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Research Article

Design And Manufacture Of Continuous Automatic 3D Printing Device With Conveyor System By Image Processing Technology

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Abstract

In parallel with the technological developments, especially manufacturing and automation, many areas are experiencing new developments in the all world. These revolutionary technological developments are mentioned with different names (4th industrial revolution, digital transformation, etc.) and new inventions are present under different disciplines. Among all these developments, the most important advancements are the field of manufacturing. In recent years, 3D printing technologies can be said to have noteworthy studies in many countries. 3D printing technologies make it easy to manufacture complex parts. Although 3D printing is a new technology, it has been rapidly spreading in many other sectors, especially in education. However, these devices have a significant disadvantage. 3D printing technologies depend on a user. After the manufactured part, the parts need to be removed from the manufacture table for a new manufacturing. This prevents 3D printing technologies from becoming a mass production tool. In this study, design and manufacturing of the continuous automatic 3D printing device based on image processing method with the conveyor system will be performed. Also, the error rate of the surface quality of the samples was determined by the image processing method. Due to the ability to print continuously without user intervention, it will be increased the capacity and the functionality of the manufacture volume of 3D printing technologies.
Keywords: Image processing, 3D printing, mass production, conveyor system

Görüntü Işleme Tekniklerine Dayalı Konveyör Sistemli Sürekli Yazabilen Otomatik 3B Baskı Cihazın Tasarımı ve İmalatı

Öz

Teknolojinin ilerlemesine paralel olarak tüm dünyada başta imalat ve otomasyon olmak üzere birçok alan yeni gelişmeleri yaşamaktadır. Yaşanan bu devrimsel teknolojik gelişmeler farklı isimlerle (4. endüstri devrimi, dijital dönüşüm vb.) anılmakta olup, farklı disiplinler altında yeni buluşlar ortaya konulmaktadır. Tüm bu gelişmeler arasında en önemli sayılabilecek olanı imalat alanında yaşanan gelişmelerdir. Son yıllarda 3B baskı teknolojileri birçok ülkede kayda değer çalışmaların olduğu söylenebilir. 3B baskı teknolojileri, karmaşık parçaların üretmesini kolayca sağlamaktadır. 3B baskı yeni gelişen bir teknoloji olmasına rağmen başta eğitim olmak üzere diğer birçok sektörde hızla yaygınlaşmıştır. Bununla birlikte, bu makinelerin önemli bir dezavantajı vardır. 3 boyutlu baskı teknolojileri bir kullanıcıya bağlıdır. İmal edilmiş parçadan sonra yeni bir imalat için tabla üzerinden parçaların çıkarılması ihtiyacı vardır. Bu durum 3B baskı teknolojilerin seri üretim aracı olmalarını engeller. Bu çalışmada, günümüzde kullanılan 3B baskı cihazlarından farklı olarak sürekli yazabilen konveyör sistemli otomatik 3 boyutlu baskı cihaz tasarımı ve imalatı gerçekleşecektir. Kullanıcı

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müdahalesi olmadan sürekli baskı yapabilme yeteneği sayesinde, 3B baskı teknolojilerin imalat hacmi işlevselliğini ve kapasitesi arttırılmış olacaktır.

Anahtar Kelimeler: Görüntü işleme, 3B baskı, seri üretim, konveyör system

1. Introduction

Staratasys has developed the Fused Deposition Modeling (FDM) system which was founded by its founder Scott Crump, inspired by his little boy playing with colored play dough. The name of this technique, which emerged in 1988, is 'Fused Deposition Modeling (FDM)'. Stratasys produced its first commercial device in 1991 (Stratasys, 2018). FDM is one of the 3D printing technology methods and constitutes 44% of the systems used in the industry in the world (Wohlers, 2012). The thermoplastic material in the form of fibers is a system based on the principle of melting the layer formed by sudden cooling and adhering to the previous layer (Burns, 1991).

