FACULTY OF ENGINEERING AND ARCHITECTURE
DEPARTMENT OF BIOMEDICAL ENGINEERING

3D PRINTER MONITORING SYSTEM BASED ON IMAGE PROCESSING USING RECYCLABLE MATERIALS

GRADUATION/DESIGN PROJECT

in partial fulfillment of the requirements for the degree of

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JUNE 2023

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by

OĞUZHAN TELLİ

submitted to the BIOMEDICAL ENGINEERING of

İZMİR KÂTİP ÇELEBİ UNIVERSITY

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ABSTRACT

This study aims to solve problems such as reducing printing problems that may occur in FDM (Fused Deposition Modeling) type 3D printers, preventing health problems caused by respiration during printing of 3D printer material, and not losing the user's time by watching the 3D printer.

Within this project, a mechanism is constructed using unused 2D printer parts. Raspberry Pi and Raspberry Pi camera are integrated and configured to work in conjunction with the mechanism. The images captured by the Raspberry Pi provide information about the printer's status after undergoing image processing stages.

Analysis of the resulting images is the basis for monitoring the operation of the printer and detecting potential problems. Important measurements such as material weight, nozzle-product distance and camera position are obtained with image processing techniques, sensors, camera and motors. This data allows real-time notifications to be sent to the user, facilitating rapid resolution of issues.

Furthermore, internet connectivity is established, enabling remote monitoring and control of the 3D printers. Users can track their printers from anywhere through a web-based interface, manage printing jobs, and intervene as necessary.

As a result of this project, benefits such as prevention of issues in FDM 3D printers, preservation of user health and time, reduction of material waste, and remote accessibility have been achieved. This project can be regarded as a method that enhances user experience and optimizes the 3D printing process.

Keywords: FDM, 3D printing, Raspberry Pi, image processing, remote monitoring.

ÖZET

Bu çalışma, FDM (Fused Deposition Modeling) tipi 3 boyutlu yazıcılarda oluşabilecek baskı sorunlarının azaltılması, 3 boyutlu yazıcı malzemesinin yazdırılması sırasında solunumdan kaynaklanan sağlık sorunlarının önlenmesi ve kullanıcının 3 boyutlu yazıcıyı izleyerek zaman kaybetmemesi gibi sorunları çözmeyi amaçlamaktadır.

Bu proje kapsamında kullanılmayan 2D yazıcı parçaları kullanılarak bir mekanizma kurgulanmıştır. Raspberry Pi ve Raspberry Pi kamera, mekanizma ile birlikte çalışacak şekilde entegre edilmiş ve yapılandırılmıştır. Raspberry Pi tarafından çekilen görüntüler, görüntü işleme aşamalarından geçtikten sonra yazıcının durumu hakkında bilgi verir.

Elde edilen görüntülerin analizi, yazıcının çalışmasını izlemek ve olası sorunları tespit etmek için temel oluşturur. Malzeme ağırlığı, nozül-ürün mesafesi ve kamera konumu gibi önemli ölçümleri görüntü işleme teknikleri, sensörler, kamera ve motorlar ile elde edilir. Bu veriler, kullanıcıya gerçek zamanlı bildirimlerin gönderilmesini sağlayarak sorunların hızlı bir şekilde çözülmesini kolaylaştırır.

Ayrıca internet bağlantısı kurularak 3D yazıcıların uzaktan izlenmesi ve kontrolü sağlanmaktadır. Kullanıcılar, web tabanlı bir arayüz üzerinden yazıcılarını her yerden takip edebilir, baskı işlerini yönetebilir ve gerektiğinde müdahale edebilir.

Bu proje sonucunda FDM 3D yazıcılarda sorunların önlenmesi, kullanıcı sağlığının ve süresinin korunması, malzeme israfının azaltılması, uzaktan erişilebilirlik gibi faydalar sağlanmıştır. Bu proje, kullanıcı deneyimini geliştiren ve 3D baskı sürecini optimize eden bir yöntem olarak değerlendirilebilir.

Anahtar Kelimeler: FDM, 3D baskı, Raspberry Pi, görüntü işleme, uzaktan izleme.

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JUNE 2023 Oğuzhan TELLİ

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SYMBOLS

% Percentage

/ Slash

/ Ratio

/ Obelus (Division Sign)

× Multiply

< Less than

> Greater than

≤ Less than or equal to (Less than or equal sign)

ACRONYMS

2D – Two dimensional

3D – Three dimensional

AM - Additive Manufacturing

FDM - Fused Deposition Modeling

FFF - Fused Filament Fabrication

CAD - Computer-Aided Design

PLA - Polylactic Acid

ABS - Acrylonitrile Butadiene Styrene

STL - Stereolithography

CA - Competitive Advantage

VOCs - volatile organic compounds

SLA - Stereolithography

HEPA - High Efficiency Particulate Air

LSTM - Long Short-Term Memory

PVC - Polyvinyl chloride

AE - Acoustic Emission

RMS - Root Mean Square

SVM - Support Vector Machine

AR - Augmented Reality

E3DP - Extrusion based 3D Printing

LED - Light Emitting Diode

Wi-Fi - Wireless Fidelity

SD - Secure Digital

DC - Direct Current

PWM - Pulse Width Modulation

IC - Integrated Circuit

CMOS - Complementary Metal-Oxide-Semiconductor

PCB - Printed Circuit Board

IDE - Integrated Development Environment

SoC - System-on-a-Chip

ARM - Advanced RISC Machines

CPU - Central Processing Unit

RAM - Random Access Memory

USB - Universal Serial Bus

HDMI - High-Definition Multimedia Interface

GPIO - General-Purpose Input/Output

DIY - Do-It-Yourself

AVR - Advanced Virtual RISC

RISC - Reduced Instruction Set Computing

GPU - Graphics Processing Unit

I/O - Input/Output

LAN - Local Area Network

CSi - Camera Serial Interface

TCP - Transmission Control Protocol

IP - Internet Protocol

UDP - User Datagram Protocol

App – Application

OpenCV - Open Source Computer Vision Library

1. INTRODUCTION

It is known that 3D printers have been widely used in recent years. However, many deficiencies and problems may occur. Additive manufacturing (AM) is the process of joining materials layer by layer to build 3D objects [1]. One of the most widely used AM processes is fused deposition modeling (FDM) patented by Stratasys [2]. After one of the first FDM patent was expired in 2009, a generic term called fused filament fabrication (FFF) was introduced, allowing 3D printers to self-replicate and develop further [3]. This lead to the development of the RepRap project utilizing open-source 3D printer hardware and software [4], which drastically decreased the cost of FFF 3D printers. The development of open-source RepRap project brought the 3D printing technology to a wide range of users [5]. Therefore, the applications of FFF 3D printers have been introduced in various fields, namely, education [6,7], rapid prototyping [8,9], robotics [10,11], scientific tools [12,13], and tissue engineering [14,15].

Figure 1

FFF, also referred to as FDM, is a popular technique in the realm of 3D printing that enables the creation of tangible objects. It is an additive manufacturing process that constructs objects layer by layer by extruding melted thermoplastic material. The procedure commences with a digital representation, usually built through CAD software or obtained from pre-existing 3D models, encapsulating the desired object. The digital model is then transformed into an STL file format using specialized software. This conversion involves dissecting the model into a series of triangles to accurately portray the object's surface geometry. Subsequently, the STL file is utilized by specific software to slice the model into thin layers. Each of these layers represents a two-dimensional cross-section of the final object, serving as a blueprint for the printing process. Within the 3D printing process, a spool of thermoplastic filament, often composed of materials like PLA or ABS, is loaded into the 3D printer. The filament is subjected to heat, melting it to a suitable consistency for extrusion. The molten filament is then guided through a movable printhead, featuring a nozzle or extruder. The printhead navigates along the X, Y, and Z axes, precisely adhering to the instructions derived from the sliced model. As the printhead moves, it dispenses the molten filament onto a build platform or the previously printed layer. Following the predetermined paths, it outlines the shape of each layer. The thermoplastic material rapidly cools upon contact with the build platform, solidifying into a sturdy layer. Upon the completion of each layer, the build platform is lowered or the printhead is raised, depending on the printer's design, to create space for the subsequent layer. This process is reiterated until the entire object is printed. Fused Filament Fabrication boasts numerous advantages, including affordability, accessibility, and compatibility with a wide array of materials. It finds extensive applications in diverse fields such as prototyping, manufacturing, education, and personal projects.

