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COMPARISON OF THE QUALITY OF 3D PRINTING BY ROBOTIC ARM AND CONVENTIONAL 3D PRINTERS

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Abstract: *The proper selection of equipment for various applications in additive manufacturing (AM) is a critical factor that influences achieving the desired quality of the final product. This experiment compares the print quality of the robotic arm DOBOT Magician with two conventional 3D printers, Creality Ender 3 V2 and Prusa i3 MK2. The experiment involves designing and printing four samples using Polylactic acid (PLA) material and the Fused Filament Fabrication (FFF) method on all three devices. The goal of the experiment is to determine the impact of the design of the devices on the print quality, identify the advantages and disadvantages of each device, and define their application possibilities. The samples are printed under the same conditions and parameters, then 3D digitized using an optical scanner ATOS II Triple Scan and compared in the GOM Inspect software. Through 3D digitization and measurement, we obtained a substantial amount of data concerning the dimensions and tolerance deviations of individual 3D printed test samples. All collected data were subsequently meticulously processed, and the results of the experiment were systematically presented using graphical representation. The results of the experiment provide relevant information for selecting equipment and optimizing the printing process for specific applications. The article presents a valuable contribution to the research in the field of 3D printing and the comparison of various devices enabling 3D printing, opening the path for further experiments and improvements in this area.*
Key words: *additive manufacturing (AM), robotic arm, 3D printers, print quality.*

1. INTRODUCTION

Additive manufacturing is becoming a widely known concept and finds extensive use in various industrial sectors, including the automotive industry, aircraft industry and medicine [1]. Technological devices that support additive manufacturing enable the production of objects from different materials, including plastic, ceramics, and metals [2]. There exists a variety of different devices and techniques for additive manufacturing and Fused Deposition Modeling (FDM) being one of the most well-known. This technique is characterized by its user-friendly nature, cost-effectiveness, environmental friendliness, and the ability to work with various materials [3]. The FDM process involves heating and melting solid material, which is then gradually deposited layer by layer to create a three-dimensional object based on predefined part geometries [4]. Additive manufacturing plays a significant role in prototyping and concept verification, as it significantly simplifies and accelerates the entire process of designing and manufacturing new products [5]. This technology enables fast and efficient production of functional prototypes and samples, facilitating early testing and feedback acquisition from customers [6]. The flexibility of design and easy adaptability of the product represent key features of additive manufacturing, ultimately reducing production times and the number of parts in the final product, which contributes to advantages in small-scale or batch production [7]. AM is the subject of intensive research and development aimed at improving its quality and expanding its application possibilities [8].

Thanks to technological advancements in the field of autonomous industrial robots, robotic additive manufacturing is becoming increasingly popular [9]. The utilization of industrial robots in this form of manufacturing opens new possibilities and perspectives in the realm of additive manufacturing [10]. Recently, there has been a significant expansion of literature supporting the use of robots to overcome the limitations of traditional additive methods. This literature demonstrates how robot utilization can shorten production time, enhance product quality, improve process efficiency, and enable the manufacturing of large components [11]. Other areas being explored, developed, and where the use of robotic additive manufacturing can be beneficial include multi-material fabrication, production of ultra-large parts with small functional features, high-precision manufacturing, hybrid manufacturing, and micro-level part production [12]. Industrial robots excel in performing repetitive tasks with high reliability and they can execute more complex movements compared to conventional gantry-based 3D printers [13]. While most additive manufacturing processes require support structures, the robot's ability to perform more intricate movements enables layering in multiple planes [14]. This fact opens new possibilities for optimizing manufacturing processes, such as reducing the need for support structures, leading to material savings, and decreased overall printing time [15]. As a result, new perspectives in printing emerge that would be difficult to achieve with traditional 3D printers [16].

2. METHODOLOGY

The comparison of print quality, the impact of the structural design, and the software configuration of the devices represents a significant aspect in identifying the advantages and disadvantages of the devices compared in this experiment. Its purpose is to define the potential application possibilities of these devices. The individual steps of the experiment are graphically depicted in Figure 1.

The test sample was designed using SolidWorks software and is of square shape with dimensions of 50x50x5 mm. Its purpose was to verify the manufacturability, quality, and accuracy of individual parts of the model.