With FDM technology, small parts such as functional prototypes, production aids and end-use parts can be produced successfully (Faes, et al., 2014). Particularly the 3D printed parts have a surface with higher quality and a more durable structure (Çelik, et al., 2013), (Ashby and Johnson, 2002), (Maden and Kamber, 2018). In this way, products that can withstand mechanical tests are created with 3D printing technology and products can be tested faster and at lower costs (Özuğur, 2006), (Erkut, 2009), (Custompartnet, 2018).

FDM technology has many application areas. It is used in plastic parts related to lighting, interior-exterior shaping in automotive sector. In defense industry, simulator, weapon system design, electronic component connection parts and prototype products are manufactured with FDM technology. In addition, FDM technology is used in the production of sealed products resistant to chemicals and high temperature values (Durgun and Başaran, 2010), (Çelik et al., 2013), (Singare et al., 2006), (Gezer, 2008).

With the help of 3D printing devices, it is possible to obtain the physical form of every kind of product drawn in computer within hours. The 3D printing devices differ in themselves, but the principles are the same. There are many 3D printing devices on the market that use different manufacturing technologies. Examples include; 3D printer, Melt Accumulation Modeling (FDM), Laser Light Curing (SLA), Layer-to-Floor Object Manufacturing (LOM), Selective Laser Sintering (SLS) / Selective Laser Melting (SLM). When the literature is examined, 3D printing technologies are used in many different fields such as medicine (Aydın and Küçük, 2017),(Akpek, 2017), education (Demir et al., 2016),(Novak, 2019), architecture (Thomas, 2018), construction (Thomas, 2018) and food industry (Lille et al., 2018).

The capabilities of FDM technologies are limited by the necessity of human operation. The need for manual part removal prevents FDM 3D printers from being used for mass production. Therefore, there is a need for a 3D printer that can print a continuous stream of parts without user interaction. A continuous automatic FDM printer can independently print and start print jobs. The conveyor belt mechanism of some FDM 3D printers enables endless long prints. Automatic Continuous 3D Printing enables small businesses, organizations and individuals to take advantage of the power of a factory (Hackaday, 2019).

Image processing is a technique for capturing data by means of devices such as cameras and scanners, and then converting them in a way that the computer or other device can read, or transferring them from one electronic medium to another electronic medium (Gonzalez and Woods, 2002), (Russ, 2016), (Neuman et al., 1989). The field hatching camera is used to control the object dimensional and detect object color by image processing techniques. Ultrasound, electroscope and computer-based images consist of different contents taken from the image source in line with a certain target (Samtaş and Gülesin, 2011). Image processing is basically examined in three steps: transferring the image to electronic media with various devices, processing the image by analyzing it and printing the data of the processed image (Neuman et al., 1989). The first step, the analysis step, aims to reduce noise (image blur, sharpness, poor image) on the image. For this, low level operations provided by the filtering of the reality of the input and output images to images, medium level operations with division and recognition operations in the recognition and classification of objects in images, and high level operations including analysis of images in image recognition are applied (Bellaire et al., 1998). In addition to the image processing steps, two methods are used for image processing: analog image processing and digital image processing. Digital and analog image processing consists of pre-processing, which data must pass through; development and visualization; information and extraction stages (Lin et al., 2018). Image processing has many application areas, for example; adjust the appropriate color and light quality with the correct aperture settings in the picture or video, enrich the colors for security scans, increase clarity, store and transfer the image efficiently, image size, color, gradation settings, barcode reading, plate reading, transcription to text, to find the number of people in the environment, automatic face hiding or aperture adjustment, to prepare 3D images, to combine real world and virtual world images, to analyze and print the image of the object to be created with a 3D printer in the medical field (Jähne, 2005), (Ma et al., 2009).

3D printer applications in image processing have recently become widespread, especially in the medical field (Rengier et al., 2010), (Von et al., 2008). The method known as rapid prototyping has application examples such as analyzing and rendering images in 3D (McGurk et al., 1997), creating a 3D skeleton of different tissue types by simultaneously pressing live cells and biomaterials (Boland et al., 2006), constructing live vessels with a 3D printer and detecting any deformation faster (Armillotta et al., 2007).