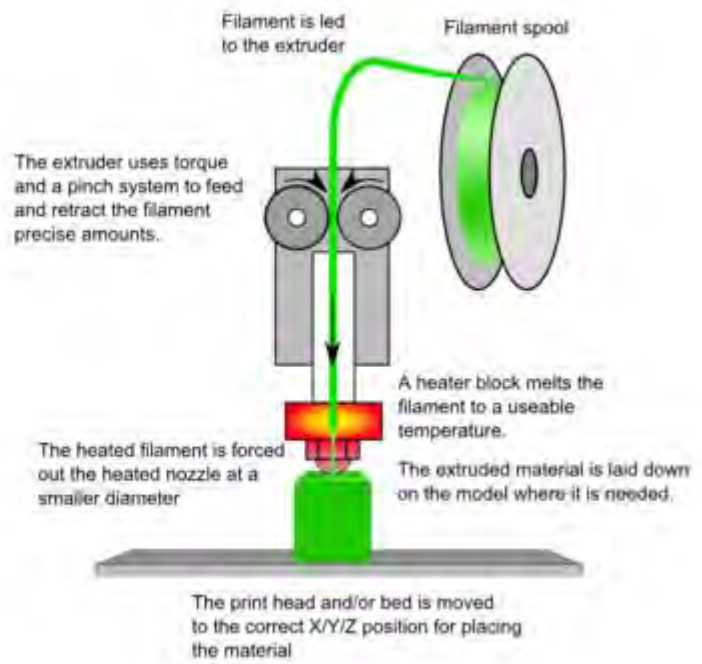


Figure 2 : 3D Printers Working Principles

However, the fabrication of parts using the FFF process often encounters quality issues, as indicated by previous research. Inexperienced users of FFF 3D printers have been found to experience a failure rate of 20% [5]. For instance, Wang *et al.* [16] conducted a study on the influence of various process parameters on the surface finish of 3D printed parts, while Boschetto *et al.* [17] demonstrated that inadequate surface roughness may necessitate additional finishing operations.

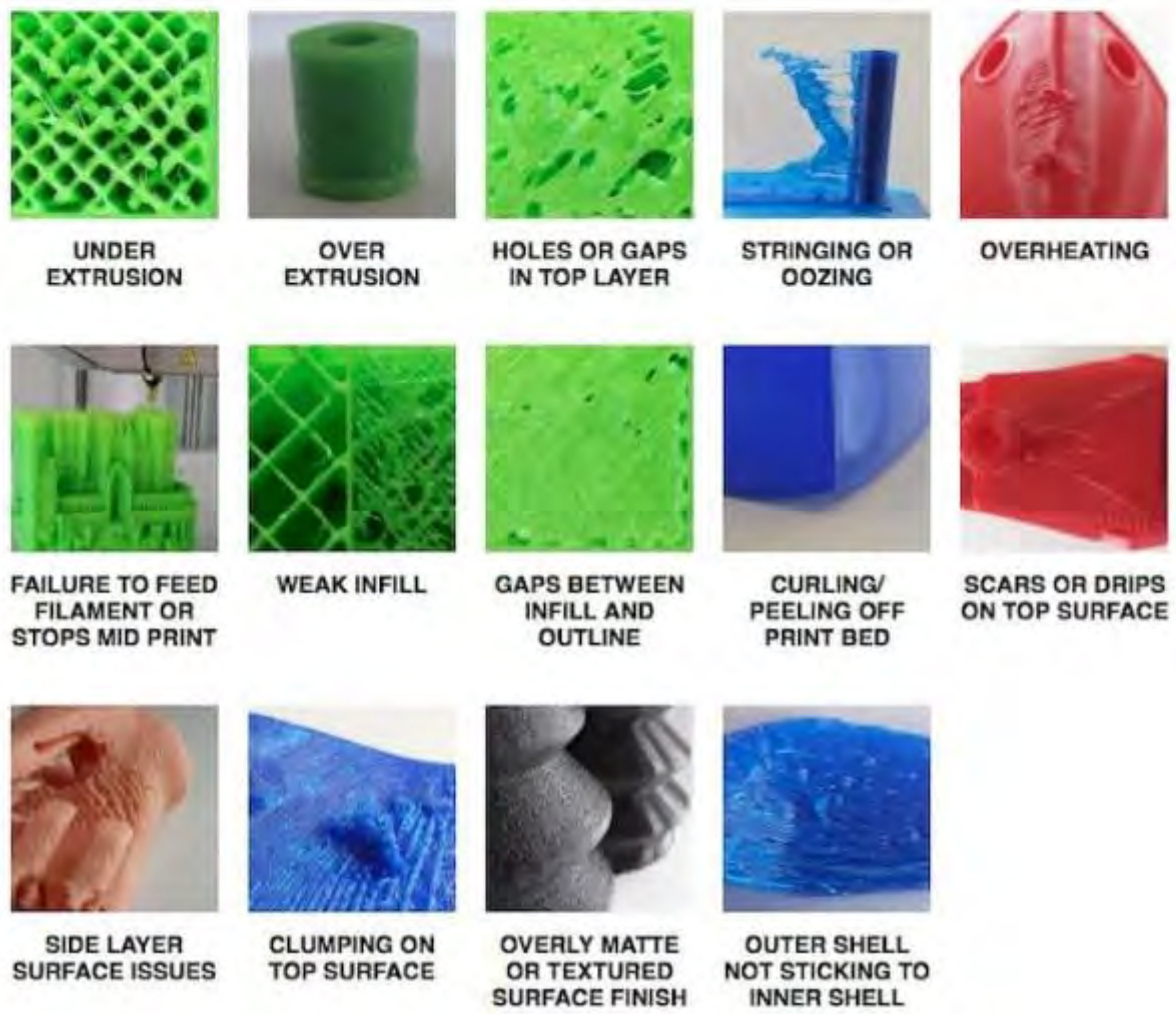


Figure 3 : Common Mistakes

Ahn *et al.* [18] characterized the properties of FFF-fabricated parts and observed mechanical strength deficiencies when compared to injection-molded parts. Furthermore, Tymrak *et al.* [19] investigated the mechanical properties of ABS and PLA components printed using FFF under realistic environmental conditions. They found that the extrusion temperature significantly impacted the mechanical properties of the printed parts.

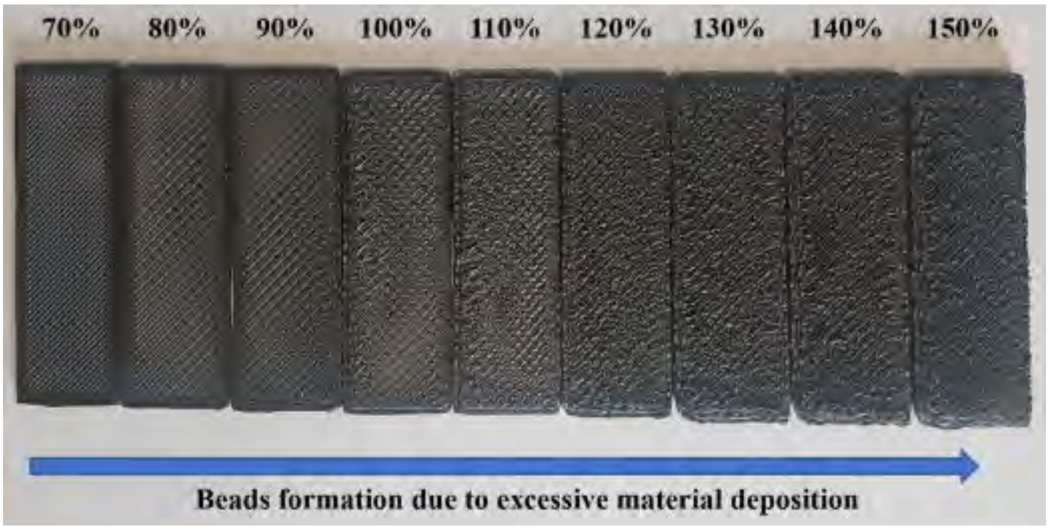


Figure 4 : Printed GPLA specimens

Costa *et al.* [20] developed a heat conduction model to predict filament adhesion quality, revealing that environmental temperature influenced filament adhesion and consequently affected the mechanical properties of FFF-processed parts. Kaveh *et al.* [21] analyzed the accuracy of FFF prototyped parts and determined that extruded temperature and raster width were the most influential process parameters among others, such as flow rate, feed rate, and raster angle. Yang *et al.* [22] introduced a temperature-control 3D printing system to investigate the effects of nozzle temperature, ambient temperature, and heat treatment methods on the mechanical properties of FFF 3D printed prototypes. Their findings demonstrated a direct relationship between tensile strength and nozzle temperature, as well as ambient temperature in the FFF process.

