INTRODUCING THE CAPABILITY TO AUTOMATICALLY ALTERNATE THE NOZZLE DIAMETER OF THE 3D PRINTER IN CURA SOFTWARE

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Abstract

In the first phase of 3D printing, the 3D model is divided into horizontal partitions or layers. The supposed cut leads to the construction of a triangular network in the modeling software. The nozzle installed at the end of the 3D printer is one of the most effective components of the final print output. The nozzle is the most attractive component of the 3D printer. Generally, people are interested in watching the first few layers of print coming out of the nozzle. One of the most flexible parts of 3D printers is the capability to alternate nozzles for different printing applications. Nozzles have various shapes and sizes leading to the realization of the same function. Another imperative component in printing is the diameter of the nozzle opening, which has a tremendous impact on the quality of print details. This effect applies not only to the width of the layer lines but also to the height of the layers. Previously, changing the nozzle for printing with a different diameter was done manually with special wrenches. The purpose of this research is to automatically alternate the diameter of the nozzle according to the 3D model of the input, detection of the surroundings, and detection inside the shape. In addition to eliminating manual and time-consuming tasks, this process improves the printing time and can realize printing in different layers with different diameters. This research aims to design a new algorithm in the production of G-Code, how to move the nozzle, and apply the corresponding hardware changes to achieve this objective.

Keywords: 3D printing, 3D printer, nozzle diameter, CURA, open source, additive manufacturing, cutting, G-Code plugin

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1. Introduction

In recent decades, 3D printing has been one of the most influential technological advances in societies. Most organizations are looking for a way to effectively use it to solve real-world problems [1]. For example, NASA is investigating the use of this technology in space for long-term food supply and increasing the volume of food on the space stations [2]. This allows astronauts to print and then consume their food instructions to maintain their food supply long-term in space [3]. In addition, doctors are looking to use this technology to produce medical implants and help people in need [4]. One of these implants has been used in one case to save a baby. Also, humanitarian efforts have used 3D printers to print low-cost prostates for children and the disabled [5]. Objects printed by this printer are limited to models and prototypes due to the limitations of this technology in materials and print size [6]. However, the next step for researchers, engineers, and designers is to try to eliminate these limitations [7].

The time-consuming process of simulating and making replicas of parts is accelerated by using a 3D printer. By printing 3D designs, it is possible to evaluate the parts in a short time. The main advantages of this system are the rapid production of prototypes, saving materials, making new shapes with special structures and shapes, and a new combination of materials. The substitution of additive manufacturing techniques has created a huge transformation in production methods [8]. This technology can produce parts with high appearance complexity, combinations of different materials, high functional complexity, etc. [9]. Today, everyone can afford a desktop 3D printer. So we are probably at the beginning of a revolution in manufacturing processes. The emergence of computers in the second half of the 20th century and the development of advanced software in the field of computer-aided design (CAD) and computer-aided manufacturing (CAM) have caused a revolution in the design, prototyping, and manufacturing methods [10].

The first 3D printing technology appeared in 1980. Dr. Kodama from Japan registered this technology for the first time. At the time, this technology was called rapid prototyping. The reason for this naming was the design of this technology for quick and low-cost manufacturing of a prototype for mass production. Charles Hale registered the stereolithography device in his name in 1986. Of course, Hale had invented his device in 1983 and was founding the Systems3D Company. This company was known as RP Systems at that time and is now one of the leading players in the field of 3D printing. The first sample of this device was made with the name SLA-1 and was introduced in 1987. The first successful test of this invention was realized in 1988.

In Jing Hu's research, adaptive cuts were applied according to the desired local window on a continuous graph of several points along the index layers. That is, smaller cut distances were imposed on the high-density local area. The objective was to adjust the thickness of the cut during cutting and reduce the running time [11]. According to Luzanian et al., another challenge of layering is thickness adjustment. The minimum layer thickness fundamentally affects the maximum bending force. That is, when the thickness of the layer changes from -1 to +1, the maximum bending force decreases more than three times [12].