The test sample comprises of the following components:

- Four circular holes with diameters of Ø4, Ø6, Ø8 and Ø10 mm.
- Four square holes with dimensions 4x4, 6x6, 8x8 and 10x10mm.
- Four cylinders with diameters of Ø4, Ø6, Ø8 and Ø10 mm with semi-spherical ends.
- Four squares with dimensions 4x4, 6x6, 8x8

For the implementation of the experiment and printing of test samples, two conventional 3D printers and one robotic arm were selected. These devices are depicted in Figure X.

- Prusa i3 MK2 – conventional cartesian rectilinear 3D printer, XYZ system: XZ-Head (X - belt, Z - leadscrews) Y-Bed (belt), Extrusion system: direct (gear+smooth wheel) nozzle: 0,4mm, workspace: 250x210x200mm
- Creality Ender 3 V2 - conventional cartesian rectilinear 3D printer, XYZ system: XZ-Head (X - belt, Z - leadscrews) Y-Bed (belt), Extrusion system: indirect (gear+smooth wheel), nozzle: 0,4mm, workspace: 220x220x250mm
- DOBOT Magician - 4-axis robotic arm, XYZ system: 4 joints, Extrusion system: indirect (gear+smooth wheel), nozzle: 0,4mm, workspace: 150x150x150mm

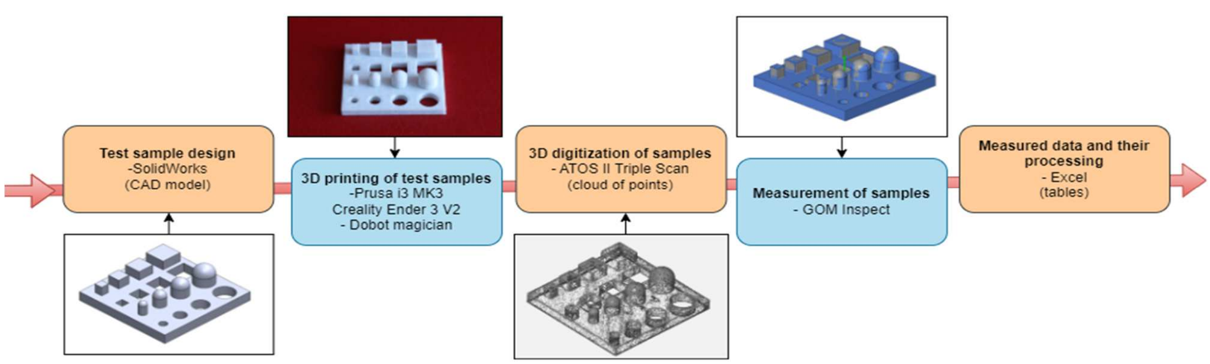

Fig. 1. The main steps of the experiment

Fig. 2. The devices investigated in the experiment

Two conventional 3D printers and one robotic arm were chosen to realize the experiments. The test samples were printed on the mentioned devices, with each device producing 4 samples using the same filament and identical printing parameters, which are listed below:

- Filament diameter: 1,75 mm
- Material of filament: Polylactic acid (PLA)
- Layer height: 0.2 mm
- Nozzle: 0,4 mm
- Side walls: 3 layers
- Top and bottom layers: 5 layers
- Infill density: 25%
- Infill pattern: concentric
- Top and bottom infill pattern: straight-line

Printing time of one test sample on devices:

- Prusa i3 MK2: 2h 21m
- Creality Ender 3 V2: 2h 35m
- DOBOT Magician: 3h 45m

After printing the samples on all three devices, the cleaning and 3D digitization process followed. The digitization of the components was carried out using the optical 3D scanner GOM ATOS II Triple Scan. Before scanning a sufficient number of reference points were applied to the printed samples. The scanning process was performed using a rotating table, capturing images at every 30° rotation in a series of 12 steps, covering a complete 360° rotation of the table. For each sample, we conducted two scanning series, capturing both the top and bottom sides of the samples. The reference points were utilized to precisely align individual scans and scanning series. The result of the scanning process was a point cloud for each sample, which was subsequently transformed into a 3D polygonal model in “.stl” format using triangulation. Subsequently, measurements were performed on the sample models in the “.stl” format using GOM Inspect software. Firstly, the model

experiment and print test samples. These devices are depicted in Figure 2.

obtained through 3D digitization was imported, followed by the 3D CAD model of the designed component. These two models were aligned, and a unified coordinate system was established using the Prealignment function. The measurement was then carried out by comparing these two models. At the beginning of the sample measurements, a color map of deviations was created, and an example of this map can be seen in Figure 3.