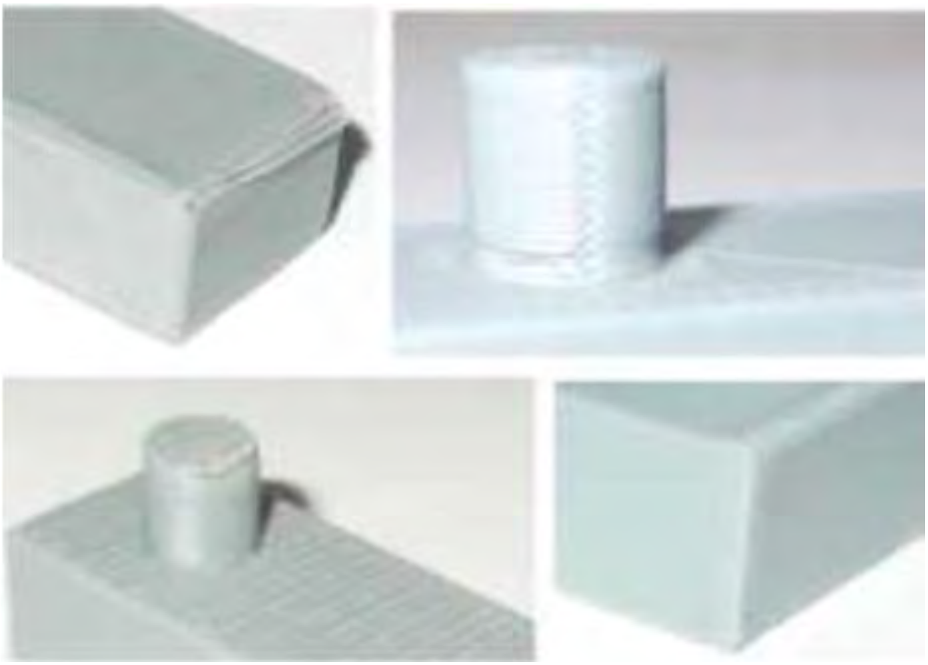


Figure 5 : Quality issues of FFF printed specimen.

The quality issues encountered in FFF-fabricated parts can be attributed to variations in nozzle clogging conditions throughout the printing process. Nozzle clogging can result in geometric misalignments and potential failures during 3D printing [23], making it a critical process error. Currently, when nozzle clogging occurs, the machine operator must identify the issue, halt the print, manually clean the nozzle, and restart the fabrication process from the beginning. Therefore, there is a pressing need to develop a technique for monitoring nozzle condition in FFF, which holds great promise for improving the quality of prototyped parts in terms of surface roughness and mechanical properties. To summarize, while FFF remains one of the most popular and extensively studied additive manufacturing processes, it is plagued by quality problems arising from nozzle clogging. Consequently, the development of a nozzle condition monitoring technique in FFF 3D printing stands as a potential solution to address this challenge.

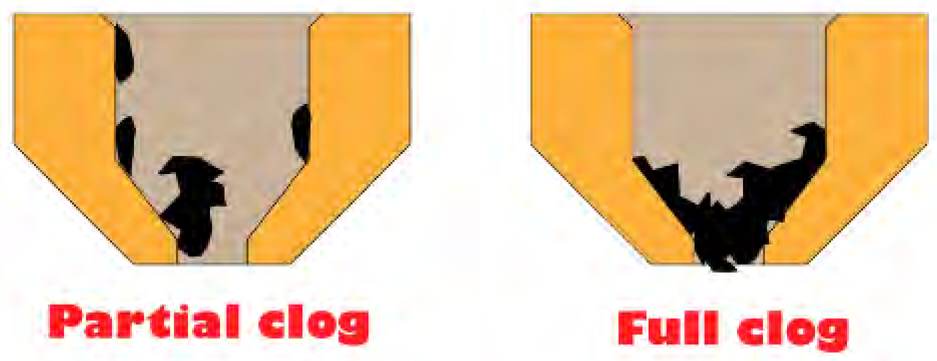


Figure 6 : Clog Status

With the rapid development of Additive Manufacturing (AM) processes and techniques today, inline quality control remains one of the most important technical challenges in this field. Many additive manufacturing systems lack the ability to assess the quality of the products they produce. Most of the most popular 3D printers on the market are based on the fused deposition modeling (FDM) method [24]. Their popularity stems from their low cost, which enables rapid prototyping for small businesses, research labs, and even consumers. Despite the popularity and continuous improvement of FDM-based systems, these systems still have many errors and printing processes fail from time to time [25]. Error modes include errors such as warpage, build plate delamination, and extrusion error. Among the causes of errors are factors such as relatively long operating time of the systems, often unsupervised operation. As a result, faults are detected after a significant loss of time and material. Failure to control the printing process leads to late or neglected detection of errors. It reduces the use of printing resources by rejecting material wastage and wasted time. The in-line quality control system can potentially monitor the process and intervene with commands if necessary, thus saving time or material. However, it is necessary to realize the appropriate integration of the cost of such a system into low-cost printing systems.

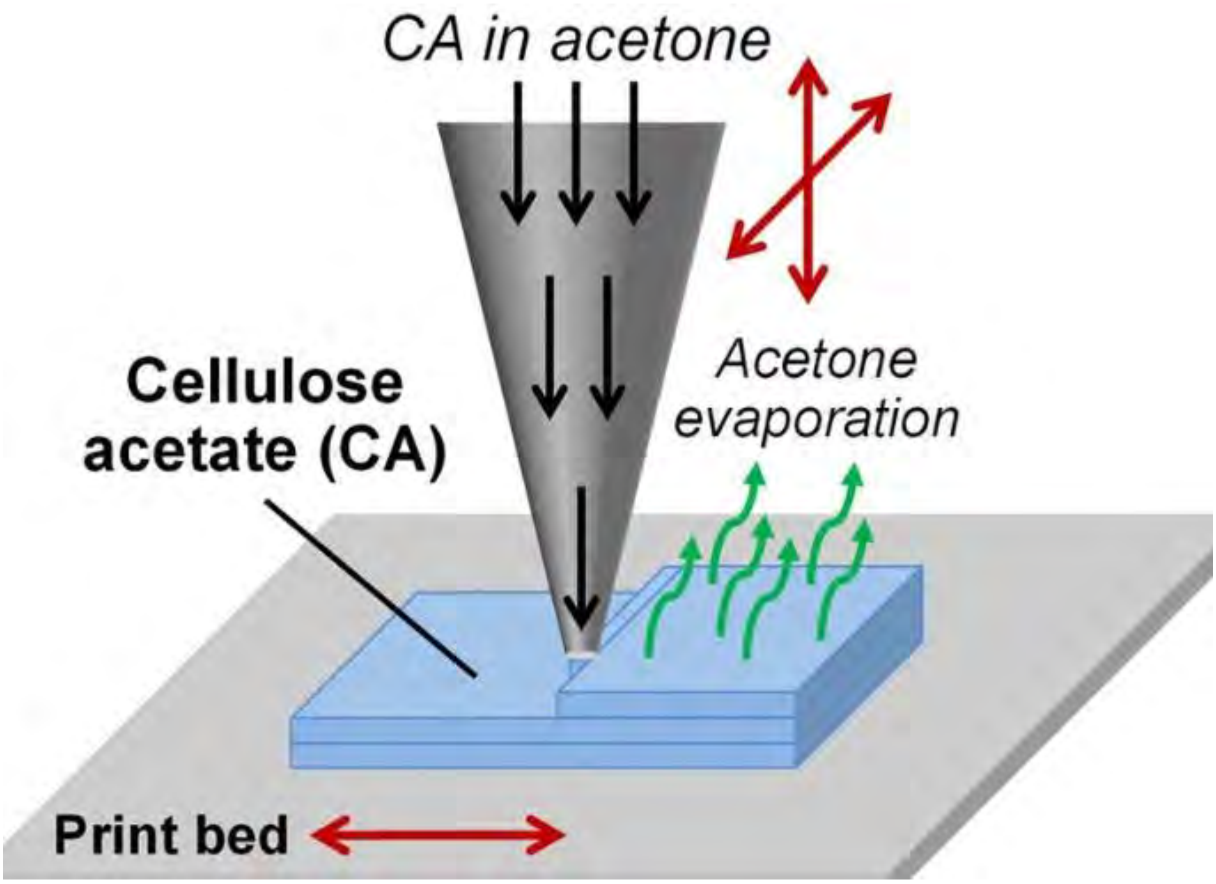


Figure 7 : 3D Printing with Cellulose

During the operation of a 3D printer, potentially harmful gases can be emitted. Specifically, the melting of materials like PLA (polylactic acid) can release various volatile organic compounds (VOCs). These VOCs can linger in the air and enter the users' bodies through respiratory pathways, potentially leading to health issues with prolonged or intense exposure.

