11th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '17

The use of self-replicated parts for improving the design and the accuracy of a low-cost 3D printer

Paolo Minetola[a],*, Manuela Galati[a], Luca Iuliano[a], Eleonora Atzeni[a], Alessandro Salmi[a]

[a]Politecnico di Torino, Dept. Management and Production Engineering (DIGEP), Corso Duca degli Abruzzi 24, 10129 Torino, Italy

* Corresponding author. Tel.: +39-011-090-7210; fax: +39-011-090-7299. E-mail address: paolo.minetola@polito.it

Abstract

Low-cost entry-level 3D printers suffer from reduced optimization, that is a consequence of development cost savings. A student challenge was used to modify four Prusa i3 machines with the aim of enhancing the design and performances by means of self-replicated parts. The challenge results were assessed through benchmarking of the four modified 3D printers, whose dimensional accuracy was evaluated by means of CMM measurements of 3D printed replicas of a reference part. The ISO IT grades related to the dimensional quality of the replicas were considered in the analysis of the CMM measures for the challenge assessment.

1. Introduction

In recent years, the expiration of Sr. Scott Crump's patent for the technology of Fused Deposition Modelling (FDM) has boosted the diffusion of 3D printers. However, the widespread adoption of FDM technology, that is more popularly known as 3D printing, is a result of the availability of open-source systems and the birth of 3D printing communities, such as the one of the makers. The benefits of an open system and the sharing of information are reduced costs, availability of processing parameters for different materials, guides for assembling or self-repairing with a DIY (do it yourself) approach and readily printable 3D models.

The FDM process is very simple in its physical principle and can be assimilated to an automatic hot-glue gun. Instead of a stick of glue, a thermoplastic filament is heated and extruded through a nozzle of the extrusion head of the FDM machine. The melted polymeric mass is subsequently deposited layer-by-layer on the printing bed along the trajectories of the extrusion head [1]. The deposited material cools down and solidifies right after deposition. The extrusion head can comprise multiple nozzles, one for each different filament and material. Commonly two extruders are present, one for the part material and another for the support material. The support material is used to create a raft for the adhesion of the part on the printing bed, but also to create support structures for overhanging features that would not be supported along the building direction because of the absence of part material in the previous layers.

The simplicity of the FDM process and the low cost of polymeric filaments has driven the development of a huge number of low-cost entry-level systems soon after the expiration of the main patent.

One of the first systems was the open-source DIY project called RepRap, that was started in 2005. Other FDM machines followed, but their architecture is based on a Cartesian structure with three degrees of freedom that controls the motion of the extrusion head in the building direction (Z-axis) and along the deposition path (X and Y axes) within each single layer.

The extrusion head of low-cost systems often has a unique extruder that can be heated up to a maximum temperature of about 270 °C to melt a thermoplastic filament. The most common materials used for the filament are ABS

(acrylonitrile butadiene styrene) and PLA (polylactic acid). Open systems allow the using also of other materials without being bound to proprietary materials by the machine manufacturer as in the case of industrial systems.

Low-cost 3D printers are sold over the net at a price starting from some hundreds of euros for a kit that the users should assemble by their selves. On the one hand, the low cost has contributed to the rapid diffusion of 3D printers among the population thanks to their high affordability. On the other hand, the affordable price is a marketing choice that limits the investment for the machine development, resulting in simple and cheap mechatronics solutions. Thus, low-cost entry-level 3D printers suffer of the lack in optimization and advanced engineering solutions, which makes those machines difficult to be used by unexperienced users. Nonetheless, the performance of such systems can be improved by advanced users or amateurs exploiting the open architecture and platform.

As concerns mechatronics and automation, Politecnico di Torino has a partnership agreement with Comau S.p.a., a worldwide leading company for industrial automation that is part of the FCA group. Within this partnership, a Specializing Master course in Industrial Automation is offered to post-graduate engineering students that are selected and employed by the company with an apprenticeship contact. In the fourth edition of this Specializing Master, an optimization challenge of a Prusa i3 3D printer was proposed to the students. The apprentices were divided into four groups with the aim of promoting also team working and managerial competences as in a real work environment. Within the challenge students had to cope with limited budget for modifying the 3D printer, the timing of materials procurement and activities planning for respecting the assigned deadline.

One of the constraints of the challenge was that most of the parts used for the mechanical modifications of the machine should be fabricated by the same 3D printer using a self-replication approach. Each group worked independently and four new printers were developed and presented with the names of Fluo, Ghostprinters, Metallica and Print-Doh. In order to assess the effectiveness in terms of performance improvements achieved by each team through the machine modifications, a benchmarking study about the dimensional accuracy was carried out.

The aim of this paper is to present the results of the challenge by summarizing the benchmarking analysis after the description of the improvements applied to the original Prusa i3 machine.

2. Description of Prusa i3 and modifications

The i3 postfix in the machine name indicates the third iteration of the design by Josef Prusa. The machine comes with the standard Cartesian architecture and all its parts are open-source similarly to the RepRap project. This 3D printer has a minimal mechanical structure, that comprises two rails for the elevation of the printing bed along the Z-axis and two rails for the motion of the extruder head orthogonally to the bed along the X and Y directions.

The four machines modified by the four groups during the challenge look quite different from the original Prusa i3 as well as from each other. The modifications mainly focused on mechanical and electrical aspects, also taking into account ergonomics and related safety issues. Aesthetics was also enhanced to mimic marketing purposes.

Although the four groups worked independently, their printing experience and testing of the original Prusa i3 machine led all teams to consider the need for the following improvements:

- introducing a holder for the filament spool and a guide to drive the filament in order to reduce the probability of jamming during the extrusion process;
- cutting down the time for bed levelling by using suitable components like a nut or a knob;
- protecting the power cables with the use of chains or tubes made of polymeric materials with the additional result of avoiding the interference with movable parts of the machine;
- increasing the stiffness of the rails by adding rigid components with the function of anti-wobble devices to support the motion of the printing bed and extrusion head.

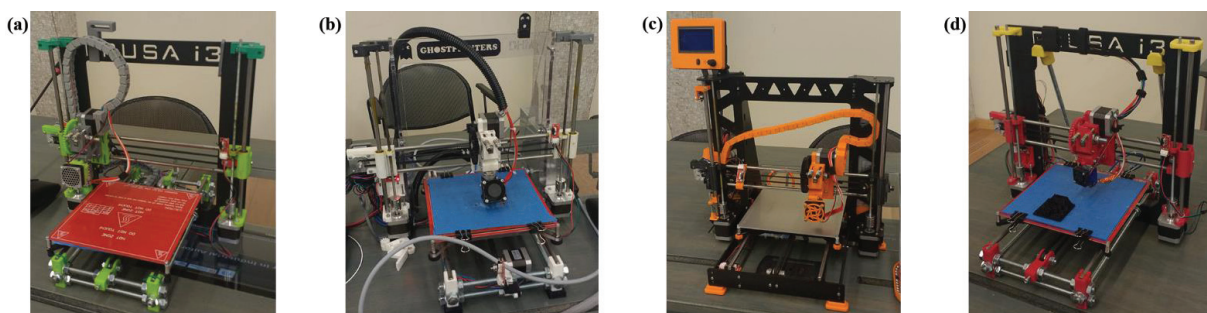The four modified printers are shown in Fig. 1.

Fig. 1. Picture of the Prusa i3 printers modified by the four teams of apprentices: Fluo (a), Ghostprinters (b), Metallica (c), Print-Doh (d).