DOI: 10.20535/1970.68(2).2024.318630
UDC 621.37, 535.8

COMPARISON OF 3D-PRINTED PARTS' QUALITY USING PRINTERS WITH "COREXY" AND "DELTA" KINEMATICS

Y. Zhuk, T. Klotchko
National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»
Kyiv, Ukraine
E-mail: zhuk.aroslav@gmail.com

Additive manufacturing, or 3D printing, describes technologies that manufacture parts by depositing thin layers of molten material on top of each other and creating the final part layer by layer. Each layer is built on the basis of geometry designed in CAD systems. Additive manufacturing technology opens up new design approaches: "design manufacturing" versus the traditional "design for manufacturing" approach. Geometric freedom allows you to design products as they are visualized, without manufacturing restrictions. Recently, 3D printers with Delta-type kinematics have gained popularity, which is an alternative to standard, cartesian 3D printers. These models use a more complex control system due to differences in the generation of print paths, but may have some advantages over a cartesian configuration. In order to expand the knowledge of additive manufacturing, a comparative study was conducted with cartesian and Delta printers to evaluate the printing performance of the test part.

This article examines 3D printers with CoreXY and Delta kinematics, compares their characteristics, and identifies key differences in printing processes. As an example, for quality comparison, arbitrary parts printed in batches of three units from the same material with the same settings inside the slicer program were considered. Parts from both 3D printers were scanned using a LIDAR scanner, and the resulting scan models were transferred to a CAD environment for comparison.

The results of the comparison were obtained by the shape and quality of the surface, the production time of one part and batch of parts, mass and dimensional characteristics. Looking at the results, it can be seen that the parts printed by the 3D printer with Delta kinematics have a better surface quality without post-processing, while the parts printed by the 3D printer with kinematics CoreXY correspond as closely as possible to the dimensions specified in the CAD model.

Keywords: *3D printing, 3D printer, CoreXY, Delta, kinematics, quality.*

Introduction

Fused Deposition Modeling (referred to as FDM), as production technology, originated in 1989 and patented in 1992 by Stratasys, USA. This technology refers to the device and process for the formation of a three-dimensional object with a predefined structure, in particular to the manufacturing of a product by applying several layers of material in a liquid state on the building base. After deposition of molten material, its temperature is controlled in such a way that it is solidified almost instantly during extrusion or distribution to the base, with the accumulation of layers that sequentially form the desired product [1, 2].

Additive production processes are characterized by the same basic stages, differing in the way of constructing layers [3, 4]. These processes were popularized through the creation of 3D printers where objects are built by a 3D model layer [5].

In the process of FDM 3D printing, the layers are obtained by deposition of the heated polymer, which is passed through a hot end (printing head). The printing head is equipped with heating components for plasticization of the filament and temperature sensors, which provide evenly high temperature inside the nozzle. The pressure created by the entrance of the thread provides extrusion of molten material through the nozzle [6].

Currently, the use of these technologies goes beyond the initial purpose of rapid prototyping, allowing the final products. The use of this technology progresses in a variety of knowledge. However, the applicability of the equipment has some restrictions, especially given the small volume of production through the size of the construction platform, small batch of printing and a small selection of commercially available material.

The most common 3D printer configuration is the Cartesian configuration (Fig. 1), that is, printing movements occur on orthogonal axes of X, Y and Z. CoreXY is a new configuration for cartesian printers, in which the extruder nozzle moves on the horizontal axes of X and Y, and the building platform on the vertical Z axis [7].

Since recent times, new 3D printers have emerged on the market who have departed from Cartesian kinematics and received Delta kinematics instead. Delta printers are based on a parallel coordinate system, the printing head moves freely on trajectories created by hinged axes, while the printing platform remains static. Although Delta printers move more difficult, they have some advantages over the Cartesian, such as high speed and height of printing, greater production volume, lower inertia of the extrusion node, reduced number of motor parts, simpler housing and better temperature control [8].

As a result of analyzing the technical capabilities of 3D printing equipment and comparing the quality of objects, the goal of this research is to create automated means of obtaining the required accuracy of the dimensions of printed parts.