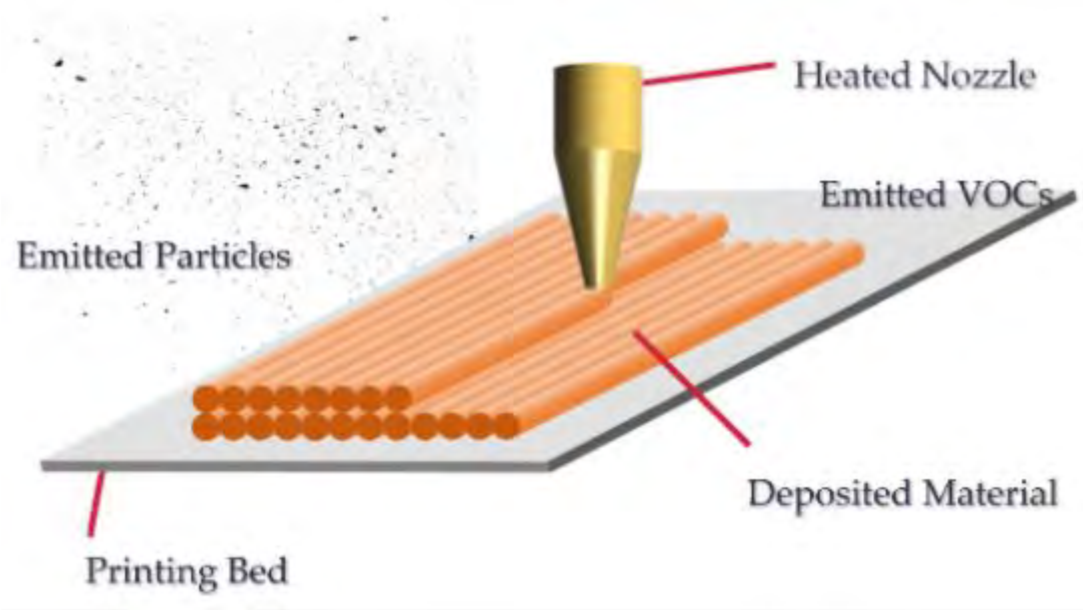


Figure 8 : Airborne emissions in FFF 3D printing.

Researchers aware of these potential hazards are conducting studies to evaluate the effects of emitted gases during the use of 3D printers. Research indicates that long-term exposure can result in respiratory discomfort, headaches, eye irritation, and allergic reactions. Furthermore, some studies suggest that these gases may have the potential to be carcinogenic and could lead to more severe long-term effects.

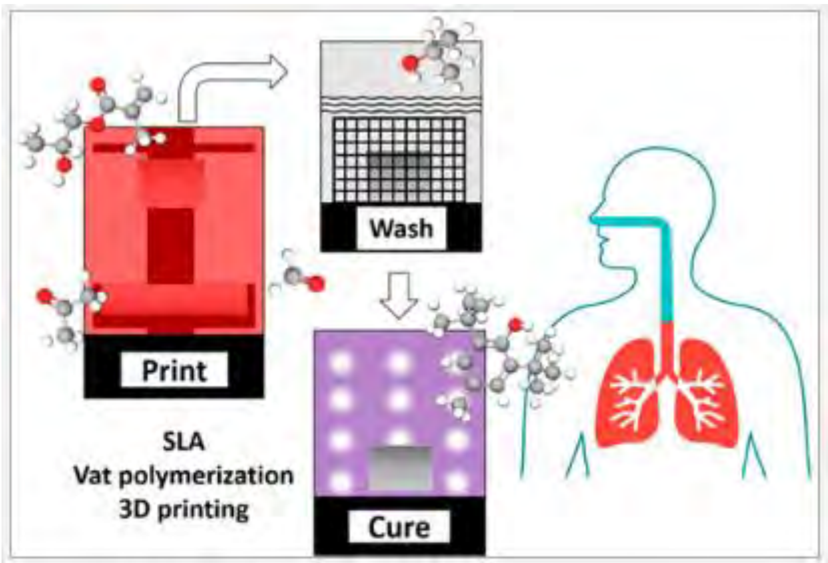


Figure 9

To minimize these health risks, users should take certain precautions when operating 3D printers. Working in a well-ventilated area, connecting the printer to an exhaust system, or utilizing a HEPA(High Efficiency Particulate Air) filter are important measures to consider.

Additionally, users should spend as little time as possible in the vicinity of the printer during its operation.

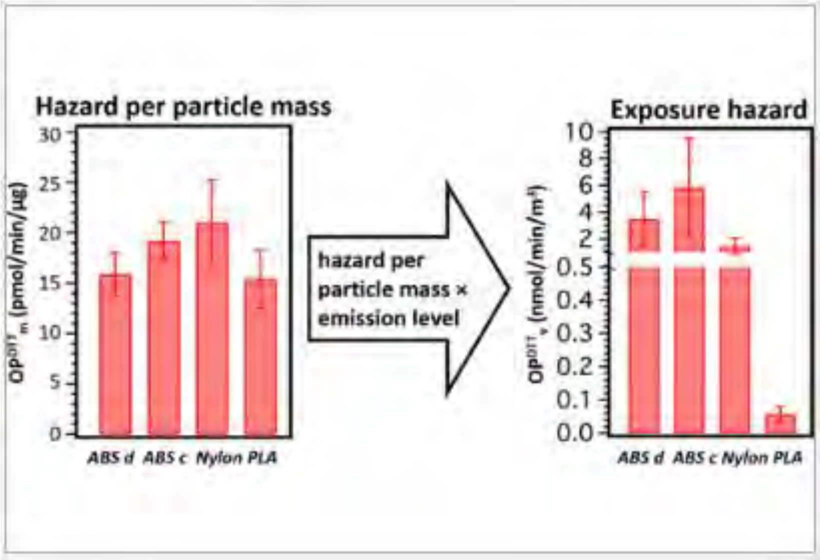


Figure 10

A new real-time detection system will be implemented that allows automatic detection of fault conditions considered outside of rated operation. In this study, each step of the printed product will be examined with the camera and remote control will be provided with commands such as stopping, canceling, restarting, and continuing the printing by giving a warning with the help of artificial intelligence in case of possible problems. In addition, the study will enable remote monitoring and control of 3D printers with the help of cameras and artificial intelligence. The system consists of a calibrated camera moving on 2-dimensional axes whose position and direction are known in the coordinate system. Among the parts that make up this system are the movable rails of the printer with idle ink in order to avoid cost and environmental pollution. Ink printers do not work very efficiently, and they are generally scrapped after the cartridge runs out. However, it is possible to recycle the rail systems and motors on it. With this study, printing errors based on machine learning will be detected with the printer parts to be recycled and it is thought to prevent possible time and material losses.

1.1. Literature Review

Several studies have been reported in the area of monitoring in extrusion-based AM processes.

Baumann and Roller proposed a methodology utilizing a camera to capture real-time images of the 3D printing process. These images were then analyzed using image processing techniques to detect and classify errors. Their developed system was capable of identifying five different errors in 3D printing, with a success rate ranging from 60% to 80% in efficiently detecting three of those errors. However, the study highlighted the drawback of high memory storage costs due to the frequent capture of consecutive video frames. The identified errors by the system included filament flow errors, surface defects, deformed parts, slippage, and deviations from the intended model [26].

Baumann *et al.* conducted another study where they developed a sensor array specifically for desktop 3D printers. The array included motion, orientation, vibration, temperature, and hygrometry sensors. Through a series of experiments, they were able to empirically differentiate between the printing and not-printing states of the 3D printer based on the sensor data [27].

In a study conducted by Nuchitprasitchai *et al.*, they introduced an approach where the FDF (Fused Deposition Fabrication) process in 3D printing is temporarily paused at specific checkpoints. During these pauses, two cameras capture the current production situation, and a 3D model is reconstructed using the captured images. This reconstructed object is then compared to the intended STL file from a perspective view. If the differences between the images exceed 5%, the print is classified as faulty [28].

In another study by Nuchitprasitchai *et al.*, they evaluated the effectiveness of an algorithm utilizing stereo calibration to detect errors during 3D printing. The algorithm successfully detected issues such as clogged nozzles, filament loss, or incomplete prints for various 3D object geometries. Errors were calculated based on data obtained from 3D reconstruction points at the current print height, and error detection was triggered when the errors exceeded 100%. Their experiments demonstrated that the error detection system achieved a 100% detection rate for both normal printing and failure states [29].

In the study conducted by Becker *et al.,* they employed a Sobel filter for edge detection. The proposed approach utilized the Sobel filter to detect the positions of occupied and unoccupied pixels. By analyzing the number of pixels between the upper edge of the printing object and the printing nozzle, an error class can be determined when it exceeds a specified threshold value, leading to extrusion stoppage. For warping and dimensional deviations, a comparison is made between the number of pixels in the image of the printed object and a rendered image of the desired state. Errors are detected based on certain percentage deviations. While the presented approach successfully detects most errors, it is noted that there is a high rate of incorrectly identifying images as defective [30].

In another study, Becker and colleagues calculated the Mel-frequency cepstral coefficient using sound measurements with the aid of a microphone near the extruder to detect defects in the printed component. Using the long short-term memory (Long Short-Term Memory, LSTM) architecture, which is one of the machine learning methods, they detected the incorrect nozzle height and realized the system that detects various errors [31].

In the Straub study, 5 different camera units were studied outside the printer. Raspberry Pi is used. A pipe made of polyvinyl chloride(PVC) is positioned perpendicular to the periphery of the printer with an apparatus taken from a 3D printer at its base. They mounted the camera and the microcontroller they used in the middle of the pipe. However, in this study, a high cost arises as there are 5 cameras [32].

Later, he used a multi-camera visible light 3D scanning system to detect interior 3D print errors and obscured exterior surfaces [33].