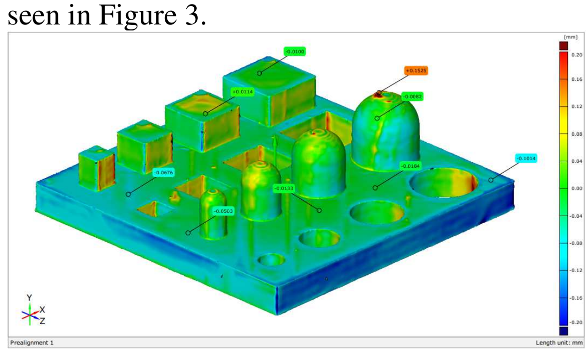

Fig. 3. Example of color map of deviations

Subsequently, the diameters and cylindricity of the cylindrical holes and protrusions, as well as the deviations in the dimensions of the square protrusions and holes, were measured. Additionally, the overall dimensions of the test sample and the flatness of individual surfaces were assessed. The measurement process was initiated on a single sample, and the measured values were meticulously recorded in a measurement report. Upon the completion of measurements and the generation of the measurement report for the initial sample, a measurement stage was established. Subsequently, all the remaining test samples were imported into the software using the STAGE functionality. Leveraging the capabilities of the STAGE module, the software automatically executed measurements on each of the test samples, capturing relevant data for analysis. The STAGE module facilitated a streamlined and efficient process, enabling the systematic measurement of all the samples without the need for manual intervention. As a result, individual measurement reports were created for each test sample, and they were saved in the PDF format. The recorded values from the measurement reports were documented in an Excel spreadsheet. For each of the 3D printing devices, the data was meticulously processed, and arithmetic means of the nominal values for the respective investigated printing parameters were computed. These data were processed with the aim of experimentally compare the devices and identify their deviations. Subsequently, graphs were generated to visually represent the analyzed variables based on the processed data.

3. RESULTS

The following tables (Figure 4.) present the processed data in the form of arithmetic means of the nominal values for each respective device, along with illustrative images of the measured parts of the test sample.

The highest value of the general deviation for square holes was measured on the DOBOT device, specifically for a square holes of size 4x4 mm. In comparison to other devices, the deviations were almost identical for all other devices and sizes of square holes.

