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Measurement of Additive Manufactured Microfluidic Devices by means of Photogrammetry: a preliminary study

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Abstract
Additive Manufacturing has become crucial in several applications of the biomedical field, such as designing and fabricating scaffolds for tissue engineering, bone regeneration, 3D models to improve surgical planning, dental models. Moreover, these processes are particularly suited for the fabrication of microfluidic devices and lab-on-a-chip (LOC) designed to work with biological samples and chemical reaction mixtures
The purpose of the present paper is to test a 3D photogrammetric measuring system to retrieve the size and geometry of features, included in 3D printed microfluidic devices, such as microchannels with a non-destructive and low cost methodology
Keywords: Photogrammetry, 3D Modeling, Microfluidics, Additive Manufacturing

1. Introduction

Additive Manufacturing (AM) is becoming particularly suited for the fabrication of microfluidic devices and lab-on-a-chip (LOC) designed to work with biological samples and chemical reaction mixtures. AM LOC devices have significant advantages including portability, higher speed, reduced waste and low cost.

A high research effort has been spent to describe fluidic properties of several configurations, manufactured by different additive technologies. However, very few papers are findable about dimensional characterization of these devices.

In the present paper a 3D photogrammetric measuring system is preliminary tested to retrieve the size and geometry of microchannels made in Stereolithography (SLA), with a non-destructive and low cost methodology.

2. Research literature

SLA has been widely applied in fabricating microfluidic devices because of its high accuracy and availability of low cost machines.

At first SLA has been used as a model for PDMS casting such as in [1] where a micro-stereo lithography 3D printer (Miicraft) is used to fabricate templates with a proprietary resin. Subsequently the 3D-printed template is covered by PDMS, after protecting the surface of the template with a PDMS compatible material.

Afterwards there has been a considerable amount of work focused on printing open microfluidic channels. This option is often chosen instead of printing enclosed channels because it is easier to remove the uncrosslinked resin. In [2] Miicraft printer is used to print a complex open microfluidic channel which was then sealed with an adhesive tape. The device was printed in XY-plane, reducing the surface roughness of the channels and printing time. This printing direction also exploited the resolution limit of the printer.

Direct fabrication of transparent microfluidic devices with enclosed channels is also reported in [3], with square sections, side equal to 250 μm. In this case the size is equal to 250 μm.

Other widespread SLA machines for microfluidics are by Formlabs, such as in [4] where open channel devices are fabricated using Form1 and compared to an i3DP drop-on-demand 3D printing machine, Shapeways Frosted Ultra Detail. The comparison is made qualitatively, using scanning electron microscope images (SEMs) observing the smallest features manufacturable with both the methods. To investigate the surface roughness of each printing method, scanning electron microscope images (SEMs) are taken of two test pieces printed using both fabrication methods.

The measurement of micro-channels is a challenging task, since sectioning the device with a destructive procedure, and analysing it with a microscope, is actually one of the most used method for the dimensional and geometric characterization.

One of the most important non-destructive, quantitative inspection methods involve confocal sensors.

As regards confocal sensors, some examples are the following: [5] that uses a confocal point sensor CF 4 and a tactile roughness device (DEKTAK 3030) for measuring laser ablated channels in terms of ablation depth, wall-angle, and surface roughness; [6] measure micro- channels by a profilometer based on confocal chromatic sensor and by a confocal microscope with higher lateral resolution; [7] compares micro-milled channels on an Electron Beam Melting (EBM) and Direct Metal Laser Sintering (DMLS) workpieces, Scanning Electron and Confocal Microscopes are the measuring instruments employed.

Unfortunately, this kind of Instrumentation suffers high limitations when highly slope surface must be measured. In micro-channels the micro-geometry retrieval of areas near vertical walls are very important to better understand and predict the fluid flow.

3. Experimental setup

The experiment was conducted using a full frame digital reflex camera Canon Eos 6 D with a 20.2 megapixel resolution (5472 x 3648 pixel2) and a APS-C CMOS sensor (22.2 × 14.8 mm2). A Canon EF 100mm f/2.8 macro lens, with the focus distance set to its minimum value, was used with magnification ratio equal to 1:1.