In another study, we see a mechanism articulated from the opposite side of the printer and a camera positioned above it for misprint detection through computer vision and computer processing of the expected printing geometry. Although the applied system is a rough prototype, the results demonstrate the success of the method and show that printing errors can be detected early and very clearly using a simple camera system. The method shown is simple, cost-effective and applicable to all FDM-based printers and avoids unexpected material build-up, print removal, etc. will detect the fault in most of the cases. However, since this system will only see the front side of the printer, it can only evaluate whether the product is printed correctly or not, based on the front side [34].

This paper introduces a non-intrusive method for monitoring the condition of Fused Deposition Modeling (FDM) machines using Acoustic Emission (AE) sensing techniques. The researchers utilized the time domain characteristics of AE hits to identify five different operating conditions of the FDM machine's extruder. They extracted features such as ABS-Energy, counts, and Root Mean Square (RMS) of AE hits. By employing a clustering approach, they were able to detect various machine states, including loading, unloading, and interrupted filament feed. They employed Support Vector Machine (SVM) classification using the mean and standard deviations of ABS-Energy. The researchers conducted three experimental studies and successfully detected both normal and abnormal conditions. The results demonstrated that AE techniques can effectively monitor FDM processes in real-time, offering the benefits of non-invasiveness and computational simplicity. Additionally, using a similar experimental setup, Wu *et al.* demonstrated the ability to differentiate between clogged and non-clogged nozzles using support vector machines [35].

The transformed representation of the frequency spectrum can be distinguished as error-free and error-prone prints using neural networks. Tlegenov *et al.* They connected an accelerometer to the extruder and were able to detect a clogged nozzle [36].

Using a camera connected to the extruder, Jin *et al.* developed a system to distinguish under and over extrusion defect categories from defect-free printing webs. In addition, a new method has been created that incorporates strain measurements to measure and predict the onset of curvature. The results show that the machine learning model can detect different delamination conditions, and the strain measurements setup successfully reflects and determines the extent and trend of warping before it actually occurs in the print job. The system shows has a very high accuracy of 98% and can correct detected errors [37].

This study suggests using AR technology to monitor the printing process of components acquired by AM technologies in real time. An AR-based software environment is used to achieve interactive superimposition of a virtual part to a real part being manufactured; it allows alignment between real and virtual worlds using markers or markerless technology, as well as options for different semi-transparency levels, colors, and shape selection at pre-set printing stages for the virtual model. In the event of a printing failure, the location of the problem may be determined so that corrective measures on the CAD model can be taken. An automatic halt of the printing process can also be accomplished without the need for human interaction [38].

Greeff and Schilling [39] proposed a filament slippage measuring approach in fused deposition modeling in which the extrusion volumetric flow rate was measured in real-time and the filament slippage quantity was decreased by closing the extruder loop.

Holzmond and Li [40] presented a 3D printing quality monitoring approach that tracked the geometry of the component during fabrication while comparing real geometry data with the CAD model, allowing them to estimate dimensional inaccuracies in situ.

In layered additive manufacturing (AM), Fang *et al.* [41] proposed a vision-based monitoring method that compares the optical images of each fabricated layer with the corresponding ideal layers from the computer-aided design (CAD) model.

Due to its very compact size, achievable accuracy and possibility to capture geometric 3D data, Faes *et al.* integrated a modular 2D laser triangulation scanner into an E3DP(Extrusion based 3D Printing) machine and analyzed the feedback signals [42].

Using multiple sensors, such as accelerometers, thermocouples, video borescope, and an infrared temperature sensor, Rao *et al.* [43] developed an online quality monitoring method for the fused filament fabrication process. They conducted sets of experiments to establish the empirical relationships between the input parameters (feed/flow rate ratio, layer height, and extruder temperature) and the surface roughness of the fabricated part.

Using computer vision, this study enabled the recognition of objects and the determination of the working status of the 3D printer in real time through an internal camera in layered additive manufacturing (AM) [44].

In light of the existing literature, various monitoring techniques have been proposed to address the challenges encountered in layered additive manufacturing (AM) processes. These techniques aim to minimize error rates and intervene promptly in case of any errors. However, it is worth noting that the research and development process for such monitoring systems is often lengthy and expensive. Despite these challenges, researchers have made significant strides in many developments such as tracking systems, AR technologies, and sound detection systems specifically designed for 3D printers. Nevertheless, the high cost and complexities associated with adapting these systems to 3D printers remain major hurdles. Building upon these findings, my project aims to overcome these limitations by devising an efficient and cost-effective monitoring solution for 3D printers, addressing the specific challenges highlighted in the literature. By integrating novel approaches and technologies, my project strives to enhance the monitoring capabilities of 3D printers, ensuring optimal performance and reducing errors in the printing process.

The proposed project aims to improve the quality control of fused deposition modeling-based 3D printing before applying more costly additive manufacturing technologies. A system that can be attached to FDM type printers will detect potential errors and prevent high expenses and possible problems of FDM type 3D printers. Recycled materials can be used for hardware parts to reduce rising costs. Nowadays, high cartridge prices of two-dimensional inkjet printers and technical issues related to cartridges make these printers unusable. As a result, old printers that are idle cause environmental problems as technological waste. Moreover, the engine, rail and various equipment they contain are seldom used and can be dismantled quite easily. In this study, a low-budget instant response system using recyclable materials is proposed to identify nozzle or extrusion errors of 3D printers. To minimize the cost of this, the rail system and engines of inactive 2D printers were utilized. In this way, as seen in the literature, it will be possible to control the printer from different angles with a single camera instead of using many cameras.

2. MATERIALS AND METHODS

I started this work as a Tübitak project. Therefore, this study has two processes. These processes are before and after receiving support from Tübitak. Before receiving support from Tübitak, I continued my work using 3D printer parts, materials such as Arduino, OV7670 camera and programs such as Solidworks and Matlab. After I was entitled to receive budget support from Tübitak, I used 3D printer parts in the same way, but I changed the other materials I used. I decided to use the much more advanced Raspberry pi 4 and pi camera v2, since I used recyclable materials and only one camera in the system I was working on. In addition to these, I started working with Python and C# as a program.

2.1. Beginning of the Project; Before TUBITAK Support

In this section, I will explain the first part of the study as I mentioned above.

2.1.1. Arduino

Arduino is an open-source electronics platform that consists of both hardware and software components. It is designed to be accessible and easy to use, even for individuals with limited electronics and programming knowledge. Arduino boards are widely used for creating interactive projects and prototypes, ranging from simple blinking LED lights to complex robots and automation systems.

Arduino offers a variety of board models, each with its own specifications and capabilities. Here are some of the commonly used types of Arduino boards: Arduino Uno, Arduino Mega, Arduino Nano, Arduino Leonardo and Arduino Yún.

The Arduino Yún is a unique Arduino board that combines the capabilities of a traditional Arduino microcontroller with a Linux-based processor. It features an Atmega32U4 microcontroller, compatibility with Arduino libraries and shields, and digital/analog input/output pins. The Yún also includes an Atheros AR9331 SoC running Linux, allowing you to run Linux-based applications alongside Arduino sketches. It supports Ethernet and Wi-Fi connectivity, has a Bridge library for communication between the microcontroller and Linux processor, and offers cloud connectivity through services like Arduino IoT Cloud. Yún has a microSD card slot for expanded storage and is one of the best Arduino models for networking, cloud integration, and for handling images from the camera sensor, processing images with basic techniques, and sending them via the cloud.

Figure 11 : Arduino Yun

2.1.2. DC Motor

There are DC motors in the movement mechanism of 2D printers. A DC motor is an electrical device that converts electrical energy into mechanical motion. It consists of a stationary part called the stator, a rotating part called the rotor, and a commutator with brushes. When current flows through the armature coil, it creates a magnetic field that interacts with the stator's magnetic field, generating rotational motion. By reversing the current direction, the motor can change its rotation. The speed can be controlled by adjusting the current or using PWM. DC motors are commonly used in robotics, automation, and various applications due to their simplicity and controllability.

Figure 12 : DC Motors

2.1.3. L9110 Motor Driver

The L9110 is a motor driver IC used to control small DC motors. It consists of two H-bridge circuits for motor control. It supports a wide range of motor voltages and receives control signals from a microcontroller. By adjusting the control inputs, the motor's direction and speed can be controlled. Pulse Width Modulation (PWM) is used for speed control. The L9110 has built-in protection features and is commonly used in small-scale robotics and automation projects.

Figure 13 : L9110 Motor Driver

2.1.4. OV7670 Camera Module

The OV7670 camera module is a popular image sensor module that can be connected to microcontrollers like Arduino. It features a 1/6-inch CMOS image sensor with a resolution of 640x480 pixels. The module communicates with the microcontroller using an 8-bit parallel bus and has control registers for configuring image capture settings. It supports various image formats and requires a clock signal for synchronization. A stable 3.3V power supply is needed for proper operation. The module is commonly used with Arduino to capture and process images.

