Sensors and Actuators A 218 (2014) 116–124

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Scanning-projection based stereolithography: Method and structure

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ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 20 July 2014
Accepted 3 August 2014
Available online 12 August 2014

Keywords:
Additive manufacturing
DMD
Micromirror
Large area exposure
Maskless fabrication
Scanning projection stereolithography

ABSTRACT

Projection-based stereolithography (PSL) is an efficient way for rapid fabrication of 3D structures. However, it is suitable for small parts requiring high resolution. The scanning-based SL (SSL) covers a larger area with a lower resolution. Fabrication time in PSL is intrinsically less than SSL due to exposing an entire image field in a single shot. This study introduces a new scanning-projection based stereolithography (SPSL) to include the advantages of both former methods. SPSL takes advantage of a digital micromirror device (DMD) and a moving stage to combine the projection and scanning methods. The DMD moves continuously over the medium while the projected pattern is continuously updated to allow the fabrication of large layers.

After modeling the approach, an experimental setup is assembled to produce real parts. An economical ultra violet light-emitting diode (UV-LED) is used as a light source for curing. Seven 3D models with defined geometry consisted of circular, rectangular, complex and overhanging parts are selected. Five copies of each model are built. The experimental results show that the method is feasible and versatile. The achieved standard deviation is lower than 32 μm.

1. Introduction

Rapid prototyping (RP) reduces the time between product conception and final design to fabricate complex shapes. Stereolithography (SL) is one of the most important methods in RP. There are two different SL techniques distinguished by their patterning process:

- Scanning-based SL (SSL) or direct writing (Fig. 1a).
- Projection-based SL (PSL) that is also called maskless or dynamic mask method (Fig. 1b).

There are distinct advantages and disadvantages associated with each technology in terms of resolution, layer thickness, accuracy, cost efficiency, and throughput. In SSL a focused laser beam with small diameter (~0.1 mm) scans large areas by small rotations of a *XY* Galvo-mirror [1].

PSL uses a spatial light modulator (SLM) as dynamic masks for generating 2D patterns with μ-scale resolution. SLM is an optical module selectively turns light pixels/strips on or off. LCD, liquid crystal on silicon (LCoS) and digital micromirror device (DMD) are the most common SLMs used in recent works as dynamic mask generators [3–5,7–12]. LCD is transmissive while LCoS and DMD are reflective SLMs.

SLM application for dynamic mask projection in SL was first introduced by Bertsch co-workers [3,4]. They built an SL machine with LCD to generate dynamic masks for micro-stereo-photolithography. Monochromatic light (argon laser) as an advantage and inhomogeneity of laser beam as the disadvantage was addressed in their work.

LCD has a few intrinsic drawbacks such as large pixel size, low filling ratio and low transmittance (specially for shorter wavelength) which reduces the efficiency of light illumination [5].

To overcome the low performance of LCDs, Sun et al. used DMD for its high contrast and resolution [5]. Mercury I-line emission was chosen as the illumination light source.

The transmittance observed by typical DMDs in visible region is approximately 97% (single-pass through two surface transitions). But the transmittance of UV spectrum (355–400 nm) is dramatically reduced to 60% [6]. Recently, a PSL system is reported based on a high resolution LCoS chip [7]. Nevertheless, the performance of the system is not compared with other SLMs.

PSL has not only micro-resolution but also a higher fabrication speed in compare to SSL, due to single shot exposure of the whole

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http://dx.doi.org/10.1016/j.sna.2014.08.002
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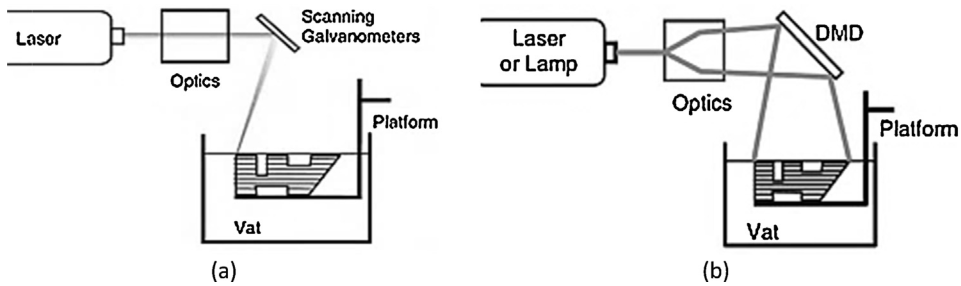

Fig. 1. Schematic of (a) SSL and (b) PSL [2].

pattern [5,8]. The key challenge in PSL is its limited resolution and small array size of DMDs. Projecting a pattern with a DMD array over a larger part/platform surface will cause a larger pixel size and as a result a lower resolution.