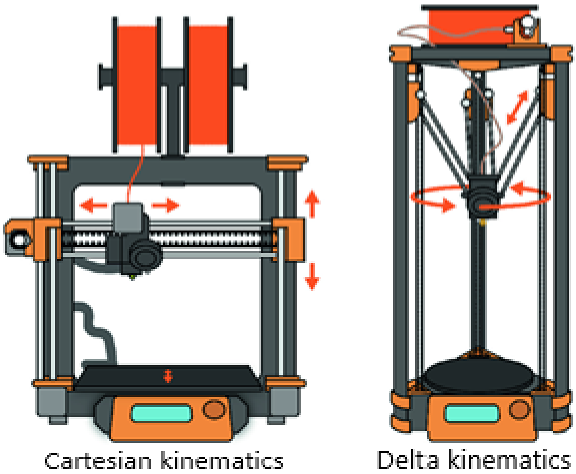

Fig. 1. Comparison of 3d-printers' kinematics

Comparative analysis

To analyze the details printed on two 3D printers with different kinematics, a special part was created, which contains elements of geometry that are difficult to reproduce with a 3D printer without having any dimensional errors. The part represents a certain variety of sizes, angles of inclination, different wall thickness and more than one shape - the part has a square base, a cylindrical vertex inside and an octagonal shape from the outside. After creating a part, segments for measurement (Fig. 2), as well as other aspects of comparison, such as printing time, mass of parts and surface characteristics, were identified.

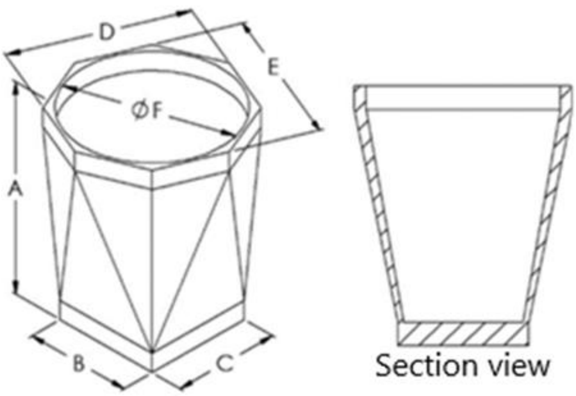

Fig. 2. Drawing of a test part

Printing procedure

The following 3D printers were selected for the manufacture of parts: 1) Creality K1Max with Cartesian Kinematics of CoreXY type (Fig. 3), and 2) Anycubic Predator with Delta kinematics (Fig. 4). The Ultimaker Cura Version 5.6 was used to create the G-code to control the printing. The program used standard settings, except for the following: printing speed - 60 mm/s, layer thickness - 0.3 mm, filling – 50 %, printing temperature - 200 ° C. To ensure the same ambient temperature, from 3D printer 1) the lining of the housing was removed, which prevented the mixing of temperature inside the printer and the ambient temperature. The material that was used for printing is regular PLA gray of the eSun supplier.

Fig. 3. Photo of a Creality K1Max CoreXY 3D printer

Fig. 4. Photo of an Anycubic Predator 3D printer

Measuring process

To check the details by comparing scanned physical samples with the CAD model, a tabletop 3D scanner SHINING 3D EinScan SE V2 was used, which, thanks to the rotary platform, made it possible to obtain clear models of parts by scanning from all sides. The result of scanning and combining models for verification is shown in Figure 5.

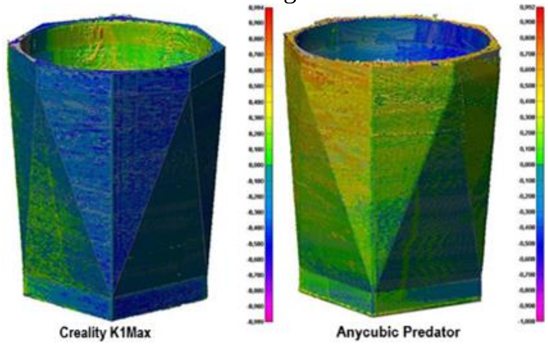

Fig. 5. Scanned part and CAD-model comparison

Data on the time spent was taken from the slicer program, the mass of parts measured using digital weights with an error up to 0.01 g.