In his study, Chen (1996) investigated the role of the alteration in the movement patterns of the nozzle over the production time in the stereolithography process. Also, the effect of laser movements, the number of path segments, and the number of jumps to change the laser path at the start of new paths were studied. The researchers also presented a new method for predicting the time to build a mathematical model based on tool paths and selected parameters [13]. Thomson and Yoon (2014) introduced the algorithm of a path planning method controlling the movement of an XY stage for an arbitrary print path and optimal speed and minimizing material waste. This process has led to the minimization of the path planning time during the transfer of the printer [14].

Several kinds of research can be mentioned that studied different aspects such as surface smoothness, polished edges, strength, accuracy in production, gentle slope of the edges, and other things related to the production of the part. As far as we know, the automatic diameter of the nozzle and the disconnection and connection of material pouring until the final production of the part have been investigated.

Kogat Pavel et al. (2017) in their study entitled "Algorithms for selecting control parameters for automating the 3D printing process" introduced important and effective parameters for 3D

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printing. One of the effective control parameters was the diameter of the nozzle. In this research, only the effect of changing the diameter of the nozzle on the thickness of the walls in the model was investigated. This parameter has an important effect on the final print quality.

To improve print quality, ULTIMAKER CURA 3.2 introduces a new feature called Adaptive Layers. The Adaptive Layers setting automatically adjusts the height of the layer throughout the object depending on the geometry of the print. However, if one small layer is used for the whole object, the printing time will be less. In this method, minimal changes in layers are controlled concerning other layers. In other words, the change in nozzle diameter in different layers is very small. Also, due to the hardware of these printers, we face the challenge of manually changing nozzles for different diameters. In the studies related to the quality and production time of the part, emphasis has been placed on the topic, but the main deficiency in the literature is the challenge of changing the diameter of the nozzle. By reducing the number of nozzles going back and forth, the production time of the part is significantly reduced. At the same time, the number of times the material pouring is very effective both in the amount of material waste and in the work speed.

The objectives of this study are to minimize the number of nozzles going back and forth, minimize the path traveled by the nozzle, minimize the number of disconnecting and connecting the nozzle, and minimize the total production time. We first define these activities in problem modeling. Then, code our algorithm in Visual C++ software to achieve the best variation for the nozzle diameter. Finally, we inject it into the program.

The nozzle at the end of the 3D printer is one of the important and effective components of the final print output. The nozzle is the most attractive component of the 3D printer. This is because people are generally interested in watching the first printed layers coming out of the nozzle. One of the most flexible components in a 3D printer is the ability to change the nozzle for different printing purposes. Nozzles have various shapes and sizes that follow the same function [15]. Another challenge in printing is determining the diameter of the nozzle opening, which has a very important effect on the quality of print details. This effect is significant not only in the width of the layers but also in the height of the layers. Changing the nozzle for printing with different diameters is achieved manually with special wrenches. This research aims to automatically modify the diameter of the nozzle according to the input 3D model and the detection of the surroundings and inside of the shape. In addition to eliminating manual and time-consuming tasks, this technology improves the printing time and performs printing in different layers with various diameters.

2. Materials and methods

CURA software cuts 3D models. This program converts STL, OBJ, or MF3 3D files into a format understandable for the printer. 3D printers have the technology of fused filament fabrication (FFF). This feature stacks each layer on top of the other to create the 3D object. There are several problems related to nozzle diameter and how to change it in the printing environment and pre-printing settings. To reduce these problems, a variable nozzle has been designed by "Cheng Maryam" a Ph.D. student in mechanics. This nozzle can increase and decrease. The way of change is formed according to the motion engine and its calibration. As a result, we design an algorithm in CURA according to this hardware to perform printing operations with different diameters and reduce the mentioned problems. Figure (1) shows the design schematic of this type of nozzle.