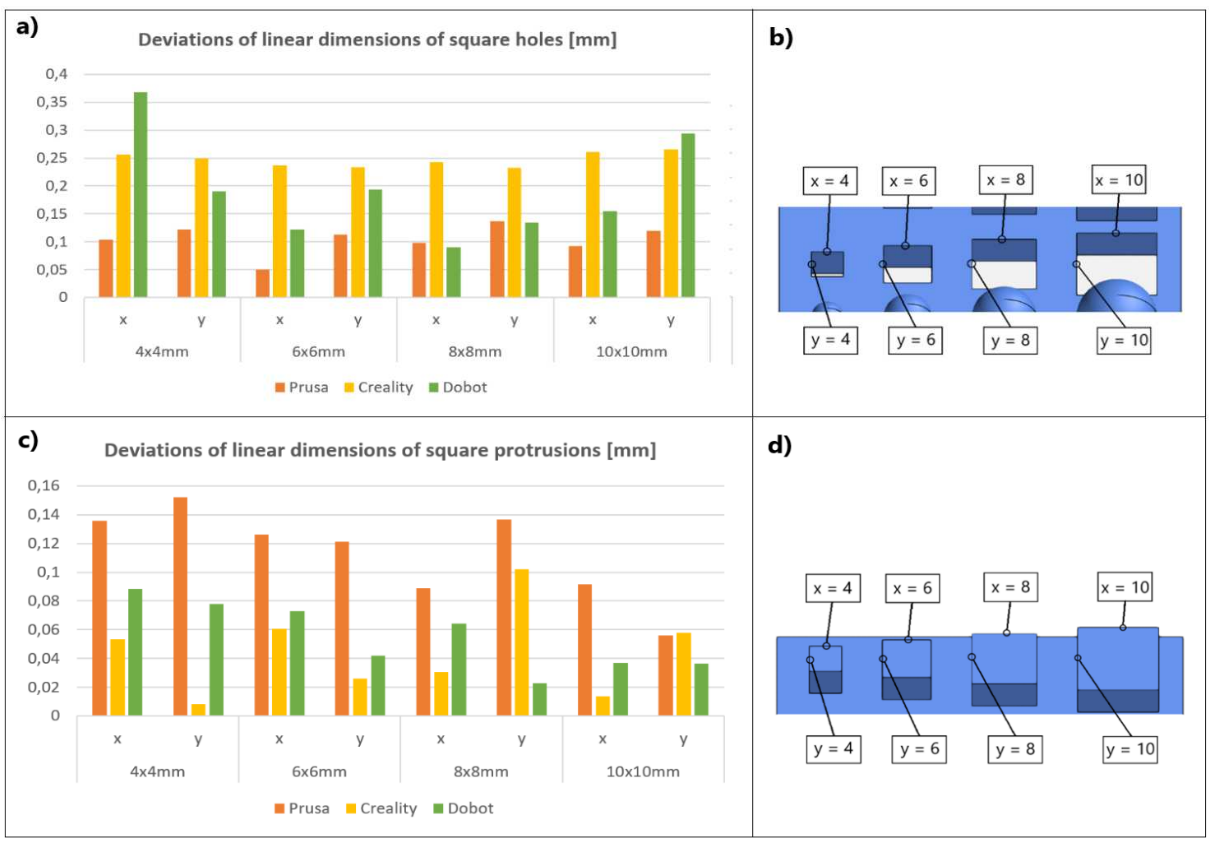

Fig. 4. Results
a) chart of the deviations of linear dimensions of square holes
b) illustrational picture of the measured parts of the test sample (square holes)
c) chart of the deviations of linear dimensions of square protrusions
b) illustrational picture of the measured parts of the test sample (square protrusions)

From the measured values, it is evident that the DOBOT device faces challenges with accuracy in the X-axis for smaller dimensions of square holes.

This issue may be attributed to various factors, such as the precision of the robot's end-effector navigation in remote areas from its base, the mechanism of motion, and the rigidity of the device during movement. To gain a better understanding of this issue, further experiments were proposed.

The Creality Ender device achieves the lowest values of the general deviation for square protrusions. On the contrary, the Prusa device achieves the highest values, which could

4. FURTHER RESEARCH

Based on the results of the experiment, it is evident that there are significant differences in the print quality among these devices, which be attributed to the software settings of material flow during the printing of the outer wall of the model.

Standard settings were used during the production of the samples, and as a result, the Prusa device exhibited inaccuracies with general deviations for square protrusions ranging from +0.05 mm to +0.152 mm, depending on the size of the square protrusions.

