Design of a Real-Time Tracking System to Eliminate 3D Printing Errors Caused by Thermoplastic Materials
Termoplastik Malzemelerin Neden Olduğu 3B Baskı Hatalarını Ortadan Kaldırmak İçin Gerçek Zamanlı Bir Takip Sistemi Tasarımı

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***Abstract*—Material-related printing errors are frequently encountered in 3D printers based on the Fused Filament Fabrication (FFF) technology. When the materials used are investigated, materials such as PLA, ABS, and Nylon are generally preferred at affordable prices. However, printing problems may occur due to the mechanical characteristics difference between the materials. Among the main reasons for this are parameters such as material characters, melting temperature, and extrusion speed. These errors cause problems such as filament breaking, nozzle clogging, and filament falling out of the holder. As a result, the filament flow is interrupted, and the printing process continues without extrusion of the filament because the 3D printer cannot detect this flow. 3D printers on the market do not have a system to detect possible printing errors. Therefore, in this study, a system design measures the filament weight via a load sensor and informs the user has been performed. 3D printers could stop the printing process since they can detect possible errors in advance with the developed system and prevent electricity consumption and time loss. In addition, the amount of used and remaining filaments, which are not yet common in 3D printers, can be followed by the user.**

***Keywords*—3D printer; printing problems; real-time tracking; thermoplastic materials; weight measurement**

***Özetçe*—Eriyik Filament ile imalat (FFF, Fused Filament Fabrication) teknolojisine dayanan 3B yazıcılarda malzeme kaynaklı baskı hataları sıklıkla karşılaşılmaktadır. Kullanılan malzemeler incelendiğinde genel anlamda en çok PLA, ABS, Naylon gibi malzemeler uygun fiyatlarıyla tercih edilmektedir. Bununla beraber malzemeler arasındaki mekanik karakterleri farkında da kaynaklı yazdırma problemleri oluşabilmektedir. Bunun başlıca sebepleri arasında malzeme karakterleri, eritme sıcaklığı ve ekstrüzyon hızı gibi parametreler yer almaktadır. Bu hatalar filament kesmesi, nozzle tıkanması, filamentin tutucundan düşmesi gibi sorunlara yol açmaktadır. Sonuç olarak filament akışı kesilmekte ve 3B yazıcı bu akışı algılayamadığı için baskı işlemi filament eritilmeksizin devam etmektedir. Piyasada bulunmakta olan 3D printerlarda olası bir baskı hatalarını algılayabilecek bir sistem bulunmamaktadır. Bu yüzden, bu çalışmada yük sensörü yardımı ile filament ağırlığını ölçen ve kullanıcıyı bilgilendiren bir sistem tasarımı gerçekleştirilmiştir. Geliştirilen sistem ile 3B yazıcılar olası hataları önceden algılayabildiği için işlemini durdurarak elektrik sarfiyatını ve zaman kaybını önlemektedir. Bunun yanında 3B yazıcılarda henüz yaygın olmayan kullanılan ve kalan filament miktarları kullanıcı tarafından takip edilebilmektedir.**

***Anahtar Kelimeler*—3 boyutlu yazıcı; baskı problemleri; gerçek zamanlı takip; termoplastik malzemeler; ağırlık ölçümü**

I. INTRODUCTION

The 3D printer, which is one of the prototype production techniques, stands out with its fast and cheap part production [1]. They are in demand with the advantages of being portable, do-it-yourself (DIY), and open source development. Despite all this popularity, many parameters need to be adjusted to get an ideal print. If any of these parameters is faulty, cost, time, and labor losses occur in the process of production. Among the printing problems, most problems happen due to the material [2]. Unsuitable printing temperatures, expired materials, poor storage conditions, and extrusion errors cause problems during printing. These errors often result in interruption of the filament flow. The filament is fixed by a holder on the back of the printer and sent to the nozzle by extrusion. However, the filament breaks during printing due to the above reasons, and the printer does not stop because it cannot detect the filament flow [3]. The ability to track the printing process in real-time in 3D printers currently used in the market is almost non-existent [4].

Moreover, another critical problem in 3D printers is that the remaining amount of filament in real-time cannot be followed

[5]. Therefore, printing processes that start with an unknown amount of filament sometimes fail due to usage amount calculation errors, and prints may be interrupted. Although the users make inferences based on observation of the amount of material and start the printing, the printing process may not be completed due to material depletion. In order to solve this problem, there is a need for weight-controlled systems that measure the weight of the filament.