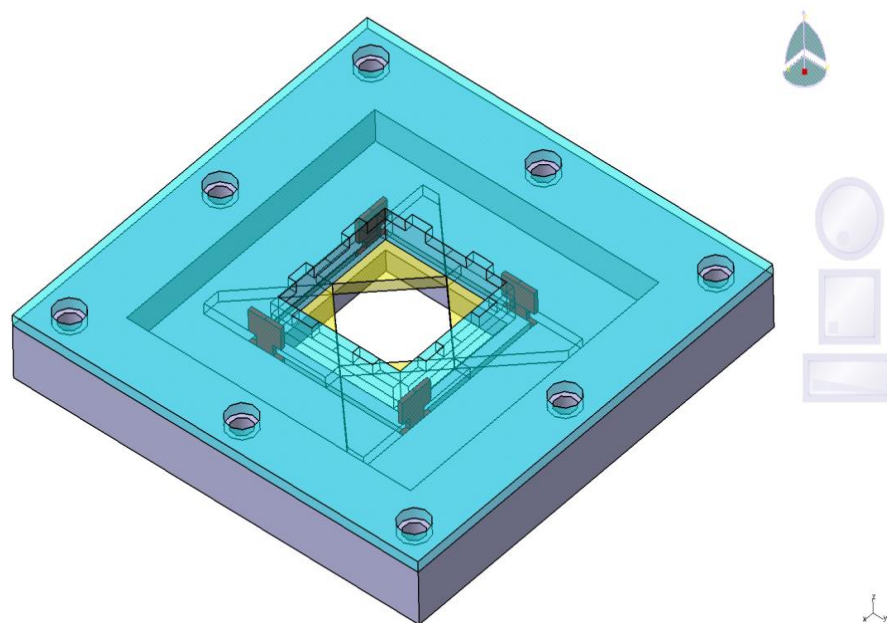*Eur. Chem. Bull.* **2023**, *12(Special Issue 7)*, *5495-5507*

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Figure 1: A sample nozzle designed by Cheng Maryam

The proposed algorithm for generating G-code related to printing and layering optimization is reflected in the flowchart of Figure 2.
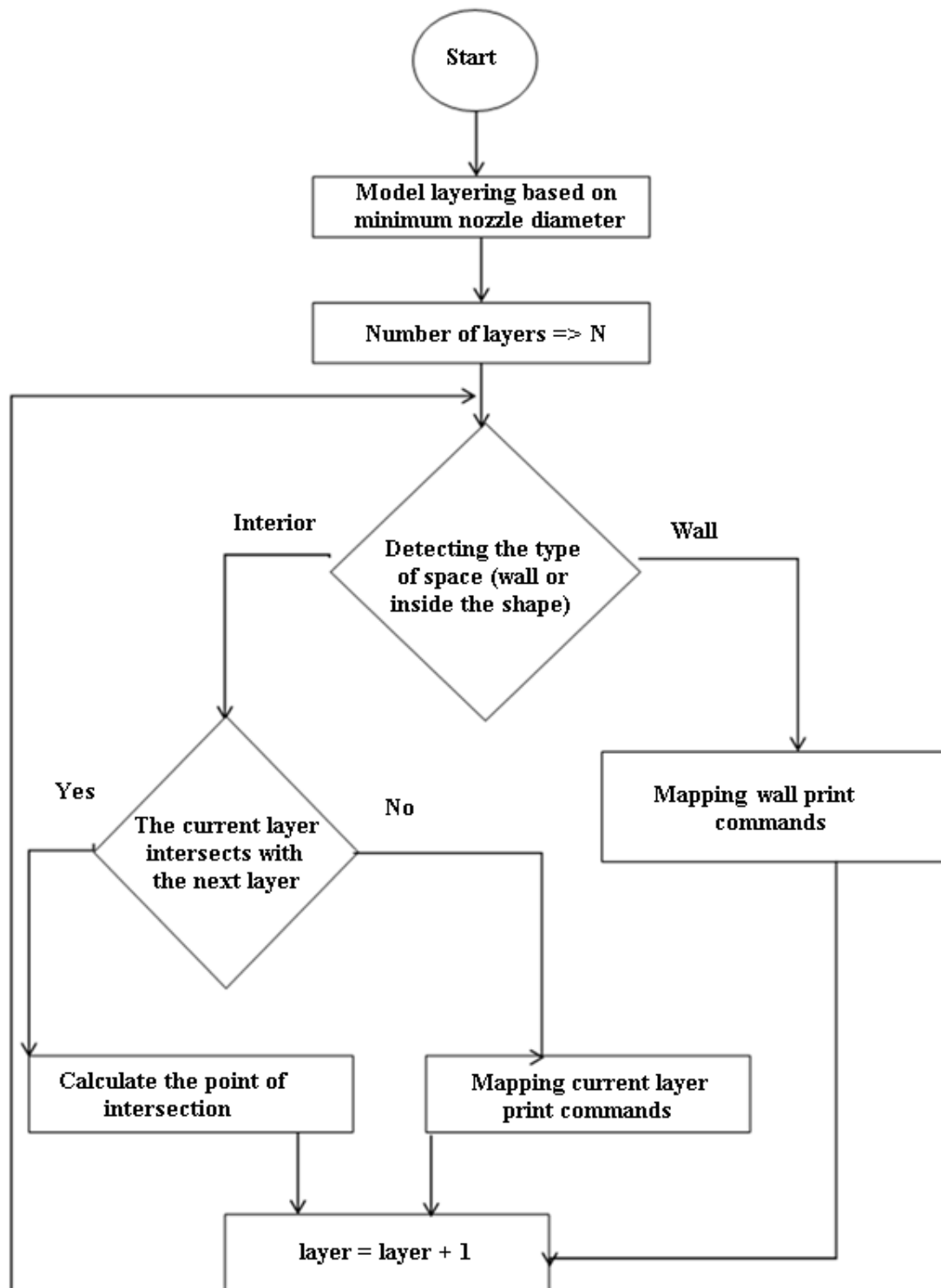
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Figure 2: The proposed algorithm

