corresponding images

After we get the sliced images from the input 3D part, we change the gray scale values from whole white 255 to the compensated value for each region. Then we can get a much uniform brightness with the projected images.

6. EXPERIMENTS AND TEST CASES

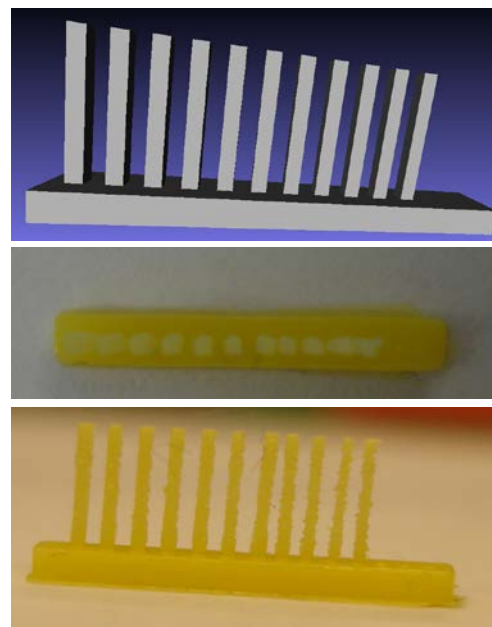


Figure 12 : The test model and built part

In order to verify this method for building big size part with micro size features, we do some test cases. Because the image planning process is so



complicated that we haven't finished it. So what we have done to verify the system is using a part combined with one big plane and some small features on it. To make the process much easier to be practiced, we use a small cube array. As shown in Figure 12, it is the CAD model of the part and the built part.

7. CONCLUSION AND FUTURE WORK

In this paper, we presented a multi-scale MIP-SLA system used for micro structure fabrication with extended area. The optical systems, movement stages and image processing are discussed. Also two test cases are presented to verify the feasibility of this process. In the future we can do more tests on this system, such as the energy analysis of this system, the curing characteristics of different resins and the image planning for the slicing process, etc.

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