Detection of a possible error and filament usage quantity tracking systems are not common enough yet [6]. However, some studies have been carried out against possible errors. One of them, Soriano et al. have designed a system that detects the filament speed with the help of an optical encoder by focusing on the problems related to the filament without changing the operation of the FDM type printer [7]. Only flow rate measurement was performed with the optical sensor. However, since the weight is not measured, it is impossible to determine the filament weight.

In this study, a system that performs filament weight measurement was designed to prevent printing interruption due to filament-related problems. The system has been implemented so that it can detect the problem, stop printing and give a warning to the user. In addition, it helps to determine the filament run-out problem in advance by evaluating the amount of the object to be printed before and after starting the printing.

II. Materials & Methods

A. Electronic Circuit Design

The electronic circuit design used an Arduino Uno R3 SMD CH340 card with a USB connection as a microcontroller. The Arduino Uno has all the necessary features for this study. There are 14 digital input/output pins and six analog input pins. Arduino has an Atmel AVR microcontroller, a side member required for programming and connection to other circuits [8]. It is a cheap, fast-running microcontroller with advanced features. The size of Arduino Uno is the appropriate standard for projects. It has writable and erasable memory capacities ranging from 2 KB to 128 KB. Each card has at least one 5 volt regulation circuit and a 16 MHz crystal oscillator (some have ceramic resonator). Since the microcontroller has already written a boot-loader program, no external programmer is needed for programming [9]–[12].

The HX711 module is a load cell amplifier circuit board for HX711 IC, which allows you to read load cells to measure weight easily. Two analog input channels have high sensitivity with 128 times the internal integration of the programmable gain amplifier. The HX711 module is a precision 24-bit analog to digital converter (ADC) designed to interface directly with a bridge sensor in scale scales and industrial control applications [13]. All controls of HX711 are via pins. HX711 is an electronic scale module that converts the changes measured in the operating principle, and resistance value variations to electrical output via the conversion circuit. The module communicates with the host via TTL RS232.

A micro-weight sensor with a capacity of 5 kg, which operates in accordance with the Arduino Uno and HX711 module, was used. The load cell is sometimes referred to as a strain gauge, a sensor or transducer that makes an electronic signal output of a load (force) that acts on it. The electrical signal output of the load cell is minimal and requires amplification. It is an industrial product used to output a voltage in proportional response to the effect applied by measuring the deformation caused by force or pressure on the load cell. The load cell consists of an Wheatstone bridge built with strain beaks. The Wheatstone bridge has two known values, one adjustable, and one value of unknown resistance. The Wheatstone bridge calculates the unknown resistance. The electronic circuit was performed in the Fritzing (v.0.9.3, Berlin, Germany) software and is shown in Figure 1.

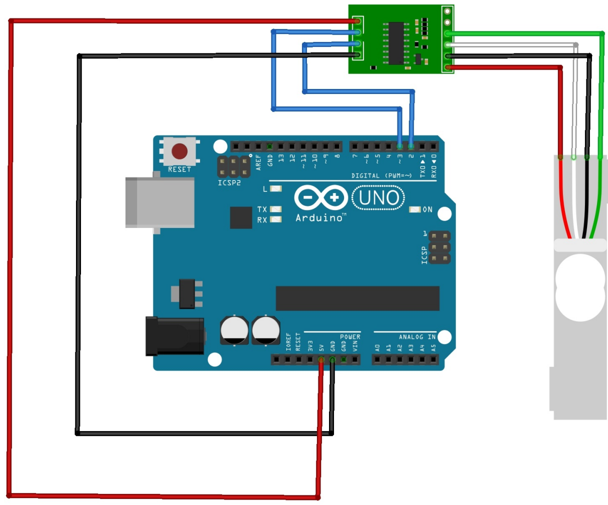

Figure 1: The electronic circuit design of the materials used in the study

B. Prototyping

This study prototyped the weight control system prototype for the FDM type 3D printer Ultimaker Extended 2+ model. Two parts are designed to fit the system with SolidWorks, a computer-aided 3-dimensional solid modeling and design software. The first part is created to be fixed to the 3D printer body and attached to the weight sensor. The second part is designed to be connected to the flexing section of the load sensor and the filament roller. The parts have been arranged in the Cura software. Parts were manufactured using PLA material on Ultimaker Extended 2+. Parts have been tested to match the printer and filament roller. After the production stage is completed, the printed parts are screwed with the weight sensor. Parts designed to measure filament weight behind the printer are shown in Figure 2.

