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50. Internationales Wissenschaftliches Kolloquium
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1. J. C. Ferreira

Development and Adjustment of a micro Rapid Prototyping Apparatus based on DMD

ABSTRACT

The new products development integrating many functions in a small volume involve more and more often the micro rapid prototyping (MRP) techniques to produce small high-resolution objects, having intricate details. To answer these demands, the micro-stereolithography process must progress towards a better resolution. Microstereolithography, a technique with resolution about an order of magnitude better than conventional stereolithography, is researched by several academic groups [1, 2].

The microstereolithography process allows the building of 3D, complex in shape, polymer structures. The process has not emerged from the microelectronics technologies, but from the rapid prototyping industry. Microstereolithography was, up to recently, a minor technology in the field of microstructuration, mostly because of the limited resolution and the problems associated with the manipulation and assembling of the obtained polymer structures.

The fundamental microstereolithography apparatus been developed at the Instituto Superior Técnico (IST) of Lisbon/Portugal for microfabrication is described in this paper. The IST apparatus is based on a optical imaging system with a digital micromirror device (DMD – Texas Instruments) to microfabricate small to midsize parts from concept to functional RP models. This MRP apparatus present some difficulties in the adjustment mechanisms [3,4] that are analysed. At the end some conclusions are reached and potential applications are presented.

PRINCIPLE OF THE MRP APPARATUS

The working principle of the micro rapid prototyping apparatus consist on built one complete open surface layer in one irradiation only, whatever its shape may be. A dynamic DMD pattern generator (PC controlled) shapes the beam coming from the light source, so that it contains the image of the layer to build up. This modulated light is then projected and reduced with an optical lens system and the image it carries is focused on the surface of a photopolymerisable medium. The irradiated resin areas are selectively polymerized whereas the non-irradiated ones remain liquid. When the liquid is irradiated, long enough for the phototransformation to occur, a PC controlled shutter stops the beam.

To manufacture the part it is held and fixed to a metal grid platform, which Z-stage is PC controlled. The part is immerged in the reactive medium to be completely covered by it. The part is then lifted by a certain height, such that, between the last polymerized layer and the surface there is a layer of fresh resin. This new layer is then selectively irradiated with a new pattern, to create the next layer of the object, and so on.

The microstereolithography apparatus schematised in Figure 1, uses a dynamic active pattern generator constituted by a digital micromirror device (DMD – Texas Instrument manufacturer) the same light-modulation technology used in DLP projectors.

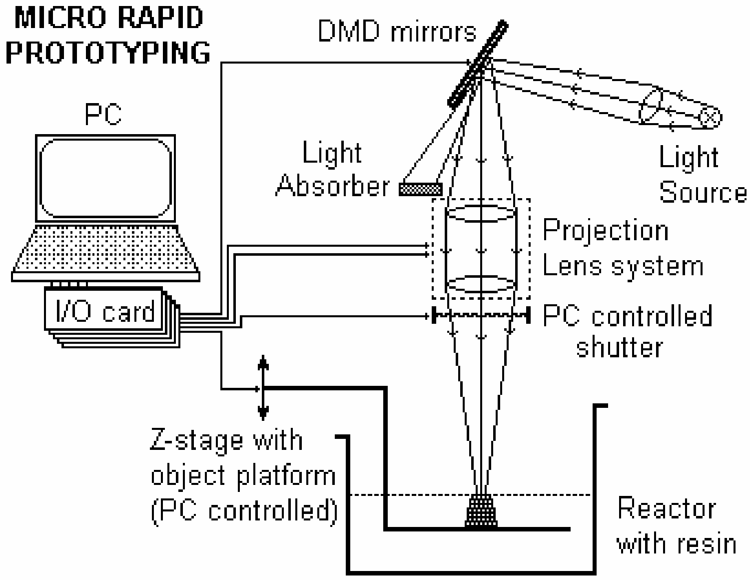

Figure 1: Micro Rapid Prototyping apparatus schema.

Once all the resin layers of the object have been built, the polymerized part is taken out of the photoreactor and washed with the appropriate solvent. No post processing is normally required if the light exposure time is correctly selected.

Even though the resolution of microstereolithography is not as good as conventional microfabrication processes, this technique has nevertheless many advantages; the manufactured micro parts are complex in shape, really three-dimensional and made of a large number of layers up to 1000 or even more. The manufacturing times are short, typically, an integral automated process can produce from one to five layers per minute, and the time needed to build one layer is the same whatever its pattern may be.

DIGITAL LIGHT PROCESSING WITH DMD

For the past ten years, digital light processing (DLPTM from Texas Instruments) technology with DMD has made significant progresses in the projection display. The DMD consists of a 1024x768 array of micro-mechanical mirrors on a 13.68 micrometer pitch. Each mirror can be individually deflected at+/- 12º about a hinge diagonal axis. Deflexion polarity (positive or negative) of the mirrors is individually controlled by changing the binary state of the underlying CMOS control circuitry and mirror reset signals. Binary frame rates up to 9,700 and 40,000 frames/second can be achieved for full array (1024x768).

For microstereolithographic applications with patterning on each slice, some photo polymeric materials need to be exposed with ultraviolet light (below 350nm wavelength). The DMD reflective properties, allows efficient modulation across a broad spectral band, and when coupled with its superior data rate, make the DMD an ideal device for the generation of microstereolithographic systems.

The microstereolithography apparatus utilises a DMD DiscoveryTM controller board GUI linked by a USB 2.0 to a PC with an user graphical interface software supporting several hundred DMD binary frames/sec of data transfer.

MRP COMPUTER ANALYSIS AND ADJUSTMENT CONTROL

The micro rapid prototyping apparatus is PC operated by four mechatronic system modules and has one analysis module, Figure 2.