Figure 14 : OV7670 Camera Module

2.1.5. Fritzing

Fritzing is an open-source software tool that simplifies the design and documentation of electronic circuits. It offers a user-friendly interface with drag-and-drop functionality and a vast library of components. Users can create circuit diagrams, simulate connections on a virtual breadboard, and design PCB layouts. Fritzing supports the generation of fabrication files for manufacturing and provides features for annotating and sharing circuit designs. It is a valuable tool for electronics enthusiasts, hobbyists, and professionals to easily visualize, design, and document their electronic circuits.

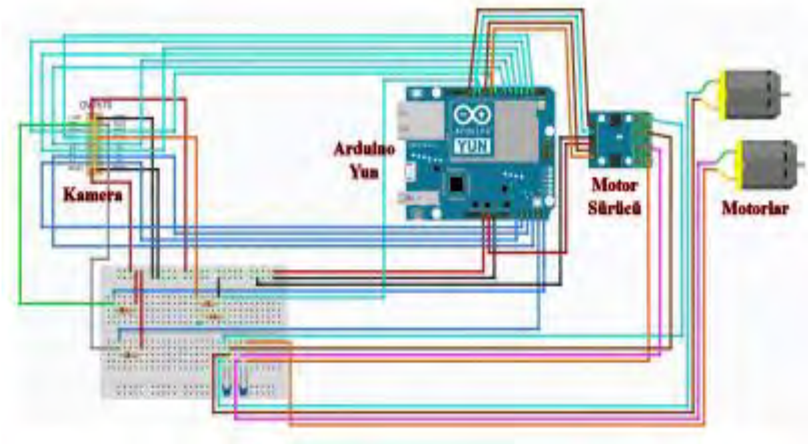


Figure 15 : Schematic Representation

2.1.6. Arduino IDE

The Arduino IDE (Integrated Development Environment) is a software application that simplifies the process of programming Arduino boards. It provides a user-friendly interface with features like code editing, syntax highlighting, and error checking. The IDE supports the Arduino programming language, which is based on C/C++. It uses the avr-gcc compiler and avrdude uploader to translate and upload the code to the Arduino board. The IDE also includes a Serial Monitor for communication between the board and computer. It supports various Arduino board models and configurations and is a comprehensive tool for developing Arduino projects. We are going to perform operations such as engine and camera control and data transmission on this platform.

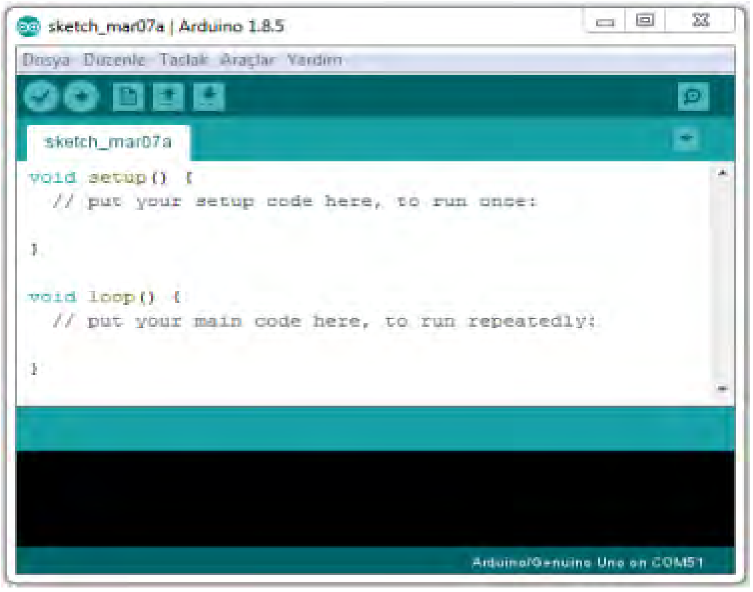


Figure 16

2.1.7. Matlab

MATLAB is a programming language and environment specifically designed for numerical computing and scientific research. It includes the Image Processing Toolbox, which offers a wide range of functions for image analysis and manipulation. With MATLAB, you can read and display images, apply filters for enhancement, perform segmentation and feature extraction, transform and register images, detect and recognize objects, and analyze image data. MATLAB's Image Processing Toolbox provides researchers and scientists with powerful tools to efficiently process and analyze digital images.

2.2. Changes and Developments in the Project; After TUBITAK Support

In this part, I will explain the second part of the study as I mentioned above. I also used the parts of the 2D inert printer at this stage.

2.2.1. Microcontroller

The Raspberry Pi is a low-cost and adaptable single-board computer created by the Raspberry Pi Foundation. Its goal is to encourage computer science education and make computing available to everyone. The Raspberry Pi has a system-on-a-chip (SoC) design, which means that several key components are integrated on a single chip. The Raspberry Pi usually uses an ARM-based CPU. The older models used ARM11 architecture, while the newer models use

ARM Cortex-A series processors. These CPUs are designed to be energy-efficient and provide enough processing power for most tasks. The main technical components include an ARM-based CPU, different amounts of RAM, microSD card for storage, various connectivity options (USB, HDMI, Ethernet, Wi-Fi, Bluetooth), GPIO pins for connecting with external components, support for multiple operating systems (e.g., Raspbian, Ubuntu), and a power supply through micro USB or USB-C. The Raspberry Pi is used for a variety of applications, from learning programming to DIY projects, home automation, media centers, robotics, and more. Its popularity comes from its low price, versatility, and strong community support. As you can see Figure 17, Raspberry pi will be more suitable in our project than Arduino.

Features	Raspberry Pi	Arduino
General	A minicomputer	A microcontroller
Operating System	Raspbian	Arduino IDE
Program running capability	Multiple programs can be run at a time	Only one program can be run at a time
Power backup	Battery packs cannot be used as it uses high current	Battery packs can be used as the current value is low
Libraries and sensors	Installing libraries and software for interfacing sensors are more complex	Very simple to interface sensors and other electronic components
Cost	Expensive as compared with Arduino	Cheap
Internet	Easy to connect by using Ethernet port and USB Wi-Fi dongles	External hardware is required to connect and the hardware need to be addressed properly by codes
Storage	No on-board storage (separate SD port is available)	On-board storage is available
Ports	4 USB ports to connect various devices	Only one USB port to connect to the computer
Processor	ARM family	AVR family Atmega328P
Power on off functions	Should be properly shutdown to avoid files corruption and software problems	Just a plug and play device, the programs start to run when in power supply and if disconnected it simply stops
Programming language	Python is desirable and C, C++ruby are pre-installed	C and C++

Figure 17 : Comparison of Arduino and Raspberry Pi

The Raspberry Pi 4 Model B (Pi 4B) is a high-performance single-board computer that is widely used for image processing and transferring applications, particularly when combined with the Raspberry Pi Camera Module. The Pi 4B offers significant improvements in CPU, GPU, and I/O performance compared to its predecessor, providing more computational power for image-related tasks.

Key features of the Pi 4B include a quad-core 64-bit ARM Cortex-A72 processor running at 1.5GHz, support for hardware decoding of H.265 and H.264 video formats, dual HDMI ports for up to 4Kp60 resolution, wireless LAN, Bluetooth 5.0, USB ports, Gigabit Ethernet, and GPIO pins for hardware integration.

Figure 18 : Raspberry Pi 4 Model B

The Pi 4B is designed to work seamlessly with the Raspberry Pi Camera Module, a dedicated camera interface that enables high-quality image acquisition. The camera module connects directly to the Pi 4B, allowing for efficient capture of images and videos without the need for external devices or additional processing steps.

Additionally, the Pi 4B provides GPIO pins that can be used to interface with sensors, LEDs, motors, and other components relevant to image processing applications. It also offers various connectivity options such as USB, Ethernet, Wi-Fi, and Bluetooth, facilitating image transfer to remote servers, cloud services, or other networked devices.

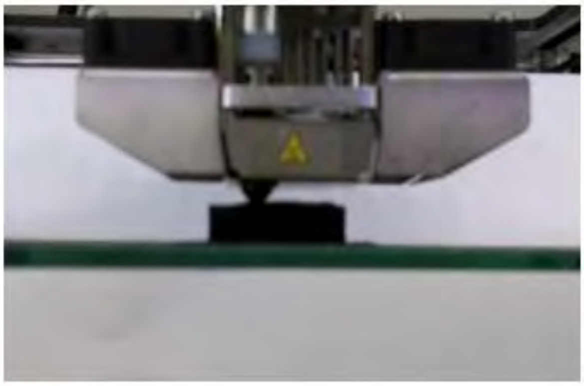
2.2.2. Camera

The Raspberry Pi Camera Module v2 is an official camera board released by the Raspberry Pi Foundation. It features an 8 megapixel Sony IMX219 image sensor and a fixed focus lens. The camera is capable of capturing high-resolution static images at 3280 x 2464 pixels and supports video recording at resolutions of 1080p30, 720p60, and 640x480p90. It connects to the Raspberry Pi through the dedicated CSi interface and is fully supported in the latest version of the Raspbian operating system.