3. Results

3.1. Algorithm design

This study aims to find and design an algorithm to simultaneously change the parameters according to the change of the nozzle hardware. To achieve this goal, we first extracted the most important parameters affecting the 3D printing process in FDM technology. How these parameters affect the final print is examined. Subsequently, the optimal values selection method is defined according to the proposed algorithm. The parameters affecting the final shape of the print

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are presented in Figure (3).

Start → Meshing → Nozzle diameter → Consuming materials → Cooling → Print
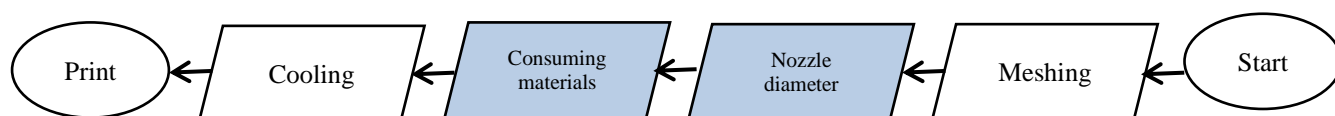
Figure 3: Parameters affecting 3D printing

The first step for printing is object modeling in CAD software. For print processing, the model is translated into a grid of trigonometry according to the STL (stereolithography) standard. The main challenge is to choose the appropriate mesh density for a model. Details should be selected according to the quality expected from the final print. After creating the model and transferring it to the CURA cutting software, the height of the layers is set in the printing settings corresponding to the smallest diameter of the nozzle, for example, in the range of 0.2-0.4 mm. This makes the layers cut with the highest quality. The golden size of the nozzle diameter is between 0.1-0.5 mm. To fill in the model, N consecutive layers are explored to find the intersection area, and the intersection points of the consecutive layers form an independent layer for printing. The 3D model is shown in Figure (3). Also, the 3D model after the initial settings in the CURA is shown in Figure (4). Figure (5) shows the multilayer aggregation with the intersection area.
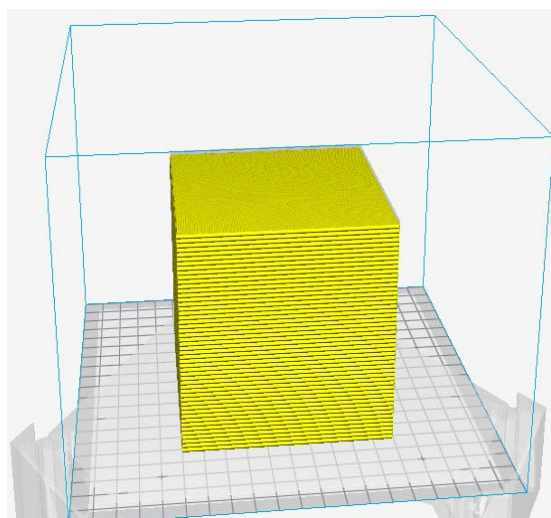
Figure 3: 3D model