Results of the study

First, a visual inspection of parts for mechanical damage and defects was performed after printing (Fig. 6). It can be noted that the surfaces of the part printed with Anycubic Predator 3D printer have a smoother outer and inner surfaces texture than those of Creality K1Max.

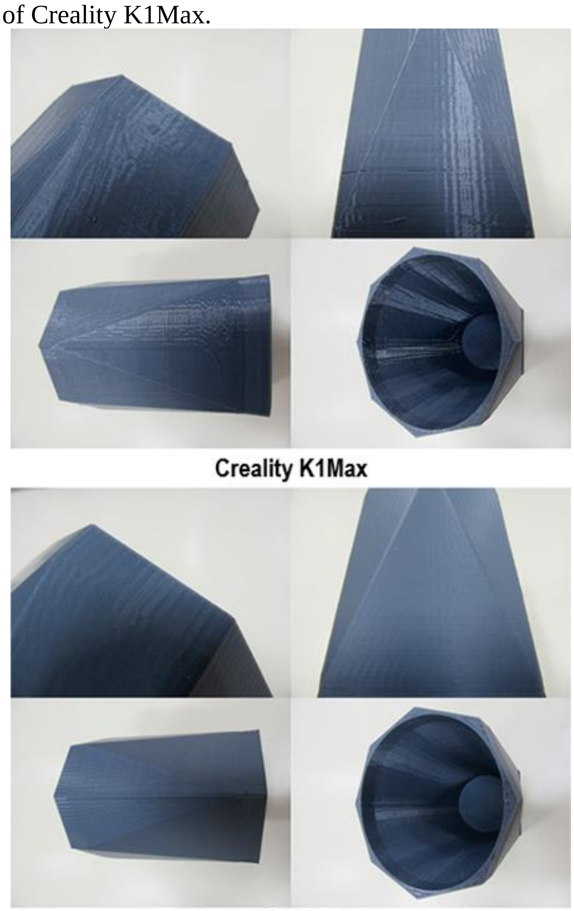

Fig. 6. Parts' surface quality camera shots

We can see from those images that the transitions between the layers on the details made on the 3D printer Anycubic Predator are better than on Creality K1Max. This may be due to the configuration of parameters for the G-code. When the layer is finished, the machine moves only along the Z axis, and since when moving the printing head, the head usually continues to apply the material, it leads to defects on the surface of the workpiece.

Some defects that are observed in Creality K1Max parts associated with excessive extrusion. These defects can also be attributed to adjusting technological parameters, such as the excessive power of the extruder stepper motor, incorrect settings of driver steps, incorrect print temperature settings and more.

According to the slicing software, the time of printing one part without taking into account the time for the preparation of the platform and removal of the part on the Anycubic Predator was 5 hours and 50 minutes, while it took longer on the Creality K1Max with the time of 6 hours and 54 minutes. It should be noted that printing time on both 3D printers can be significantly reduced by raising the speed of printing. At best, print time can take up to one hour, but the quality of the surfaces will be reduced.

The data on the mass and dimensions that were measured during the study are given in Table 1. The dimensions, except for 3D scanning, were physically measured by a digital caliper with an error up to 0.01 mm.

The characteristics of the mass of the parts were very close, the parts made with the Creality K1Max were 5% higher compared to Anycubic Predator. However, such a deviation is not significant because it is included in the permissible margin of the error of printed parts.

As for the measured size of parts, Creality K1Max showed the best result, with an average deviation up to 0.5% of the CAD model. Anycubic Predator showed a slightly worse result, with a deviation of up to 1.1% of the CAD model. It is worth noting that Creality K1Max comes in prebuilt, while Anycubic Predator – disassembled. This also may include an error in the 3D printing process. Also, when creating a G-code, the part was not scaled according to the polymer shrinkage ratios due to cooling.