Figure 19 : Raspberry Pi Camera Module V2

The camera module itself is compact, measuring approximately 25mm x 23mm x 9mm and weighing just over 3g. Its small size and lightweight design make it ideal for mobile and space-constrained applications. It connects to the Raspberry Pi via a short ribbon cable. The Sony IMX219 image sensor offers a native resolution of 8 megapixels and comes with a fixed focus lens.

In summary, the Raspberry Pi Camera Module v2 is a high-quality camera add-on for the Raspberry Pi, capable of capturing high-resolution images and videos. It is supported in the latest version of Raspbian and is suitable for various projects where size, weight, and image quality are important considerations.



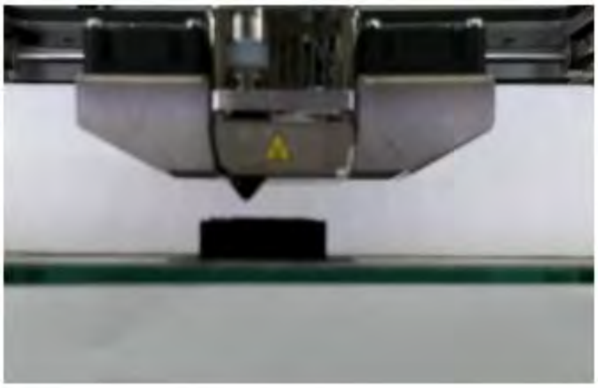


Figure 20 : Example of problem printing ***Figure 21 : Example of printing with problems***

First of all, the two pictures above will serve as an example for us so that everyone can understand what we are going to do. In Figure 20 you can see the image taken during a print run smoothly. In Figure 21, you can see the image that occurs when the filament does not come. We have previously discussed that this situation can have many causes and lead to many different consequences. The aim of this project is to reduce these consequences. One goal of our project is to create a warning system based on the distance between the nozzle and the print sample and to make this issue clear with these images. Figure 22 shows the general operation of the project.

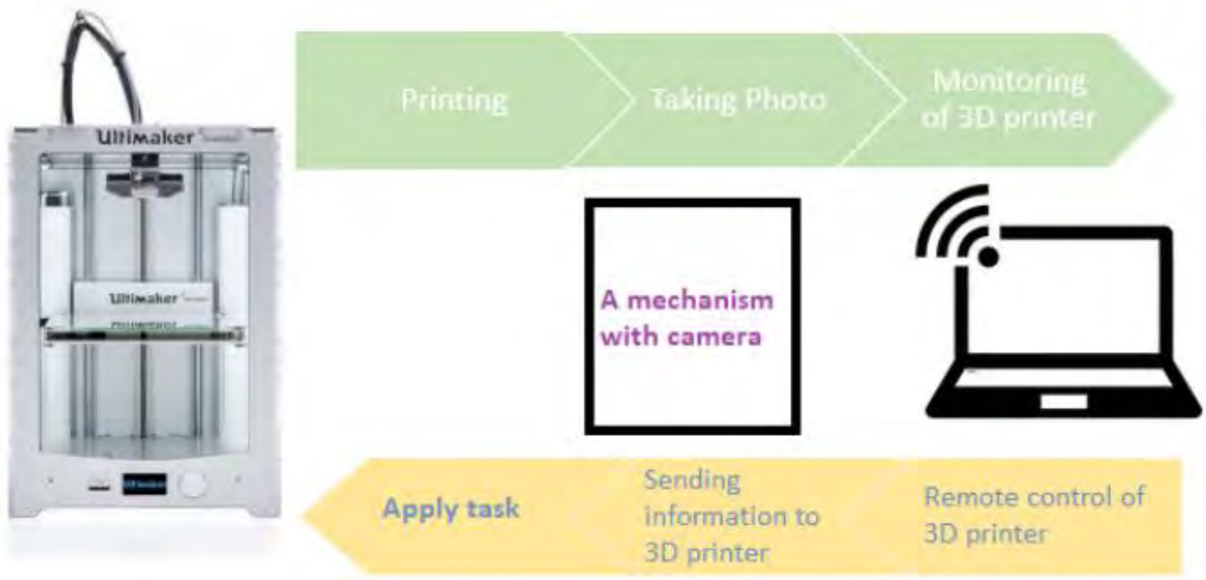


Figure 22 : General flow of the project

As a result of my research, I decided to develop a Windows Form application with C# programming language to transmit images from Raspberry Pi to another computer connected to the same network. Since we will send the image data in the form of pictures or short videos at regular intervals, there will be no need for the use of a video card or other hardware. We will perform this operation on a client-server architecture shown in Figure 23. In this architecture, Raspberry Pi will act as a server, while C# Windows Form application will act as a client.

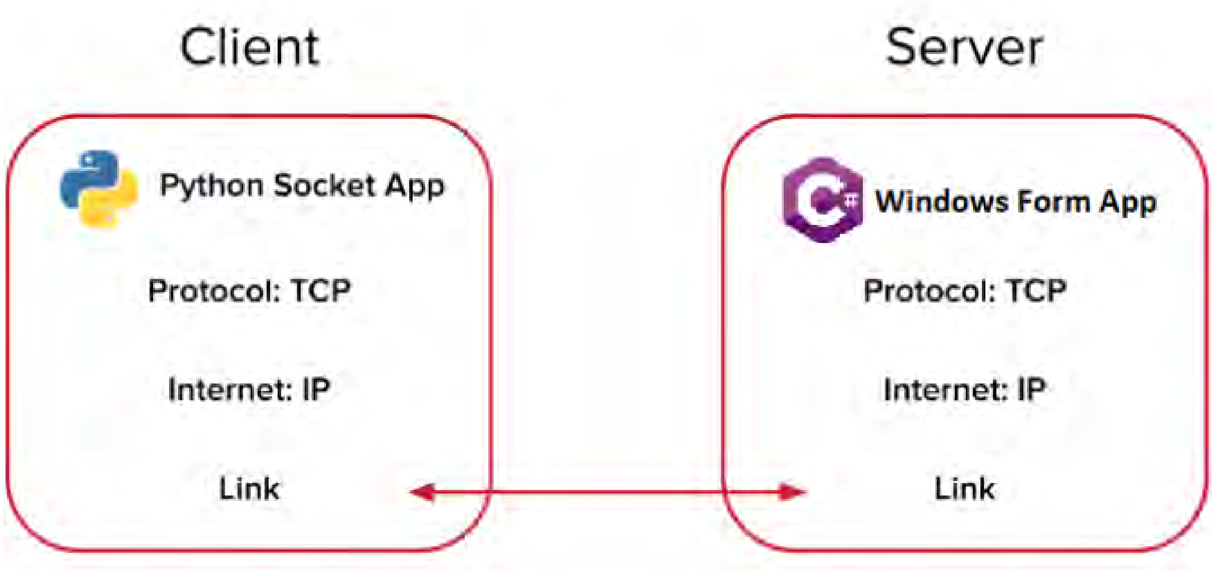


Figure 23 : Image transfer flow

TCP or UDP can be used for communication of this client-server architecture. TCP is short for "Transmission Control Protocol". TCP is a communication protocol that runs on the Internet Protocol (IP) and is a reliable, flow-controlled, connection-oriented protocol.

TCP's data transmission is accomplished using the three-way handshake method. This method starts when the device that wants to send data first sends a "connection request" to the other device. If the other device receives this request and accepts the connection, it sends the "connection accept" response. The first device also receives this response and finally completes the connection by sending a "connection confirmation".

This three-way handshake process is known as TCP unfolding. TCP stands for establishing a connection before sending data, ensuring that communication is reliable and error-free.

UDP is an abbreviation for "User Datagram Protocol". UDP is a communication protocol that runs on Internet Protocol (IP). It is not as reliable and flow-controlled as TCP, but it is faster and consumes less resources.

UDP protocol, unlike TCP, allows sending data without establishing a connection. Therefore, sending data is faster, but resending in case of error is user-managed.

UDP is mainly used in real-time applications such as games, video or audio. In such applications, fast and low-latency data transmission is essential, and data integrity or error correction may be secondary.

A server must be installed on the Raspberry Pi that can send image data to the client. This will be accomplished by writing a Python script that captures the image from a camera and then sends the image data over a network connection using the TCP protocol. This script will send image data from Raspberry Pi using libraries such as socket, opencv, struct and picamera.

Opencv library is a module used for image processing. With this module, we perform various operations on the image or video data received on the Raspberry Pi. For example, we perform operations such as filtering, segmentation, edge detection on images.