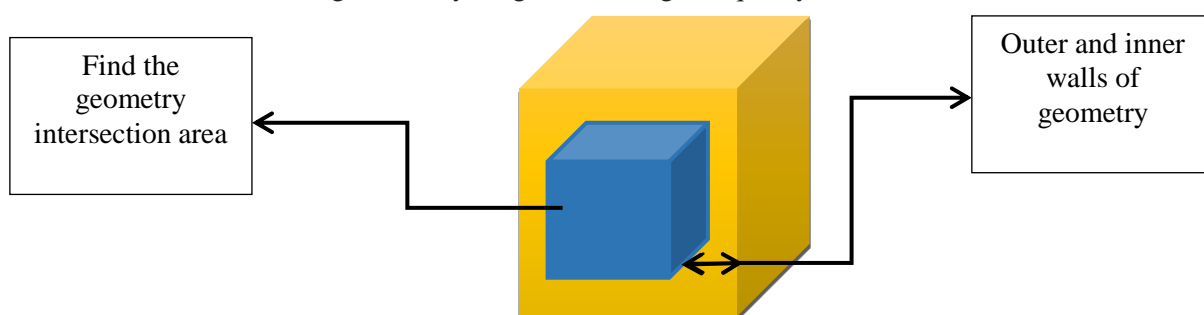Figure 4: Layering with the highest quality in Slicer

Find the geometry intersection area ← [3D model] → Outer and inner walls of geometry

Figure 5: Multilayer aggregations with intersection area

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According to Figure (6), the walls are printed with good quality and guarantee the strength of the shape. Also, separate layers within the model have been formed according to intersection areas for printing.
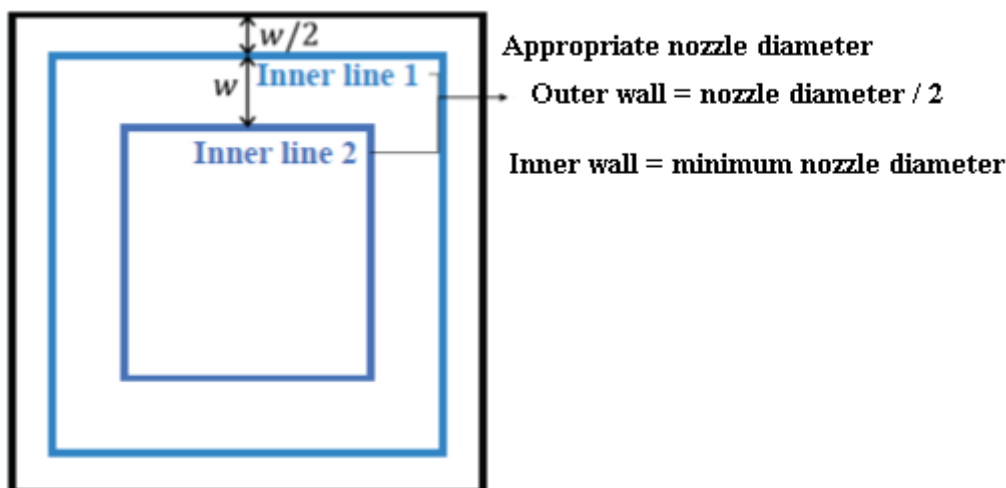

Figure 6: The diameter of different print areas

First, the intersection area is measured. If the diameter of the nozzle is less than the intersection area, the material is poured as much as the maximum diameter of the nozzle. Then the remaining area is again compared with the diameter of the nozzle and the previous process is repeated until the entire intersection area is filled. Because the height of the new vertical layer has changed, the height is calculated again for the vertical layer according to the following formula.