Development of control software for the high-speed dimensional measurement module (HSM)

Along with the hardware of HSM module, it was necessary to develop and test its software.

The software of HSM module consists of two main parts: the movement/rotation part and the measurement part. The movement/rotation part tracks the movement and rotation of the camera using stepper motors. The signals that the microcomputer will send to the stepper motor drivers will ensure the movement of the stepper motor itself.

The measurement part is responsible for photofixing the printed part under investigation by the camera, morphological image processing, recalculating the size of the part from pixels to millimeters, and providing the operator with information about the measured parameters.

In the process of research, an image processing algorithm was created (Fig. 7)..

Table 1. Mass and dimensions measurement results

CAD model		Creality K1Max					Anycubic Predator				
		Pt. 1	Pt. 2	Pt. 3	Avg.	%	Pt. 1	Pt. 2	Pt. 3	Avg.	%
A, mm	110	110.49	110.44	110.45	110.46	0.11	110.10	110.01	109.96	110.02	0.06
B, mm	55	54.96	55.02	55.33	55.10	0.20	55.85	56.10	56.01	55.986	0.12
C, mm	55	55.02	55.10	55.27	55.13	0.17	55.55	55.76	55.67	55.66	0.11
D, mm	85	83.50	84.93	84.80	84.41	0.80	86.02	86.40	86.18	86.20	0.25
E, mm	85	84.78	85.20	85.59	85.19	0.42	86.32	86.14	86.29	86.25	0.15
F, mm	82	81.70	81.36	81.48	81.51	0.92	82.66	82.39	82.50	82.516	0.19
Mass, gr	117,00	132.76	133.30	127.37	131.14	9.27	126.25	125.87	119.29	123.8	6.27