In this study, unlike the 3D printing devices used today, images were taken after sample production by a CMOS field scanning camera. In the Python programming language, using the Opencv Qt and Diffimg libraries, the sample images obtained from the camera were compared with the reference image and then the surface quality error rate was determined. Thus, with the ability to print continuously without user intervention, the production volume functionality and capacity of 3D printing technologies will be increased.

2. Design and Prototype

In this study, a 3D printing device with automatic conveyor system that can print continuously was designed and manufactured. The size of the Continuous automatic 3D printing device is 420x427x490 mm. This size is similar to standard 3D printers. Technical drawing and dimensions of the continuous-printing automatic 3D printing device are given in Fig. 1. In this device there are five stepper motors called “Nema 17” used to provide the movement mechanism. The axes were obtained by conventional manufacturing methods.

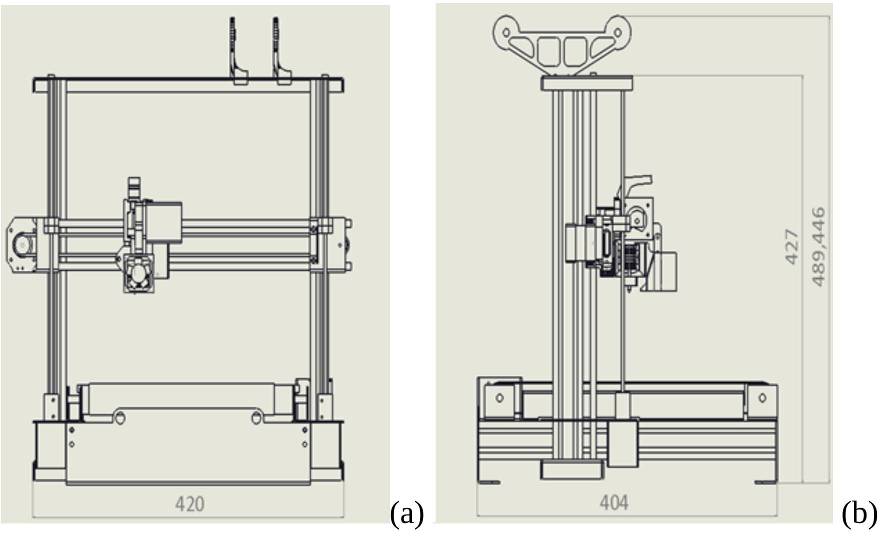

Fig 1. Display of dimensions of the 3D printing device a) Front view, b) Side view

General body of the device consists of 20x40 mm profiles and 1.5 mm thickness bending sheets. Figure 2 shows the model and the manufactured image of the designed device. In contrast to other studies, the design and manufacture of an automatic 3D printing device capable of continuous printing with a conveyor system was manufactured in this study.

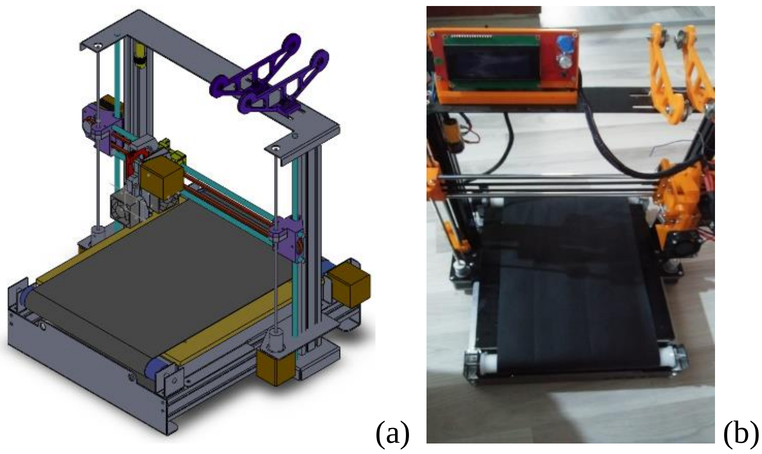

Fig 2. Continuous Automatic 3D printing device a) perspective view b) Manufactured image

The technical specifications of the Prototype and manufactured cartesian type continuous 3D printing device are given in Table 1.