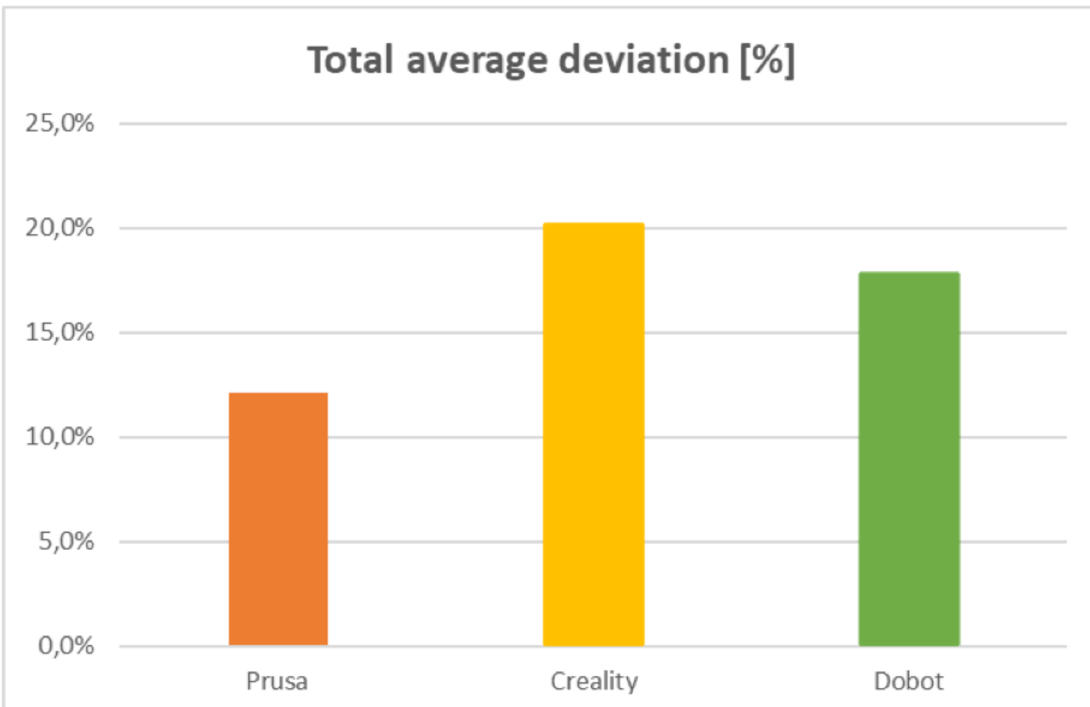

Fig. 5. Chart of overall average deviation of the measured data

The last chart (Figure 5.) displays a summary of the deviations of the measured values, indicating that the Prusa device appears to be the most accurate with a percentage deviation of 13.6%.

On the other hand, the Creality Ender device performed the worst in this experiment, with a percentage deviation exceeding 20%. The Dobot device achieved an overall percentage deviation of 17.8%.

The highest measured values were recorded for square protrusions of size 4x4 mm, with the deviation in the Y-axis reaching approximately +0.152 mm could be attributed to various factors. Furthermore, there are several ways to improve the accuracy and quality of the experiment. One possible improvement would be to include a larger number of devices and samples, enabling a broader and more precise comparison.

In addition to geometric tolerances, other printing parameters, such as material strength, surface quality, or mechanical properties of the printed models, could be investigated.

Advanced measurement and analysis methods, such as using sophisticated software tools or 3D scanning techniques, could also be employed to enhance the experiment.

Implementing repeated measurements for each sample could provide more reliable results. These approaches will be considered in future planned experiments to gain more comprehensive understanding of the print quality of individual devices.

During the experiment, a substantial amount of data was collected and analyzed. Due to the extensive content of certain results, it was not possible to provide a detailed description of all of them in this article. Therefore, some of these findings, such as dimensional deviations and the cylindricity of cylinders and holes, will be further elaborated upon in subsequent publications.

Nevertheless, the results of this experiment provide valuable insights into print quality, contributing to the selection of the appropriate device and the optimization of the printing process for specific needs.

Our primary research is focused on developing a research station dedicated to AM using an industrial robot. Therefore, our essential goal in this experiment was to assess the competitiveness of robotic arm printing compared to conventional 3D printers.

Our future research will be centered around the advancement and optimization of AM with industrial robot and the creation of a research station that combines additive technologies with industrial robotics.

This station will serve to investigate and refine manufacturing processes, precision, and quality in robotic AM.

The research will focus on developing novel approaches and techniques to enable the utilization of robotic AM across various industrial sectors. The current state of the research station is depicted in figure 6.

