

Execution of Non-Metallic or Metallic Duplicates, Cast with 3D Scanners and 3D Printers

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In this paper, the authors show a part of research works performed on the use of 3D scanners and 3D printers to execute the molds required for the cast of parts with complex surfaces. 3D scanning allows copying of certain surfaces in our environment, based on existing models. The finished parts may also be executed from metals that are relatively easy to cast (bronze, aluminum etc.). In order to execute the molds destined for the casting, various pieces may be scanned, with a volume size in the range of $[150 \times 150 \times 200 \text{ mm}^3 \div 500 \times 500 \times 2000 \text{ mm}^3]$. Plastic model printing is performed depending on the capacity of the 3D printer used. This paper shows the results achieved with general-purpose scanner and printer, valued at affordable prices.

Keywords: 3D scanner, 3D printer, plastic models

3D printers operating with plastic filaments are widely used [1-3] in various industries and other fields. They have affordable prices, a wide range of such printers is available, allowing execution of varying objects with a single color or in multiple colors and shades [4].

3D scanners allow the digital caption of the spatial image of a piece. These are several methods for the performance of this scan. There are even some mobile phone apps available, which allow easy performance of scans. However, the method that is currently used most frequently is the *3D Laser scan* method [4, 5]. The size of scanned object, the work conditions, the scanning speed and accuracy are all dependent on the type of scanner used [4- 6]. Authors of this paper used the 3D printer and the 3D scanner that are shown in figure 1. Their basic characteristics are presented below [7].

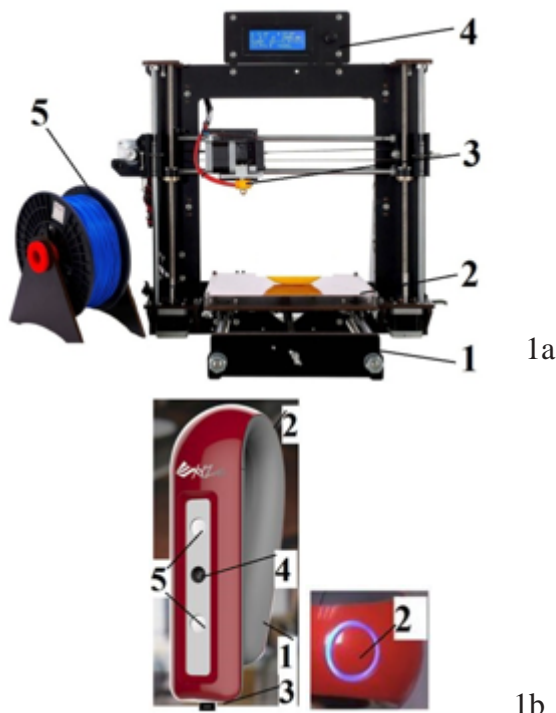


Fig. 1. CTC DIY 3D PRINTER and XYZ printing 3D Scanner

In figure 1a, the following legend was used for the main elements of CTC DIY 3D PRINTER: 1 - fixed frame, 2 - bed, 3 - extruder unit, 4 - programming module and display, 5 - filament used (PLA).

The following characteristic features of this printer must be mentioned: maximum printing size $200 \times 200 \times 180 \text{ mm}^3$, layer accuracy $0.1 \div 0.5 \text{ mm}$, nozzle diameter 0.4 mm , maximum operating temperature 260°C , work speed $35 \div 40 \text{ mm/s}$, fast speed mode $30 \div 100 \text{ mm/s}$.

The material used for printing is PLA-type plastic filament with 1.75 mm diameter. The following temperatures were set for printing: 180°C - at extrusion head, 70°C - at the bed.

Figure 1b shows the *XYZ printing 3D Scanner*, for which the following legend was used: 1 - handle, 2 - on / off switch, 3 - USB 3 power cable, 4 - photo camera, 5 - laser. Its main characteristics are as follows:

- Scan resolution 1 - 2.5 mm ;
- Operating range 30 - 70 cm ;
- Depth image size $640 \times 480 @ 30 \text{ FPS}$;
- Color image size $640 \times 480 @ 30 \text{ FPS}$;
- Data interface USB 3;
- Output file types XYZscan Handy/.stl, .obj, .ply;
- Windows Version Supported OS: Windows 8.1, Windows 10 (64-bit).

Overview of objects scanned to be subsequently printed in 3D with PLA filament

3D images of scanned objects may be enlarged or reduced in size in order to execute the 3D printing of models as needed for casting. Therefore, the final pieces, which are originals or duplicates of existing objects, may be executed in expended or shrunk version. Considering the characteristics of printers used, usually they are limited by the rated size of the workpiece ($200 \times 200 \times 180 \text{ mm}^3$).