Table 1 Technical specifications of 3D printing device.

Type	Cartesian
General Dimension (XYZ)	420x427x490mm
Platform Dimension (XYZ)	250x300x240mm
Nozzle	0.4 mm
Platform Heating	N/A
Drive	XY Belt-Pulley, Z M8 Screw
Field Scanning Camera	Exists
Conveyor System	Exists
Filament	1.75 mm Composite PLA/ABS

In addition, general characteristics of CMOS camera are given in Table 2.

Table 2. General features of the camera.

Sensor Type	CMOS
Resolution (HxV)	2592 px x 1944
Resolution	5 MP
Frame Rate	14 fps
Colored / Colorless	Colored
Datapath	USB 3.0

The design phase of the study consists of two parts. The first is the installation of the 3D printing device and the second is the integration of conveyor system parts into the printer. In order to produce the axis movements of the continuous automatic 3D printing device, 8 mm diameter rod and 4 mm diameter screw rod were used on the main body. It is assembled with couplings to keep the screw rods stable. Figure 3 shows the main body elements of the 3D printing device.

Fig 3. Mechanical parts of the 3D printing device (Doğuş Kalıp, 2019)

For Z-axis movement of the continuous automatic 3D printing device, 2 rails were mounted directly on the sheet metal at the edge of the body. The screw shaft was located in parallel. The parts printed on the 3D printer were fastened on top of the screw rods and rails. Together with these parts, rails and timing belt were used perpendicular to the z-axis to move along the x-axis. There were no parts to create platform movement in the y-axis. Figure 4 shows the manufacturing platform and axes of the continuous automatic 3D printing device.

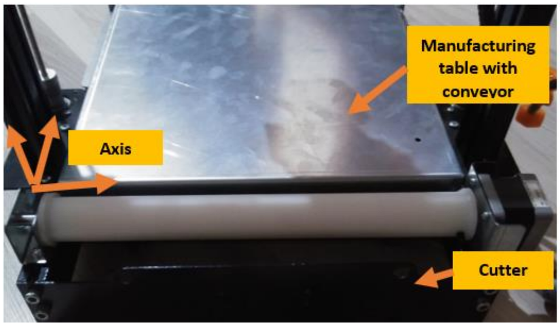

Fig 4. Axis and manufacturing platform view of the conveyor system of the continuous automatic 3D printing device

In this study, the manufacturing platform of the 3D printing device was fixed on a sheet metal and the movement mechanisms on the y-axis were canceled. The rollers and sheet metals in the conveyor system were obtained by conventional manufacturing methods. Conveyor system components are shown in Fig. 5.

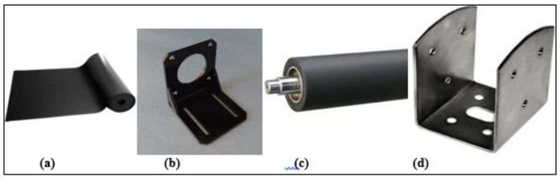

Fig 5. a) Conveyor belt b) L-shaped sheet metal which supports the motor c) conveyor roller d) roller support (Doğuş Kalıp, 2019)

Y axis movement was provided by the conveyor belt on the platform. In the conveyor system, a belt stretched by 2 rollers was driven by stepper motor. The rollers were mounted on the front and rear of the platform. The bearing of the roller was connected to the body on the right and left sides using L-shaped sheet metal. There were also bearing cases at the end of the roller. Together with the L profiles, the bearing and rod were placed in the housing of the roller for the circular movement of the roller. Figure 6 shows the design of the conveyor system.