C. Programming

In the programming, it was utilized the Arduino IDE (v.1.8.13), which is compatible with the Arduino Uno R3 card. The HX711 module has been identified in the Arduino program library. The Arduino Uno R3 is connected to the corresponding

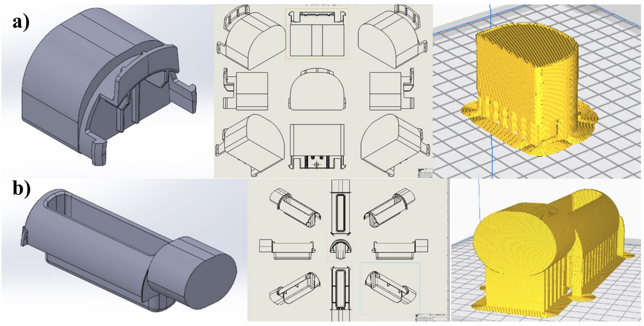

Figure 2: a) The part that can be fixed to the body of the 3D printer and bears the weight of the filament; 3D drawing, 2D engineering drafting, and placing the part on the printer bed for printing, respectively, b) The part to which the load sensor is connected and to which the filament is attached; 3D drawing, 2D engineering drafting, and placing the part on the printer bed for printing, respectively

COM using a USB connection. The HX711 module converts the voltage from the weight sensor to values that can be read in kg or lb to indicate its output on the serial monitor display. The read voltage value is converted digitally by the analog converter. The calibration factor was tested for accuracy setting. A trial and error method was used by changing the calibration factor to find the appropriate calibration factor [14]. The system continuously measures the filament weight. The system alerts if there is no change in weight values for a certain period. This allows users to intervene early and is also designed to avoid wasting time and materials.

D. Calibration Process

Calibration is an essential process in measuring filament weight and relying on the measurement result. The calibration process used F1-grade Huray brand 100gr, 200gr, and 500gr calibration weights by ISO 9001 quality standards. Outputs of the weight sensor were tested with calibration weights. Measurements have been recorded to define the accuracy and accuracy of the system periodically using calibration weights. In addition, actual weight values were obtained using the precision scale. Comparing the measured value to the reference weight is to understand how accurately the system is weighing. The deviation of measured values in the system from the actual value was calculated and documented manually. This has been repeated three times for each calibration weight. Deviation calculations demonstrated that the system complies with the desired measurement standards.

III. Results

The black PLA filament was used to print the parts. The printer settings were selected infill density 80%, infill pattern grid, nozzle size 0.6 mm, layer height 0.15 mm, and print speed 35.0 mm/s. The first part was printed on Ultimaker Extended 2+ using 49 grams of PLA material at the cost of approximately $1 and was completed in 4 hours and 2 minutes.

Figure 3: Measurement of filament weight with precision scale and calibration of the system performed with standard weights

In the second part was used 71 grams of PLA material were used, printed at 1.43$, in 6 hours and 56 minutes.

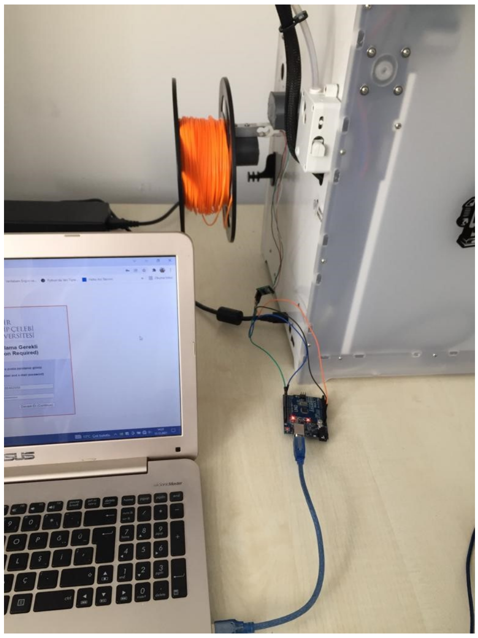

Figure 4: Installation behind the printer and working stage of the system with a computer

An example printing problem is shown in Figure 5. The printing process has been started on the printer for printing square-shaped parts. While the filament weight is 650 grams initially, it decreases as time progresses. In the 3rd hour of printing, the rate of weight reduction slows down due to nozzle clogging. At this stage, the measurement continues for a certain period, and since there was no change in the weight measurement, the printing was stopped and the user was expected to intervene. The system sends the G-code communication (M84; disable motors, M104 S0; turn off temperature) from the serial port to stop the printer.