The scanner used in this project allows optimum use for:

- 1 - scanning of objects at a rated size of maximum $400 \times 250 \times 400 \text{ mm}^3$;
- 2 - scanning of people in order to achieve the volume described by the head and bust of such person at a rated size of maximum $600 \times 600 \times 300 \text{ mm}^3$;
- 3 - full scanning of a person or a body, is his / her size is within a volume of $1000 \times 1000 \times 2000 \text{ mm}^3$;

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In such conditions, a marble statue, a stuffed toy and a person in *HEAD* scanning were selected for 3D scanning and printing. These objects and their size values are shown in table 1.

Table 1
OBJECTS SCANNED

No.	Body	Photo (2D)	Sizes L x B x H [mm ³]
1	Statue		125x67x124
2	Stuffed toy		200x220x300
3	Bust		~600x300x550

Scanning was performed with the *SENSE* software, and scanning results are shown in table 2.

Table 2
SCANNING RESULTS

No.	Body	Scanning result (3D)
1	Statue	
2	Stuffed toy	
3	Bust	

After scanning, adjustments are made as required, using special software programs and, in the end, after determining the size of objects to be printed in 3D so that they match the useful volume of the printer, the file is saved in a file type compatible with the printing software, in this case the *CURA* suite.

Table 3 shows the final shape of objects to be printed.

Experimental part


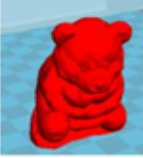
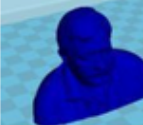
Improvement of performance and of viability of 3D printers

The 3D printer used, shown in figure 1a, has the inconvenient that the filament advance system, its drive engine, the heating system and the cooling system are located in the same area, as shown in figure 2.

Work head 1, which includes the extruder nozzle, is fed by the stepper motor 2 using the advance system 3. Cooling of 1.75 mm diameter filament is provided by with the radiator 4 and fan 5 [6]. Thus the advance system is provided so that it does not allow monitoring of the processed filament or efficient cooling of, as its enclosure is completely closed and made of plastic.

If we consider that, when the filament enters the advance system, its temperature is at ambient temperature's level (20°C), and in the extruder nozzle its temperature is at the value required for the flow of melted plastic (~180°C), we can take into account a temperature distribution as shown in figure 3.

Table 3
THE FINAL SHAPE OF OBJECTS TO BE PRINTED

No.	Body	Objects scheduled to be printed	Sizes L x B x H [mm]
1	STATUE		50.8x25.6x50
2	Stuffed toy		38.1x39.2x45.3
3	Bust		53x49x48

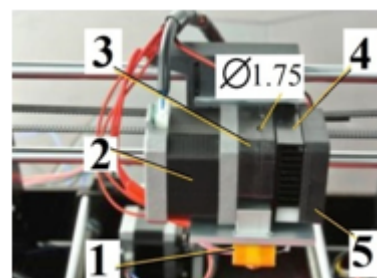


Fig. 2. Original extruder head of the printer

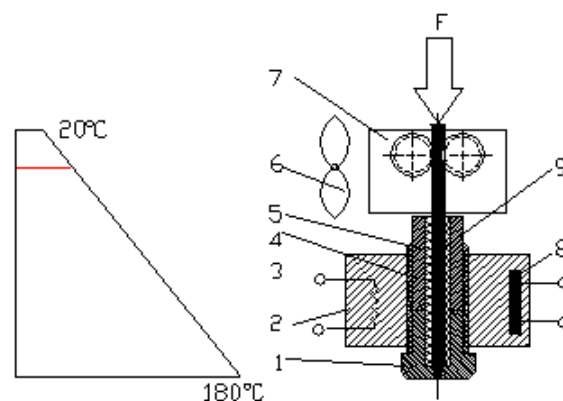


Fig. 3. Operating principle and temperature diagram for the separation-free system

- 1 - nozzle Φ 0.4, 2 - heating block (Al), 3 - resistor, 4 - guide tube, 5 - Teflon tube, 6 - cooler, 7 - advance system, 8 - temperature transducer, 9 - filament, F - press force

Due to force F developed by the advance system 7, filament 9 is pushed to the nozzle 1 with 0.4 mm in diameter. Block 2 is heated by the electric resistor 3. Through the Teflon tube 5, installed in the guide tube 4, the filament reaches the heated area causing its local melting. Temperature control is provided with the temperature transducer 8. In the area where force is applied the material is solid, and the next area is an intermediate space where the material has a mixed structure (both solid and liquid), and then the material shall become completely fluid due to the high temperature of resistance adjacent to the nozzle. Regarding the filament structure, we can distinguish three areas, as shown in figure 4.