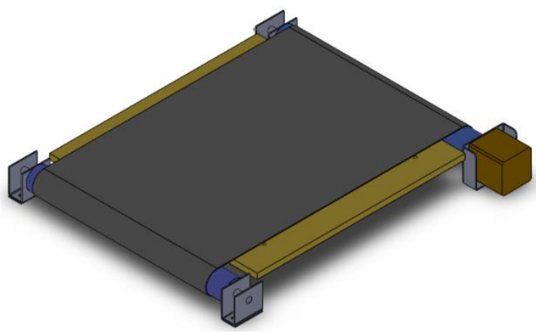

Fig 6. View of the manufacturing platform with conveyor system.

The image of the electronic elements of the continuous automatic 3D printing device is given in Fig. 7.

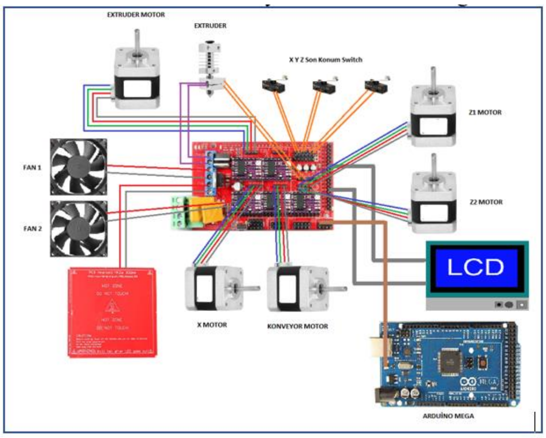

Fig 7. Schematic view of electronic circuit of continuous automatic 3D printing device

In addition to the electronic part, an field scanning camera is mounted on the extruder. Also, the connection between the camera and computer is provided. After the product is manufactured with continuous automatic 3D printing device, the extruder brings the camera onto the part and automatically takes its image Fig. 8.

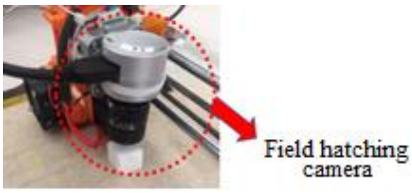

Fig 8. Field scan camera location image

3. Resarch Findings

Experimental studies of continuous automatic 3D printing device consist of three parts: working test, surface quality test and accuracy test.

3.1. 3B Operation Test of The Manufactured Device

There was a significant shift in the y-axis in the layers of the samples that were produced with the automatic 3D printing device that can write continuously. This is because the step settings inside the device are incompatible with the conveyor rollers. In addition, the conveyor belt system slides a little on the roller and disrupts the axis. Figure 9 shows the layer shift images of the samples.

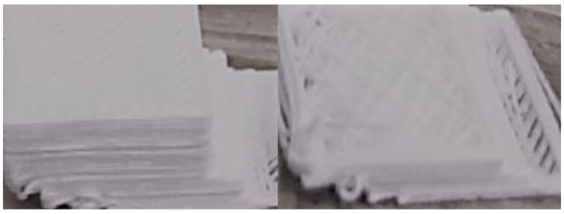

Fig 9. Layer shift images in samples

In the first experimental studies of the 3D printing device, due to the difference between the diameter of the motor shaft and the roller diameter, it went wrong to the desired tool path in the y-axis. For example, if 10 mm movement is desired in the y-axis, 3 mm is reached. To solve this problem, the tool path is multiplied by the default number of steps in arduino in mm. The result is divided by the wrong value (3mm) to reach the required step parameter value for that motor in the arduino. Figure 10 shows the sample image after the sliding problem was corrected.

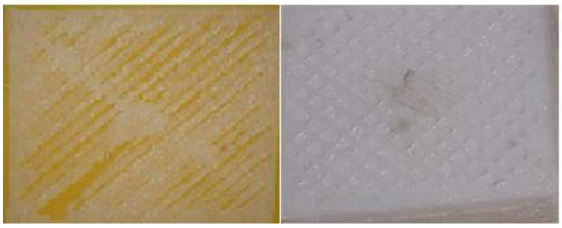

Fig 10. Sample image after sliding problem was corrected

In this study, conveyor belt system was used instead of standard production table in 3D printer. Sample prints were created on the conveyor which was stretched between the rollers on the front and back and coated with heat resistant belts. After the printing process was completed, the conveyor starts to move in the y axis and the sample was transferred to the external environment. The export process was done by G code settings made from slicing programs. The STL file was continuously added to the G codes which are fixed in the file. After the printing was finished, the motor that provides the y-axis movement worked a little more and made the conveyor belt to rotate one turn. The same G codes were added to all STL files. Thus, with the completion of printing, the nozzle moved to the zero position and the motor continued to run in the y-axis and provided movement to the conveyor. This process continues in a cycle.