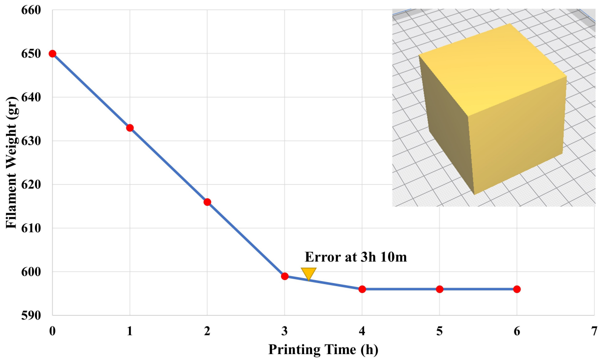

Figure 5: Measurement chart of filament weight during printing

IV. Conclusion

There are many problems during printing on 3D printers. In this study, a solution-oriented approach has been taken to problems caused by a material during printing on 3D printers. At the beginning of these problems, it can be a filament breakage, nozzle blockage, power failure, material shortage, or filament holder drop. As a result, the filament flow is interrupted, and the printing process continues without melting the filament because the 3D printers cannot deliver this flow. This means that both the printer is idle and the printing process is interrupted, resulting in a waste of time. This study aims to eliminate the time and material loss that results from problems. With the help of a load sensor, the system following the filament weight detects that the filament is moving smoothly, providing an opportunity to detect problems during printing. If the system does not affect the operation of 3D printers, it can be adapted to different types of printers.

References

[1] Attaran M. The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons 2017; 60(5): 677-688.

[2] El-Sayegh S, Romdhane L, Manjikian S. A critical review of 3D printing in construction: Benefits, challenges, and risks. Archives of Civil and Mechanical Engineering 2020; 20(2): 1-25.

[3] Selek MB, Solmaz A, Cetintas A, Ugur K, Isler Y. Design of 3D digitization integrated robotic arm to help clinical applications. Journal of Intelligent Systems with Applications 2019; 2(2): 162-166.

[4] Khan MF, Alam A, Siddiqui MA, Alam MS, Rafat Y, Salik N, Al-Saidan I. Real-time defect detection in 3D printing using machine learning. Materials Today: Proceedings 2021; 42: 521-528.

[5] Kutlu Y, Alanoglu Z, Gokcen A, Yeniad M. Raspberry pi based intelligent robot that recognizes and places puzzle objects. Journal of Intelligent Systems with Applications 2019; 2(1): 85-89.

[6] Lambos N, Vosniakos GC, Papazetis G. Low-cost automatic identification of nozzle clogging in material extrusion 3D printers. Procedia Manufacturing 2020; 51: 274-279.

[7] Soriano Heras E, Blaya Haro F, De Agustín del Burgo JM, Islán Marcos M, D'Amato R. Filament advance detection sensor for fused deposition modelling 3D printers. Sensors 2018; 18(5): 1495.

[8] Sani RA, Maha AI. Konstruksi timbangan digital menggunakan load cell berbasis arduino uno dengan tampilan lcd (liquid crystal display). EINSTEIN (e-Journal) 2018; 5(2): 1-6.

[9] Altan U, Gokcen A, Kutlu Y. An integrated incubator module for pediatric patient monitoring systems. Journal of Intelligent Systems with Applications 2019; 2(2): 106-110.

[10] Demir E, Gokcen A, Kutlu Y. Android controlled mobile robot design with IP camera. Journal of Intelligent Systems with Applications 2019; 2(2): 157-161.

[11] Selek MB, Uzal VA, Isler Y. Arduino based probe bag alert system design. Journal of Intelligent Systems with Applications 2020; 3(1): 20-24.

[12] Yasar B, Isler Y, Topaloglu Avsar N. Manufacturing multicolor led-based phototherapy device with a novel 3d design. Journal of Intelligent Systems with Applications 2021; 4(2): 120-124.

[13] Al-Mutlaq SARAH, Wende A. Load cell amplifier HX711 breakout hookup guide. Retrieved from Sparkfun Start Something Website from https://learn.sparkfun.com/tutorials/load-cell-amplifier-hx711-breakouthookupguide/introduction.

[14] Itikala V. Arduino Weighing Machine Using Load Cell and HX711 Module 2021; SSRN 3918720.