*The height of the new vertical layer = the number of aggregated layers * the thickness of the layer (in CURA initial settings).*

Finally, the nozzle with the maximum diameter performs the printing operation with the aforementioned height. At the same time, the parameter of the amount of material pouring in the new layering has also changed which must be recalculated and applied. Figures (7) and (8) show the schematic of this process.

3.2. Pseudo code to find intersection area

define the `Detection` object

boxA=Layer i

boxB=Layer i+1

determine the (x, y)-coordinates of the intersection rectangle

xA = max(boxA[0], boxB[0])

yA = max(boxA[1], boxB[1])

xB = min(boxA[2], boxB[2])

yB = min(boxA[3], boxB[3])

compute the area of the intersection rectangle

interArea = (xB - xA + 1) * (yB - yA + 1)

compute the area of both the prediction and ground-truth

rectangles

boxAArea = (boxA[2] - boxA[0] + 1) * (boxA[3] - boxA[1] + 1)

boxBArea = (boxB[2] - boxB[0] + 1) * (boxB[3] - boxB[1] + 1)

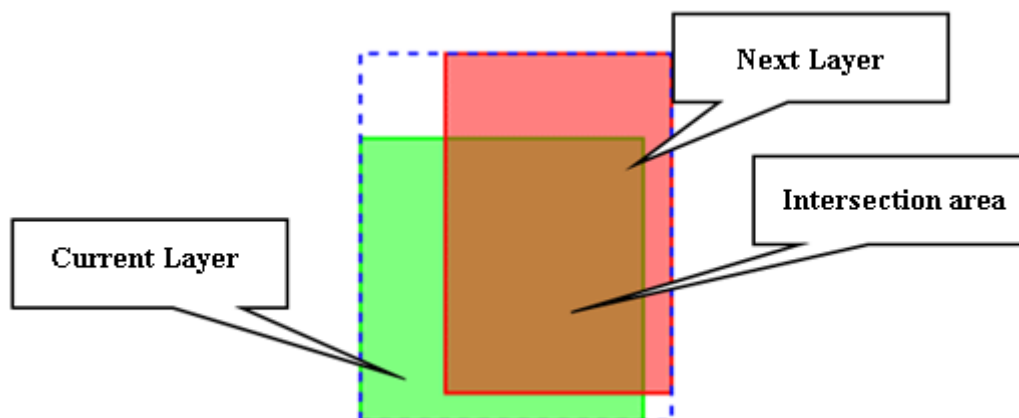*Eur. Chem. Bull.* **2023**, *12(Special Issue 7), 5495-5507*

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Figure 7: A view of two layers

Figure 8: Intersection area between two layers

3.3. Pseudo-code to find the point of intersection with the shared area

After finding the intersection area between the layers and creating a new layering, the remaining points are determined for subsequent calculations. To do this, the equation of the line was used to find the point of intersection.

Y = MX + C

M= (y2 - y1) / (x2 - x1)

intersection_X = (c2 - c1) / (m1 - m2);

intersection_Y =m1 * intersection_X + c1

4. Calculating the amount of material pouring

The amount of material pouring E is another critical parameter in 3D printing. The value of E corresponds to the position of the thread spool. So if you move the E-axis by 10 mm, the thread will move 10 mm into the nozzle. Since the diameter of the nozzle is usually much smaller than the diameter of the filament, 10 mm of filament is transferred into the nozzle. This process may produce extrusions hundreds of millimeters long. As a result, the E values observed in the file are very small compared to the X, Y, and Z values. To be more precise, the amount of pouring is calculated according to the length of the filament. The calculation of pouring rate with a fixed nozzle diameter is calculated in the software according to the following formula.

E_{value} =layer height * flow % * extruder diameter * distance [852]

*Material pouring rate = layer height * pouring density * fixed nozzle diameter * distance*

%flow: The default value of this parameter is 100%. This indicator shows the density of filling, which can be changed in user settings.

DiametrNozzle: This is a variable parameter that is determined according to the user's needs and generally varies between 0.3-0.5.