Figure 1 shows the white box illuminated from all sides with a led strip, integrated to the workpiece located at the center of the box, positioned at the center of a turning table ISEL-RFII, with an angular position resolution equal to 3°. The rotation angle of the table was set at 5°and the camera was tilted with respect to the table at 45°. This choice derives from previous experiences [8], a high-tilt angle value, up to 60°, is preferable for objects with high depth values such as deep holes, while for objects with lower deep values also lower tilt angles work well.

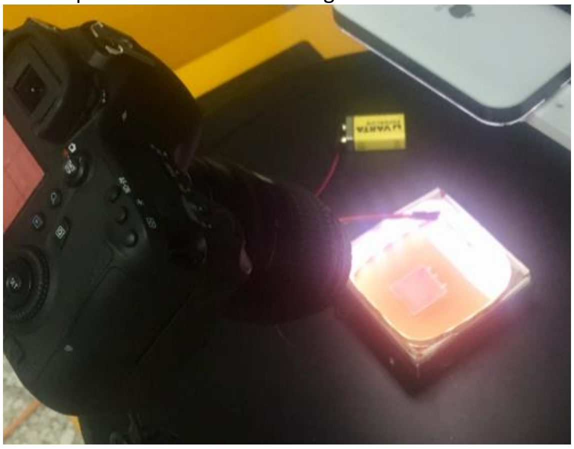

Figure 1. Experimental setup

The analysed micro fluidic device is shown in Figure 2 and was fabricated with a Formlabs Form II available at the Optical Devices Laboratory of the Linköping University in Sweden. It is a micromixer consisting of two inlets, one outlet and a serpentine necessary to mix two fluids in a laminar flow to achieve mixing by diffusion.

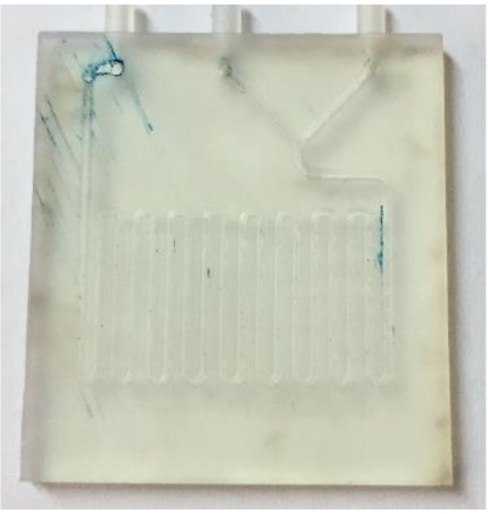

Figure 2. The measure micromixer

One of the most important problems of the photogrammetric technique is the attribution of the scale to reconstructed point clouds due to an inherent limitation of the technique. In this paper the scaling method described in [9] has been employed.

4. Results

The photogrammetric point cloud was achieved using the image processing software Agisoft PhotoScan Pro version 1.3.2, using the autocalibration function. Photogrammetric measurements were compared to the point cloud obtained with the optical profilometer CCI-MP-HS TAYLOR HOBSON with a high magnification lens (20x), field of view 0.8x0.8 mm, maximum slope 17° and global scanning time approximately equal to 10 hours.

In Figure 3 the comparison between tessellated photogrammetric and profilometer point clouds is shown. The colour scale is in millimetres. The agreement of the photogrammetric cloud to the profilometry is satisfying, especially if we consider that profilometry does not acquire vertical walls at all, and the difference in cost between the techniques.

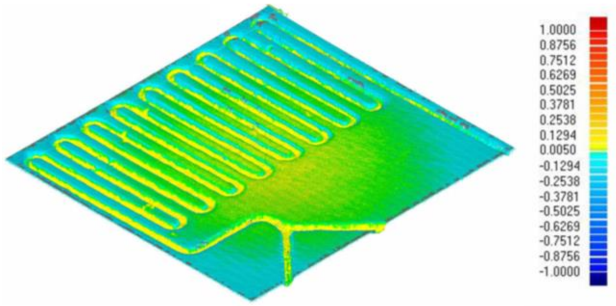

Figure 3. Coloured distance map generated by the comparison between photogrammetric and profilometer point clouds

5. Conclusions

Photogrammetry can become a state of the art technique for the measurement of objects with micro features and additive manufactured micro devices as well. Further research will be extended to higher magnification ratios and other available AM technologies available for micromanufacturing.

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