During the design and manufacture of the conveyor belt system, the movement in the y-axis may occur as in a standard printer for the purpose of the work, but it can provide continuous movement when desired. For this reason, the back and front parts of the printer were equipped with rollers of 30mm diameter to allow the belt to rotate. These rollers were placed in the printer with sheet metal profiles. There are bearings in the inner part of the roller to make the rotation movement easily.

3.2. Surface Quality Testing Based on Image Processing

In this study, printing tests were performed at different working speeds with automatic 3D printing device that can write continuously. Images of the manufactured samples were scanned using the Opencv, Qt, Diffimg, Numpy libraries in Python programming language and a package program was prepared as shown in Fig. 11.

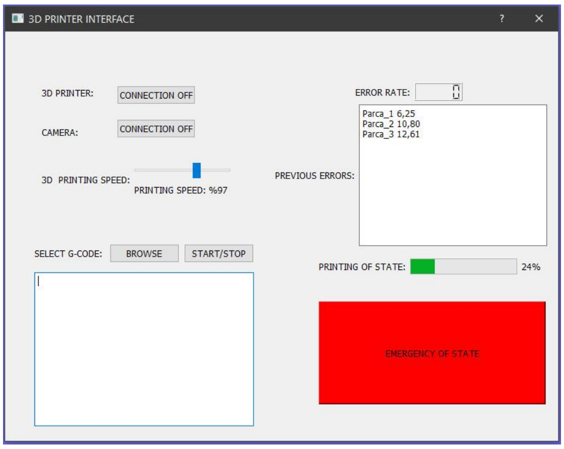

Fig 11. Interface of the image analysis programme

In the prepared package program, the reference image of the sample to be produced first was added to the database. After the sample production was completed, RGB (Red Green Blue) pixel values of the image were transferred to the sequence variable by using Image Diffimg Library taken from each part. In Equation (1-3), the percentage error rate was determined by calculating the similarity ratio of each pixel [37].

$$A_{ixi} = RGB(R_a, G_a, B_a)$$

$$B_{ixi} = RGB(R_b, G_b, B_b) \qquad (1)$$

$$PBO = \frac{(R_a/R_b)/255 + \frac{G_a/G_b}{255} + \frac{B_a/B_b}{255}}{3} \qquad (2)$$

$$Error\ rate\ (\%) = \sum_{0}^{son\ piksel} \frac{PBO}{last}\, pixel \qquad (3)$$

In Equation (1), Aixi represents the ixi pixel values of the reference image. Ra, Ga, Ba values are the index of RGB color pixel values respectively. Bixi represents the ixi pixel value of the sample. Rb, Gb, Bb are the index of RGB color pixel values, respectively. In Equation (2), PBO refers to the pixel similarity ratio. Pixel similarity ratio is calculated by starting from zero pixel to the last pixel value. In Equation (3), the obtained pixel similarity ratios were calculated and divided by the total number of pixels, thus calculating the error rate as a percentage.

After the reference image sample manufacturing, the surface of the part was photographed with a camera. The operating speeds of the continuous 3D automatic device are 75, 100, 125, 150 and 175 mm/s respectively. The experiment was repeated three times at each speed, with a total of 15 sample prints of 20x20x20 mm. Parts manufacturing times at each speed are 46, 38, 30, 23 and 18 minutes, respectively. The time it took for the sample to be transported out of the printer for each sample manufacture was measured as 27 seconds. The images of the produced samples are given in Fig. 12. Here, as the speed of the axes increases due to motor acceleration, the deterioration of the component surface increases.