Distance: This parameter reflects the distance printed in one move.

LayerHeight: This is the layer height parameter applied by the user in the pre-print settings.

This research aims to change the diameter of the nozzle according to the design hardware. Figure (9) shows the hardware view of a sample nozzle.

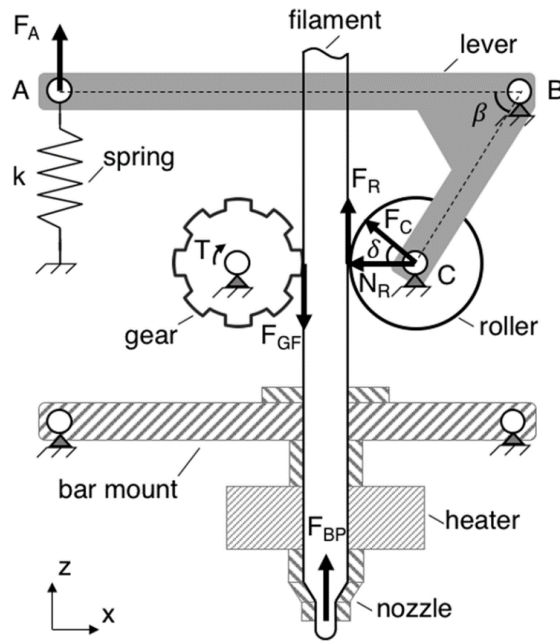*Eur. Chem. Bull.* **2023**,*12(Special Issue 7), 5495-5507*

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Figure 9: Nozzle hardware schematic

Contrary to usual, the nozzle opening here is square, which in turn can be calculated by the following equation (variable nozzle schematic is shown in the figure).

D = nozzle diameter

A = new nozzle diameter

$$a^2 = \frac{\pi D^2}{4}$$

$$\boxed{D = 1.31\,a}$$

$$E_{value} = L * \frac{D}{filament\ Diametr}$$

where L is the path filled by the filament and D is the diameter of the new nozzle.

The schematic of the nozzle is shown in Figure (10). Based on the nozzle shown in Figure (10), we calculate the type of material pouring according to Table (1).
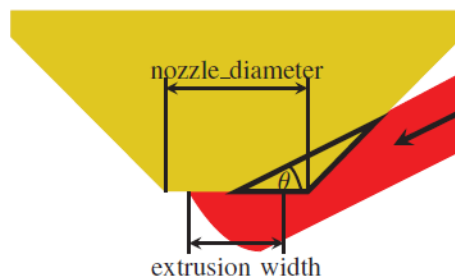

Figure 10: a nozzle with a square diameter required for coding.

Table (1) shows the defaults and values

Table 1: defaults and values required for coding

Parameter	Description/Value
3D printer	Ultimaker
Filament	PLA

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layer height	According to the aggregation of intersection layers
Extrusion speed	100 mm/s
Material speed	100 mm/s
Filament diameter	1.75 mm
Nozzle diameter	0.4 mm – 20mm
Nozzle change time	4 s

5. Time calculation

Quality and time are the most important effective parameters in 3D printing. We calculate the printing time of the variable diameter of the nozzle, subject to the fixed diameter.

Build time: the time it takes to print a 3D model with a 3D printer. This parameter is represented by T_{Print}. In this regard, we consider the following items in order.

Two movement commands G0 and G1 allocate most of the printing time.

G0: Rapid movement to the segment where the printing operation starts.

G1: Determine the rate of progress of the operation or movement with the pouring of the material

When the diameter is constant, the time is calculated according to the number of movement commands. G0 movement time and G1 movement time are represented by T_{G0} and T_{G1} respectively. Sub-times such as nozzle heating time etc. are displayed with T_{Other}. As a result, the total time is calculated as follows.

$$T_{Print}= N(TG0) + N(TG1) + T_{Other}$$
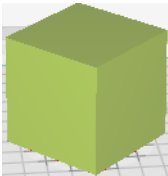
Here N represents the number of commands.