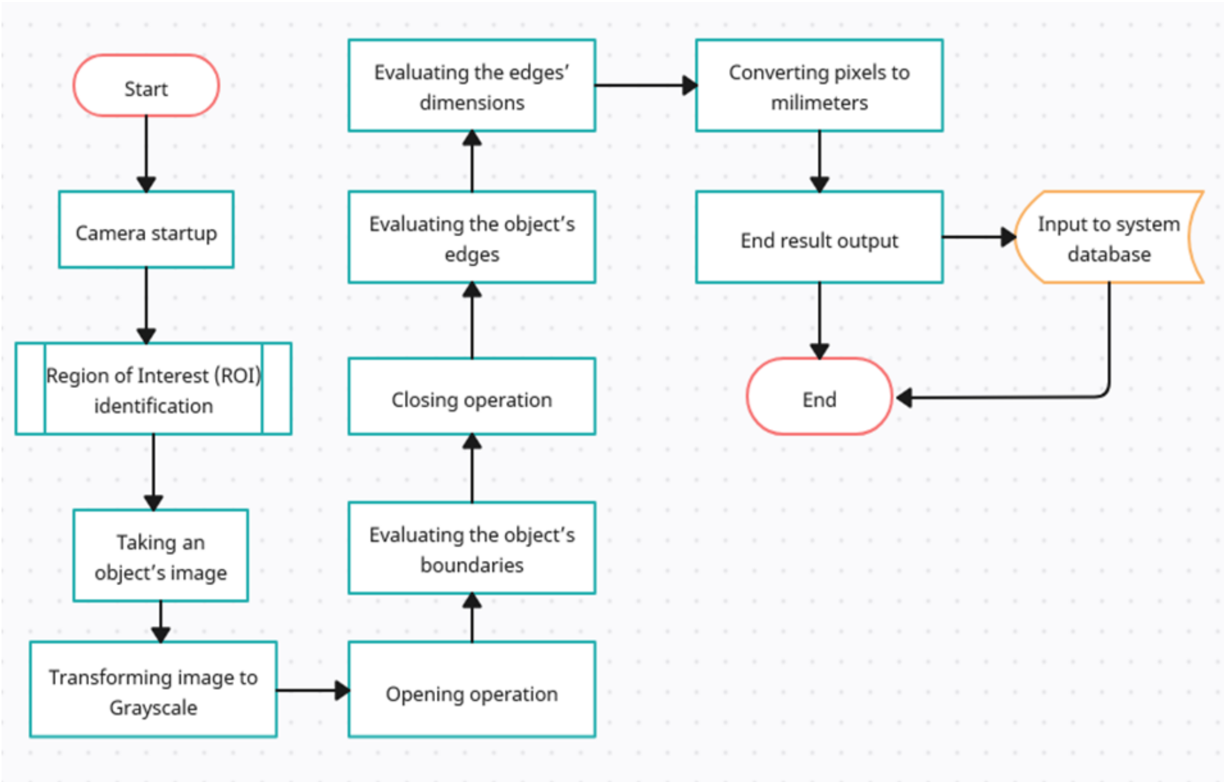

Fig. 7. Image processing algorithm

So, for image processing, finding contours, and getting rid of unwanted artifacts during photo fixation, the OpenCV library was used, namely such functions and methods as cvtColor, Canny, Opening, Closing.

The next step after converting the image to black and white is the Opening operation. The Opening operation in OpenCV consists of two simpler operations – Erosion and Dilation, and is a sequential processing of the image first by erosion, and then by dilation. The Opening operation consists in removing noise from the image – first erosion "removes" unnecessary points and artifacts from the image, and then dilation returns the image to its original state, but with the artifacts erased) [9].

In the case of photofixation of HSM module, the unfolding operation removes the image from dots and artifacts on the surface where the part is located.

Next, the Canny function is executed, as one of the main tools in OpenCV, allowing you to determine the contours of the desired object [10].

The Canny function is an algorithm with several stages, which are noise removal operations using a Gaussian filter with a 5x5 kernel, gradient intensity determination using a Sobel kernel, and removal of unwanted pixels that do not constitute the object boundary [11].

The last image processing function is the Closing function. Like the Opening function, Closing also consists of the basic Erosion and Dilation functions, but in Closing they are performed in reverse order. First, Dilation enlarges the boundaries of our image, closing the gaps and gaps in the photo of the object, after which Erosion returns the image without artifacts inside the object to its previous size [9]. During image processing using the software of the HSM module, these operations are also performed on the image of the part. That is, the sequential conversion of a multi-color image into a contour image.

After performing image transformations, the program calculates the image dimensions in pixels. For this purpose, the cv2FindContours function is used, which finds and determines the dimensions in pixels of the bounding box of the object contours. Since in our case the boundaries of part have already been determined by the Canny, Opening and Closing methods, the bounding box will be applied as accurately as possible. After finding the dimensions of the border frame in pixels, it is necessary to convert them to millimeters. To do this, using an object whose exact dimensions in millimeters are known in advance, for example, a metal ruler scale from 0 to 100 mm, it is necessary to find the pixel-to-millimeter conversion factor. At a distance of 150 mm, the camera was fixed in a stationary position and the image was centered relative to the camera focus to reduce image distortion. After that, OpenCV tools similar to the previous methods were used to determine the length of the straight line drawn from the ruler division 0 to the division 100. In the end, a factor of 7.42 was obtained, which shows that at a distance of 150mm from the camera, 1 millimeter of the object corresponds to 7.42 pixels in its image.

Having received the dimensions of the bounding box of the part from the cv2FindContours function, the dimensions in pixels are converted to dimensions in millimeters. Information about the measured dimensions is fed to the console (Fig. 8) and stored in global variables, which allows the automated system to obtain data about the dimensions at any time.

The detection and measurement of the bearing hole are performed in a similar way, only if a rectangular mask was used in the detection of the boundary box, then in the case of the hole, circle masks are used.

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Press 'c' to capture an image for measurement. Press 'q' to quit.
Capturing and processing the image
Object's sizes are as follows:  33.82749326145552 mm x 22.911051212938006 mm
Image captured and processed
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Fig. 8. Console of the software environment with the obtained dimensions

So, based on the experiment and the developed model of the module operation, the algorithms of the module operation and software were created, the hardware application was selected and the CAD model of the HSM module was created. Also, the software of the HSM module was developed, which performs the detection and measurement of the dimensions of the part being investigated.