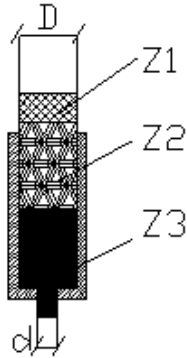


Fig. 4. The three physical states of material

In Z1 area, the filament with a D diameter is solid, being pushed by the advance system to the Z2 area, where temperature is already increasing, therefore we may say this an intermediate area where the material is in a viscous, solid-liquid state. In Z3 area, the material is liquid and therefore it is extruded through the nozzle with the d diameter.

For a certain material and in certain conditions, it is recommended that the advance speed should have a specific value, v .

This speed may be considered to be:

$$v = K\omega \quad (1)$$

In equation 1, the following legend was used: K - the constant that incorporates the characteristics of motor and of the advance system, ω - angular speed configured on the advance motor.

In Z3 area, considering that the fully melted material occupies the V_q volume and it has the E_M elasticity volume, the pressure p is developed due to the force applied by the advance system. In such conditions, the flow rate v_c of melted material through the nozzle with diameter d may be expressed as:

$$v_c = \frac{v \frac{\pi D^2}{4} - \frac{V_q dp}{E_M d\tau}}{\frac{\pi d^2}{4}} \quad (2)$$

For a certain angular speed \dot{u} , pressure p developed in the Z3 area is:

$$p = \frac{K^2 \omega^2 D^4}{2C_p^2 d^4} \rho_T \quad (3)$$

In equation 3, the following legend was used: C_p - nozzle's throttling constant, ρ_T - density of viscous liquid in Z3 area. Density in this area is dependent on temperature. Angular speed variations lead to pressure variations and, based on equation (2), implicitly to variations of the advance speed. Viscosity is also dependent on temperature. Due to heating of material, it slips in relation to the driving system in the driving area. All these events may lead to material depositing at a varying rate, or even clogging and blocking of the advance system or of the nozzle.

Given these circumstances, attempts were made to achieve better separation between the melting area and the driving area. Also, attempts were made to improve visibility of the filament advance system and improved cooling of this system. Therefore, a new head was purchased, with a circular cooler, an open, fully metallic advance system and a fan with adjustable direction. These new components are shown in figure 5.

After replacing the existing equipment with the new equipment, the structure shown in figure 6 was obtained.

Figure 6 maintained the legend used in figure 2. This time, the head 1 and extruder nozzle are separated by the

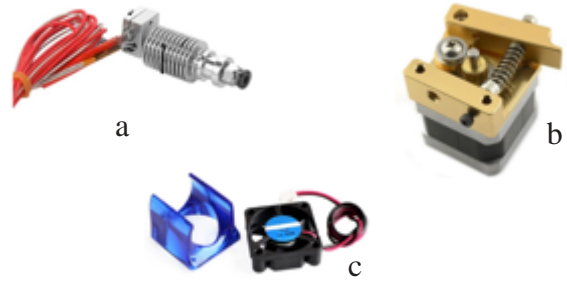


Fig. 5. New components used to improve operating conditions

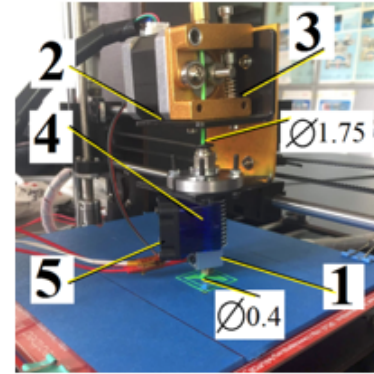


Fig. 6. The new driving and extruding solution

advance system 3 and the advance motor 2, which have a temperature equal to the ambient temperature. Cooler 4 and fan 5 only control the temperature in the extruder area. The advance system is completely metallic and open, which allow improved cooling performance and the possibility to view the filament during operation. Noticeably, all parts required for these changes and installation of components were executed by the authors of this paper from plastics or aluminum, with a 3D printer or a GANTRY-type machine-tool [3].

In this case, temperatures distribution is as shown in figure 7.