When the diameter of the nozzle is variable, the time of increasing and decreasing the diameter of the nozzle should also be applied. By default, it takes 4 seconds to change the diameter every time.

$$T_{Print}= N(TG0) + N(TG1) + N(T_{NozzleDiameter})+ T_{Other}$$

6. Comparison

The obtained results are the result of executing the STL file of the 3D model. This file is modeled in CATIA. The resulting model has been tested with the CURA algorithm and the proposed algorithm separately. The results obtained in this section are evaluated and compared.

Table 2: Implementation of the algorithm on the cube

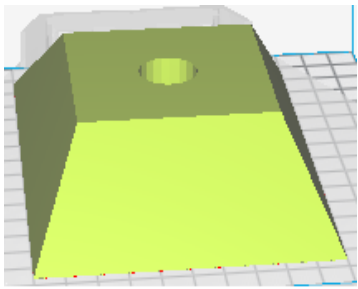| Method	3D model	Dimensions	The number of G0	The number of G1	Nozzle diameter	Time
CURA algorithm		5 × 5 × 5 mm	108 movements	1000 movements	1 mm	1108

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The proposed algorithm		5 × 5 × 5 mm	37 movements	930 movements	1-20 mm	975
Explanation	In the CURA algorithm, the layers (1 outer wall, 2 inner walls, 3 inside the shape) are printed with a diameter of 1. In the proposed algorithm, the outer wall and the inner wall were printed with a 1 mm nozzle, and then the inside of the model was printed with a 3.4 mm nozzle (once) and a 1.6 mm nozzle (twice).					

An island is a separate part of a model that occurs in 3D printing and is known as one of the most important models. In this section, we implement an example of an island model (the details of the G0, and G1 commands are provided in the appendix).

Table 3: Implementation of the algorithm on the island model

Method	3D model	Dimensions	The number of G0	The number of G1	Nozzle diameter	Time
CURA algorithm		5 × 20 × 15 mm	108 movements	1000 movements	1 mm	1103
The proposed algorithm		5 × 20 × 15 mm	204 movements	536 movements	1-20 mm	756

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Explanation	In the CURA algorithm, the layers (1 outer wall, 2 inside the shape) are printed with a diameter of 1.
	In the proposed algorithm, the outer wall and the inner wall were printed with a 1 mm nozzle. Then the remaining space of the intersection area is printed with a diameter of 1 mm. Subsequently, the lower intersection area with a diameter of 2.4, the right intersection area with a diameter of 2.3, the left intersection area with a diameter of 2.32, and the upper intersection area with a diameter of 2.43 are printed.

7. Conclusion

In recent years, the use of 3D printing in the production of objects and products has been greatly appreciated. Many industries such as mechanical engineering, manufacturing, medical engineering, aerospace, and even food industries use 3D printing technology. 3D printing was originally a modeling or unit manufacturing process. However, today it has introduced itself as a modern production technology. Today, most of the activities carried out in the industry are realized based on 3D printing. Wohlers are serious players in the 3D printing market and publishes regular progress reports. They believe that the global 3D printing industry will reach more than 15 billion dollars in revenue by 2020. According to the same trend, the revenue of the industry is expected to be 9.23 and 6.35 billion dollars by 2022 and 2024, respectively.

The progress and evolution of 3D printing are revolutionizing all industries in the world. The future of work, life, and even gaming and entertainment will be transformed with 3D printing technology. However, this technology faces several challenges, such as the lack of automation in some implementation steps. One of these challenging cases is manually changing the nozzle diameter. The main goal of this research was to provide a suitable algorithm for automatically changing the nozzle diameter based on the hardware used.

This process, in addition to reducing the time of changing the nozzle as well as related software settings, can increase the printing speed. The reason is that in successive layers with an intersection area, it is possible to print with a larger diameter of the material. At the same time, this process strengthens the print quality because the print walls, which represent the appearance and endurance of the model, are printed with the highest quality and the smallest nozzle diameter. Testing and evaluation of this program are desirable for printing more complex models containing geometric shapes with variable nozzle diameters. In future work, this algorithm can be optimized for more complex geometric models that require polished or angular edges.

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