Conclusion

This study made possible the comparison of the quality of parts created by 3D printers that use different configuration, Cartesian (CoreXY) and Delta. Depending on the material, the type of further postprocessing (coating, special surface parameters, etc.), it is possible to choose a 3D printer configuration, which will reduce the number of postprocessing operations, which in turn will help to avoid production defects, increase the number of parts in the batch and increase the profit.

The study shows that 3D printers with Delta kinematics will have a smoother overall surface after printing, which will eliminate the abrasive grinding from the post-processing. In addition, the part will have stronger connections between the layers due to the absence of external interventions, which will help avoid the unnecessary defects of printed parts.

Given the dimensional parameters, the 3D printer with CoreXY kinematics showed better result, providing smaller deviations from the initial CAD model. This is confirmed by both scanning and measuring the size by hand. On the other side, despite the dimensional accuracy, the surface was printed in a less satisfactory condition, but the right choice of material and print parameters will help to avoid these errors. In addition, taking into account the coefficient of the polymer thermal shrinkage will help print a detail with more accurate dimensions, which can even be a substitute part for the basis of critical and precise parts and mechanisms.

The details printed with both 3D printers showed an almost identical result, but the 3D printer with Delta kinematics showed a much better result as a surface without post-processing. The end result of the printing will depend on how much the process parameters and the software every 3D printer is suitable for printed parts.

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УДК 621.37, 535.8
Я. Б. Жук, Т. Р. Клочко
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна

ПОРІВНЯННЯ ЯКОСТІ ДЕТАЛЕЙ, ВИКОНАНИХ 3D-ДРУКОМ З ДОПОМОГОЮ ПРИНТЕРІВ ІЗ КІНЕМАТИКАМИ "CoreXY" ТА "DELTA"

Адитивне виробництво, або ж 3D-друк, описує технології, за допомогою яких виготовляються деталі наплавленням тонких шарів матеріалу один поверх іншого та створення кінцевої деталі шар за шаром. Кожен шар будується на основі геометрії, спроєктованої в CAD-системах. Технологія адитивного виробництва відкриває нові підходи дизайну: «виробництво дизайну» проти традиційного підходу «дизайн для виробництва». Геометрична свобода в дизайні дозволяє проєктувати продукти так, як їх візуалізують, без виробничих обмежень. Останнім часом набули популярності 3D-принтери з кінематикою, що є альтернативою стандартним, декартовим, 3D-принтерам: з кінематикою типу Delta. Ці 3D-принтери використовують більш складну систему керування завдяки відмінностям у генерації траєкторій друку, але можуть мати деякі переваги перед декартовою конфігурацією. Щоб розширити знання про адитивне виробництво, було проведено порівняльне дослідження з декартовими та дельта-принтерами для оцінки продуктивності друку тестової частини.
В даній статті розглянуто 3D-принтери з кінематиками CoreXY та Delta, порівняно їхні характеристики, визначено ключові відмінності процесів друку. В якості прикладу для порівняння якості розглянуто довільні деталі, надруковані партіями по три одиниці з однакового матеріалу, з однаковими налаштуваннями всередині програми-слайсера. Деталі з обох 3D-принтерів відскановано за допомогою LIDAR-сканеру, отримані моделі сканів перенесено у CAD-середовище для порівняння. Отримано результати порівняння за формою та якістю поверхні, часу виготовлення однієї деталі та партії деталей, масово-габаритними характеристиками. З огляду на результати видно, що деталі, надруковані 3D-принтером з кінематикою Delta, мають кращу якість поверхні без постобробки, в той час, як деталі, надруковані 3D-принтером з кінематикою CoreXY якомога точніше відповідають заданим в CAD-моделі розмірам.
Ключові слова: 3D-друк; 3D-принтер; CoreXY; Delta; кінематика, якість.

Надійшла до редакції
24 жовтня 2024 року

Рецензовано
19 листопада 2024 року