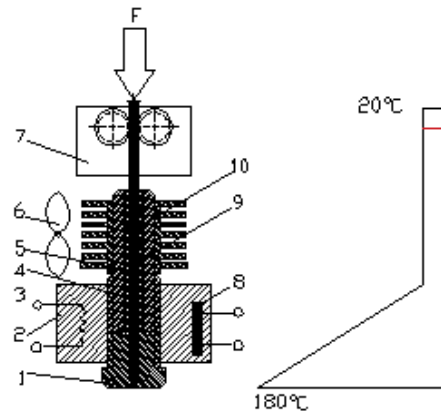


Fig. 7. Operating principle and temperature diagram for the system using separation of advance area from the heating area.

1 - nozzle \varnothing 0.4, 2 - heating block (Al), 3 - resistor, 4 - guide tube, 5 - Teflon tube, 6 - cooler, 7 - advance system, 8 - temperature transducer, 9 - filament, 10 - radiator, F - press force

This time, the drive system 7 is metallic and completely isolated from the heating system 2 that includes the resistor 3, temperature transducer 8 and nozzle 1. It pushes the filament 9 through the Teflon tube 5 installed in the guide tube 4. Separately, the special radiator 10 is cooled by the fan 6. The route of filament before melting is easily viewed.

After execution of these adjustment, it was noted that printing is more accurate, and interruptions due to filament slipping or nozzle clogging are less frequent. In some cases, after 3D printing, parts obtained may be machined [3, 8, 9].

Table 4
OBTAINED PARTS AND MEASURED SIZES

No.	Part type	Part manufactured	Size L x B x H [mm ³]
1	STATUE		50x25x50
2	Stuffed toy		37.5 x 38.9 x 44.7
3	Bust		52 x 47.5 x 47.8

Overview of printed parts

After execution of aforementioned adjustments, scanned parts shown in table 3 were printed.

Parts obtained are presented in table 4. Also, this table shows the sizes as measured.

Sizes of printed parts are close to the programmed sizes. Therefore, tables 3 and 4 are used to calculate deviations shown in table 5.

Table 5
DEVIATIONS OF SIZES

No.	Part type	Deviation $\Delta L \times \Delta B \times \Delta H$ [mm ³]
1	STATUE	0.8 x 0.6 x 0
2	Stuffed toy	0.6 x 0.3 x 0.1
3	Bust	1 x 1.5 x 0.2

Objects manufactured after 3D scanning and printing are not destined to be included in assemblies that require special accuracy. They cannot be adjusted with high accuracy. Therefore, we may consider that deviations shown in table 6 are acceptable.

Results and discussions

Using 3D scanning and printing, scale models of objects shown in table 1 were obtained. The final purpose may be execution of such unique duplicates or execution of molds intended for casting, for the mass production of a large number of duplicates.

The statue shown in table 5, with sizes of 50x25x50 mm³, was used as a cast mold. Casting was performed in a special sand, and the material used was aluminum. Table 6 shows the part obtained after casting in various stages.

The final size, after casting, burring and painting is of 49x23.5x49 mm³. Size deviations are due to contraction following casting and burring.

The part obtained did not require designing or rendering works. Therefore, after scanning, processing of scan capture, 3D printing and metallic casting, a part is obtained that is similar to the original object, similar in shape however having other sizes and being executed from another material. Figure 8 shows the original part, the scanned part and the part obtained.

If models obtained are to be used for execution of accurate castings (in molds), the final parts shall be of a higher quality, and burring and adjustment works - including grouting - shall be largely reduced.

Table 6
PART OBTAINED AFTER CASTING IN VARIOUS STAGES




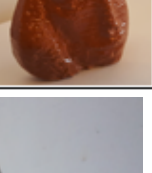
No.	Stage	Part manufactured
1	After casting	
2	After burring	
3	After grouting	
4	After painting	



Fig. 8. Original part and the part obtained after casting

Conclusions

3D scanning allows execution of *digital* objects that may be processed and subsequently 3D-printed. The printing result may be the final purpose, or it may represent a model for execution of other objects, metallic or non-metallic, executed by casting or injection.

This method shall allow fast execution of clones of an object without any design works. Various objects may be used as scanned models. The parts achieved in the end have a size limited by the rated capacity of the scanner and printer used. The scanner and printer used herein are acceptable considering the size accuracy, provided that

parts manufactured are not used in assemblies that require accurate adjustments.

Usual 3D printers use simple thread driving and heating systems. A clear separation of cold sections from sections to be heated allows an easier use of these printers. Using 3D scanning and printing, models may be obtained to be used for the mass production of complex parts executed by casting or injection. This method eliminates the need for designing and rendering of models. The final parts may be made of: plastics, metals, gypsum, ceramics, food products (sugar) etc.

The use of 3D scanners and printers allows execution of clones with sizes that are equal to, or differing from, the size of the original part, without requiring any special design / drawing skills.

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