The highest available resolution of DMD is 1920 × 1080 micro-mirrors [9]. With this DMD, the minimum feature size in each layer for a micro platform (9.6 mm × 5.4 mm) is 5 μm × 5 μm. But, it results in the minimum feature size of 200 μm × 200 μm in a macro platform (384 mm × 216 mm) due to magnification of the pattern.

To overcome the limitations of projection method (creating a large part with high resolution), three approaches exist. The first one is coupling of multiple DMDs to make a larger array. This is very expensive and it is difficult to obtain uniform illumination.

The second method is a moving DMD that stops over a portion of platform, exposing the area underneath, moving to the next position and repeating this cycle. This method is usually called "step-and-repeat" and may cause increased polymerization in overlaps. This process is demonstrated by Ha [10] and Zheng [7] for batch production and Micro Stereolithography.

The third method is the subject of this work and it is not reported before. It is called scanning-projection stereolithography (SPSL). It combines the advantages of both SSL and PSL. In this method, DMD moves continuously over the area of the medium while the projected image is continuously updated. In SPSL scanning and projection are carried simultaneously while in step-and-repeat projection and movement are done separately; one after the other. Thus SPSL should clearly be faster. Also, it is anticipated that the exposure non-uniformity, which is frequently reported [11,12], may be improved; because the illumination cumulatively received by each point from different μ-mirrors during the scan.

In this investigation, a SPSL system is modeled and built. Several parts are manufactured to prove the feasibility of the idea. An economical high-power UV light-emitting diode (UV-LED) is innovatively used as a light source for curing as well.

2. Process description and background

Fig. 2 shows the schematic of SPSL method. It is composed of a scanning stage, a resin bath, a UV projector and a *Z*-stage. The scanning stage moves along *X* and *Y* directions over the resin bath. UV light is emitted toward DMD and is reflected through the lens over the resin surface. A computer, controls the reflectivity of each DMD μ-mirror. In this way, a selective exposure area is created.

The scanning stage moves continuously while the computer changes the reflection status of each μ-mirror to create a dynamic exposure pattern. Once the exposure of a layer is finalized, the *Z*-stage moves and allows the liquid resin to form a new layer to be exposed.

2.1. Top and bottom exposure

The structure described above can be implemented in two distinct ways. Based on construction and irradiance direction, these methods are top exposure (TE) and bottom exposure (BE). In TE, the top surface of resin is exposed to a 2D pattern while the platforms

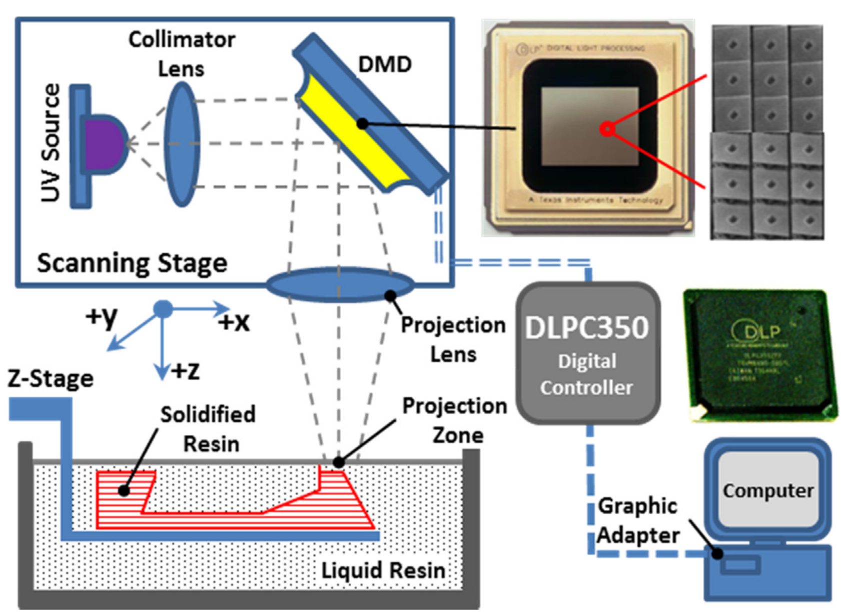

Fig. 2. Schematic drawing of SPSL.