One of the control modules simply commands the shutter system on/off that is programmed in time, by software, function of the photocurable resin reaction delay.

Other of the control modules commands the Z-stage to immerge the microprototype in the photocurable resin and positioning the resin level to control the thickness of each slicing layer.

The DMD module has at the heart the TI 0.7 XGA DDR DMD semiconductor that allows to manipulate light digitally. When integrated with light source and optics the DMD spatial light modulator creates binary light patterns with efficiency and precision.

The lens adjustment module is coupled with an analyse module for the automatic control focusing adjustment of the microprojection lens image on the photopolymer surface.

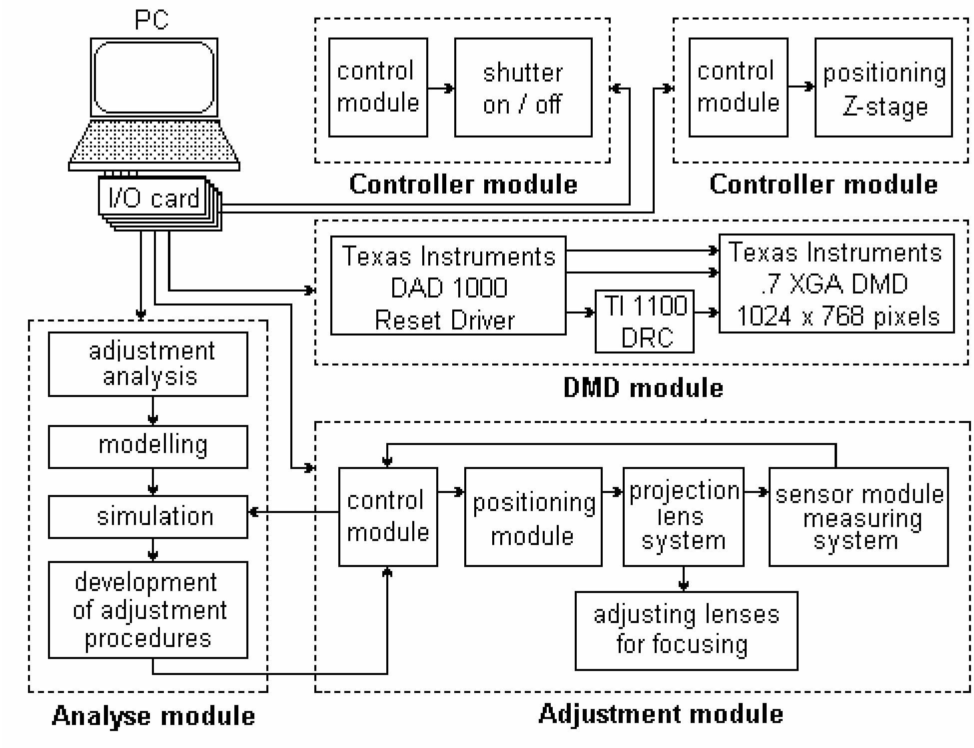

Figure 2: Computer procedures to automatically analyse, control and adjust the MRP apparatus.

MRP ADJUSTMENT NC CONTROL

This work aims the theoretical development of adjustment matrix equations [3-4] that guide the optical mechatronic system, based in automatic computer procedures to analyse and automatically adjust the microprojection lens system in the course of microstereolithography, yielding that focusing and optical axes stay aligned with the greatest precision to increase the prototypes geometry accuracy. The adjusting mechatronic system, for the microprojection lens focus, is set in motion by a numerical control (NC) or by an auto-numeric control system, schematised in Figure 3.

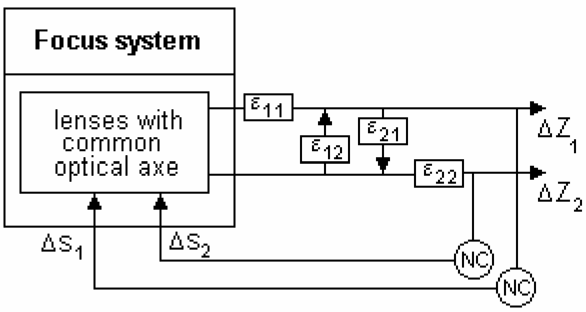

Figure 3: Auto-numeric control to adjust the microprojection focus system.

The Z-axis lens focusing is necessary until the projected image is well defined on the surface resin level. An influence with the Z automatic position module around ΔS_1 and ΔS_2 leads only to variations of the focus situation $F_1 \cong F_2$ around ΔZ_1 and ΔZ_2. Under use of linear approximations, the matrix equation (1) arises:

$$\begin{bmatrix} \Delta Z_1 \\ \Delta Z_2 \end{bmatrix} = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} \\ \varepsilon_{21} & \varepsilon_{22} \end{bmatrix} \cdot \begin{bmatrix} \Delta S_1 \\ \Delta S_2 \end{bmatrix} \tag{1}$$

When the lens focus converges on the resin surface level the matrix extreme values (ε_{12} and ε_{21}) become very small or null. It now follows mathematical connection calculation. In result of that, the matrix solution is simplified and become equation (2):

$$\begin{bmatrix} \Delta Z_1 \\ \Delta Z_2 \end{bmatrix} = \begin{bmatrix} \varepsilon_{11} & 0 \\ 0 & \varepsilon_{22} \end{bmatrix} \cdot \begin{bmatrix} \Delta S_1 \\ \Delta S_2 \end{bmatrix} \tag{2}$$

SUMMARY

The Digital Micromirror Device module with light source and optics allows manipulating light digitally generating binary light patterns with efficiency and precision for microstereolithography. The analysis and adjustment module commanding the Micro Rapid Prototyping apparatus microprojection optics allows the automatic focusing adjustment.

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