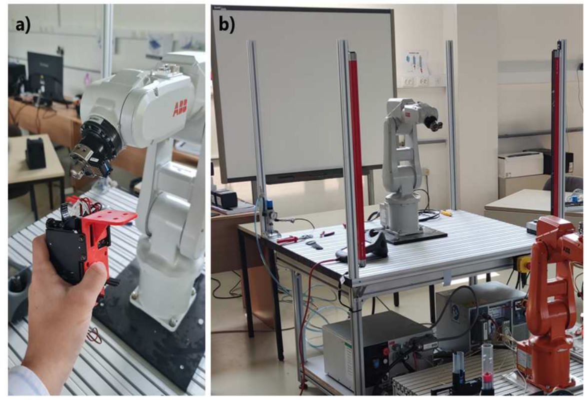

Fig. 6. Current state of research station
a) current state of extruder with industrial robot
b) current state of research station for additive manufacturing with industrial robot

5. CONCLUSION

This scientific paper aimed to compare the print quality of three devices and identify the advantages and disadvantages of the examined equipment. The investigated devices included the DOBOT Magician robotic arm and two conventional 3D printers, namely the Creality Ender 3 V2 and Prusa i3 MK2. The experiment involved printing test samples using the Fused Filament Fabrication (FFF) method and subsequently measuring and comparing the print quality of the utilized devices.

The results of the experiment revealed differences in print quality among the individual devices and emphasized the significance of design and printing parameter settings. When comparing the deviations of the printed models, it was demonstrated that each device has its own unique characteristics and limitations.

Specifically, the Prusa i3 MK2 achieved the most accurate results, with the lowest values of general dimensional deviations for square protrusions. In contrast, the Creality Ender 3 V2 exhibited the largest deviations. The DOBOT Magician robotic arm proved to be competitive and, in certain cases, demonstrated comparable print quality to conventional 3D printers.

This scientific paper provides a valuable contribution to the research in the field of AM and the comparison of various devices used for 3D printing. The results of the experiment assist in identifying the advantages and disadvantages of each device, and they pave the way for further experiments and improvements in this field.

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COMPARAREA CALITĂȚII IMPRIMĂRII 3D PRIN BRAȚUL ROBOTIC ȘI IMPRIMANTELE 3D CONVENȚIONALE

Rezumat: În lumea fabricației aditive (AM), unde evoluția tehnologică este rapidă, alegerea cu înțelepciune a echipamentului devine un factor crucial pentru obținerea unei calități superioare a produsului final. Acest experiment exhaustiv compară calitatea de imprimare a trei dispozitive distincte: sofisticatul braț robotic DOBOT Magician și două imprimante 3D binecunoscute, Creality Ender 3 V2 și Prusa i3 MK2. Acest studiu implica conceperea și realizarea a patru piese de test, folosind exclusiv materialul de acid polilactic (PLA) și tehnologia de fabricație cu filament topit (FFF) pe toate cele trei platforme. Scopul profund al acestui experiment constă în analiza atentă a impactului designului dispozitivelor asupra calității de imprimare, identificarea meticuloasă a avantajelor și dezavantajelor fiecărui aparat, și, nu în ultimul rând, în definirea cu precizie a domeniilor de aplicare specifice pentru fiecare. Procesul de fabricație pentru probele experimentale se desfășoară în aceleași condiții și parametri riguroși, iar ulterior, acestea sunt supuse unei digitalizări 3D amănunțite cu ajutorul scanerului optic ATOS II Triple Scan, pentru a fi apoi analizate în detaliu cu ajutorul software-ului GOM Inspect. Prin intermediul acestui proces complex de digitalizare 3D și măsurare, am adunat o cantitate semnificativă de date, cu privire la dimensiunile precise și deviațiile toleranțelor pentru fiecare dintre probele imprimate în 3D. Toate datele obținute au fost apoi supuse unui riguros proces de prelucrare și analiză, iar rezultatele experimentului au fost prezentate cu precizie, folosind o gamă variată de reprezentări grafice. Concluziile obținute din această cercetare exhaustivă reprezintă un ghid valoros pentru cei interesați să selecteze echipamente adecvate și să optimizeze procesele de imprimare pentru aplicații specifice în domeniul fabricației aditive. Acest articol reprezintă, astfel, nu doar o contribuție semnificativă la cunoașterea în domeniul imprimării 3D, dar și o investigație profundă în ceea ce privește compararea diverselor dispozitive destinate imprimării 3D, deschizând astfel drumul către viitoare experimente și îmbunătățiri într-un domeniu în continuă evoluție.

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