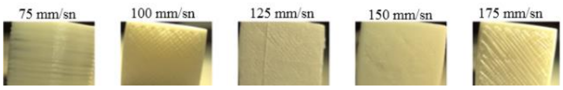

Fig 12. Image of cube models manufactured in 20x20x20 mm size at different operating speeds

In Equation 1, the pixel values of the reference image and the sample image are taken respectively. The numerical values obtained have RGB color space for each pixel and consist of 3 channels. Then the average differences of the values obtained with Equation 2 are subtracted. This difference is the surface quality between the reference image and the printed sample image. Differences obtained in Equation 3 are expressed as a percentage. In the image processing technique, images were converted to matrix arrays according to the size of the image. In Figure 13, the necessary calculations were performed with the Numpy library, which can be integrated with the OpenCV library according to the reference image and provides faster processing of arrays. The digitized images were compared by using the diffimg library using the numerical calculation methods given in Eq. (1-3). The error images resulting from the comparison of the reference image and the sample images were given in the Fig. 14.

Fig 13. Reference image

Fig 14. Error images resulting from image processing analysis with Python programming language

The surface qualities of the three samples were checked in each press. The reference image and the images of the manufactured samples were compared using the Phyton programming language. As shown in Table 3, the mean percentage error rate for each group was calculated by comparison.

Table 3. Working speed of parts, manufacturing time and error rates.

Group	Speed(mm/s)	Time (dk)	Avg. Error(%)
Group 1	75	46	3.33
Group 2	100	38	9.28
Group 3	125	30	13.72
Group 4	150	23	15.02
Group 5	175	18	16.72

3.3. Dimensional Accuracy

15 pieces of 20x20x20 mm cube samples were calibrated for its slicing by the Cura program and then were loaded into the continuous automatic 3D printer. The manufactured samples were measured with caliper. The dimensional difference of the samples was calculated as the lowest 0.1% and the highest 2%. This is because the higher the operating speed of the 3D printer, the greater the amount of error. Dimensional measurements, average pressure measurements and error amounts of the manufactured samples are given in Table 4.

Table 4. Working speed of parts, manufacturing time and error rates.

Group Id	Model Dimensions (mm)	Avg. Printing Dimensions (mm)	Error Amount (%)
Group 1	20x20x20	20.16x20.05x19.98	%0.8 - %0.2 - %0.1
Group 2	20x20x20	20.18x20.22x19.96	%0.9 - %1.1 - %0.2
Group 3	20x20x20	20.19x20.21x20.11	%0.9- %1.0 - %0.5
Group 4	20x20x20	20.21x20.20x20.05	%1.0- %0.99- %0.2
Group 5	20x20x20	20.25x20.26x20.24	%1.23- %1.28- %1.18

4. Results

In this study, prototype of automatic 3D printing device that can print continuously based on image processing method has been build and the working tests, surface quality test and dimensional accuracy tests have been performed. The device is manufactured as a conveyor-based and a camera is integrated to measure the surface quality. The surface quality error rates of the samples were measured as 3.3- 16.72% by using image processing application. The dimensional accuracy error values of the samples were determined in the range of 0.1% -2%.

The results of this study, which was carried out with the design and manufacture of continuous 3D printing device based on image processing method, are summarized as follows:

• 3D printing technologies are human-dependent. For a new manufacturing, there is a need to remove parts from the platform. With this study, the design and manufacture of the device with continuous conveyor system capable of mass production were made.

• Shifting problems on the parts printed by the printer solved by printing tests. As a result, the usability of the system has been proved.

• The prototype was designed to increase the use of 3D printing devices in the industry and serve as an example for other studies.

• An implementation that can be used actively in the industry and will support other studies has been performed.

• Thanks to the ability to print continuously without user intervention, the manufacturing volume, functionality and capacity of 3D printing technologies will be increased.

In the future studies, it is expected that the 3D printer system can be controlled during the production of the sample with the error rate calculated according to the images obtained at the end of the sample production and the images taken in real time during production by using image processing methods.

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