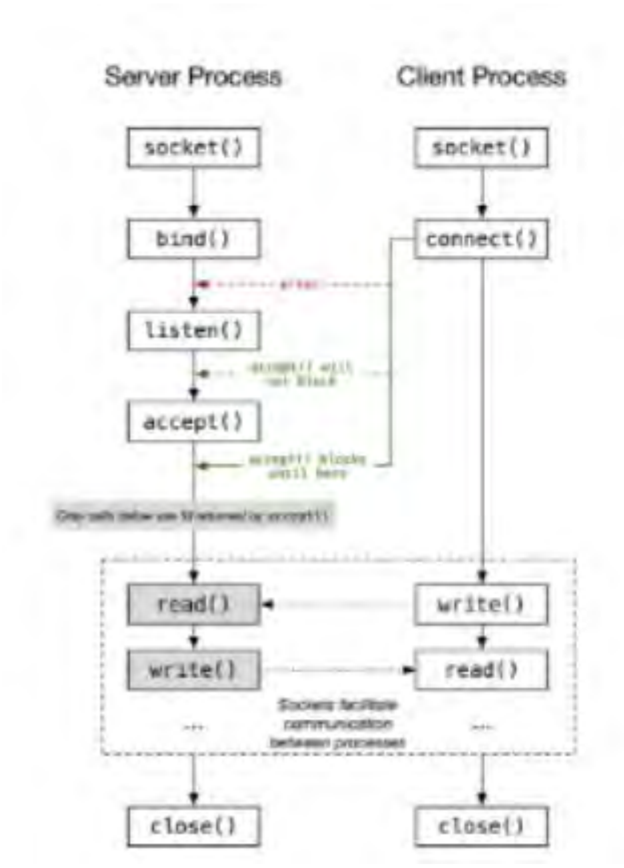


Figure 24 : Socket library algorithm

Socket library is a module for sending messages over the network. In Figure 24, the general operation of the socket library is shown. With this module, we establish a network connection between Raspberry Pi and C# windows form. Thanks to this connection, we send the image or video data from the picamera to the Windows form application. The c# windows form application on the other computer can receive this data with the socket library.

In the C# Windows Form application, it is necessary to create a client that can receive image data from Raspberry Pi. This process involves C# code that connects to the Raspberry Pi's IP address and port and then retrieves the image data from the server using the same protocol. When image data is received by the client, C# libraries such as System.Drawing, System.Windows.Forms, System.Net.Sockets, System.IO will be used to decode this data and display it in the Windows Form application.

2.2.3. Image Processing

In part of our project, we aimed to segment the nozzle, sample and base regions using image processing techniques and then measure the distance between the nozzle and sample and notify the user when it is greater than a specified threshold value.

First of all, we analyzed the image we obtained in detail. We focused on features such as shape, size, type, and data type. Then we halved the size of the image and selected the relevant region. We converted the image to gray. We then used morphological operations to expand the edges of binary objects in the image. Then we reduced the noise by applying a Gaussian filter to the gray image. This filter reduces high frequency noise in the image, softening the image and blurring the edges. We performed morphological occlusion and pixel-based operations to clear the background.

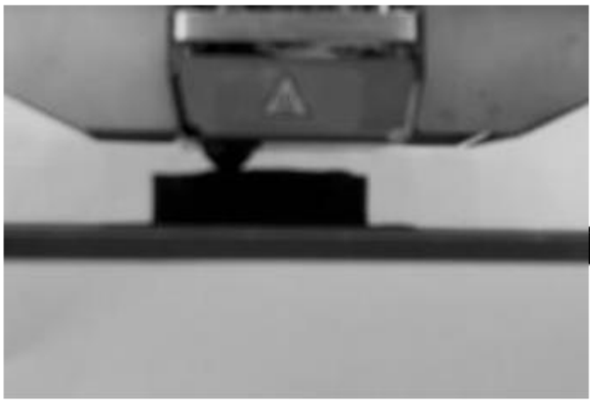


Figure 25 : Gray image

Figure 26 : Black and white image

We used the Canny edge detection method to identify the edges in this image. The Canny edge detection method detects the edges in the image and determines the pixel values of the edges with high accuracy. Thus, it is used to more clearly define the edges and contours of objects in the image.

We performed an image morphology operation called “dilate” to expand the edge image obtained as a result of canny edge detection. This enables more accurate and reliable use of edges in edge-based image processing applications.

Figure 27 : Cleaned image

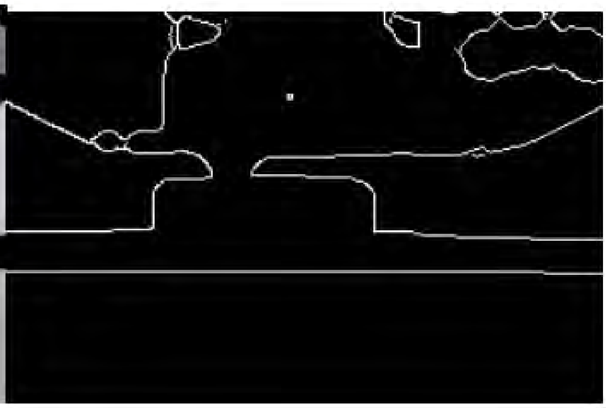


Figure 28 : Canny edge detection

The Gaussian blur filter softens the edges in the image, reducing noise and making the edges look smoother and more natural. This allows edge-based operations to produce more accurate and stable results in image processing applications. We draw contours around the edges. With the color-based segmentation method, we divided the image into nozzle, sample and base. We determined the coordinates and areas of these regions by contour analysis. By measuring the distance between the nozzle and the sample, we set up a control mechanism that notifies the user when it is greater than 0.25mm.

In Figure 25, Figure 26, Figure 27, Figure 28, Figure 29 and Figure 30, some outputs of the image processing steps can be seen.

Figure 29 : Blurred edges

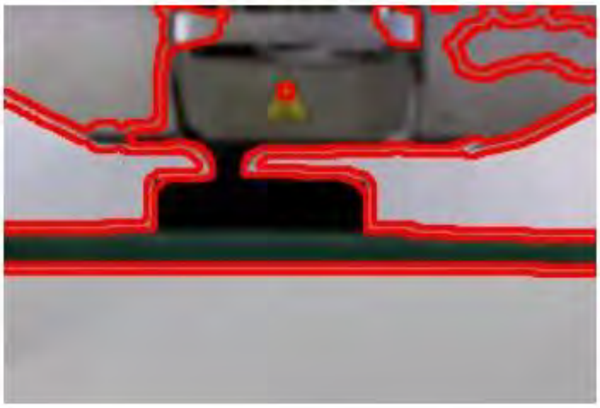


Figure 30 : Blurred edge and original image

3. SUMMARY AND CONCLUSION

3.1. Results of Before TUBITAK Support

The images obtained from the camera and the results obtained as a result of the image processing algorithms are shown in Figure 31. There is slight blurring of the image as it is acquired during nozzle movement and due to camera features. Figure 31a shows the raw data, while Figure 31bcd shows the images obtained after background cleaning and edge detection algorithms. The borders formed as a result of segmentation based on three different colors, namely nozzle, print sample and printer glass base, are shown on the image. Figure 31b indicates that there is no problem in filament flow as the distance between the nozzle and the sample is quite small. In Figure 31c, it is observed that the distance is widened. After this point, the filament flow was interrupted due to nozzle clogging. In Figure 31d, the distance has passed the threshold value [50].

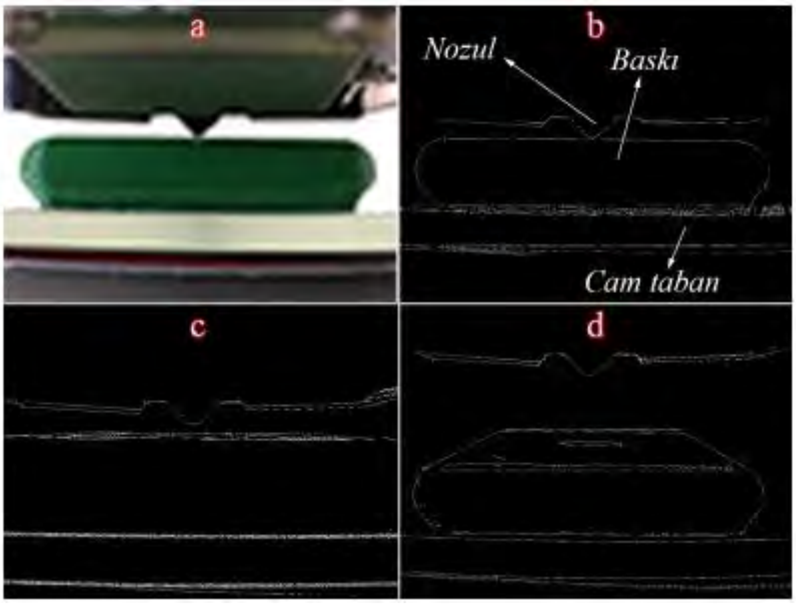


Figure 31 : The image obtained from the camera and the processed images, a) The image of the camera positioned between the nozzle and the print sample at 640x480 resolution, b) The distance between the nozzle and the print sample is quite small (d≤0.06mm), c) The The distance approaches the threshold value (d≤0.06mm) 0.25mm), d) The distance exceeds the threshold value (d>0.25).

The distance measurement obtained as a result of image processing during the printing process is shown in Figure 32. The difference between the nozzle and the print sample is calculated in each layer, and when this value exceeds 0.25mm, the printing process is paused with a warning. During printing, this error occurred at layer 54.

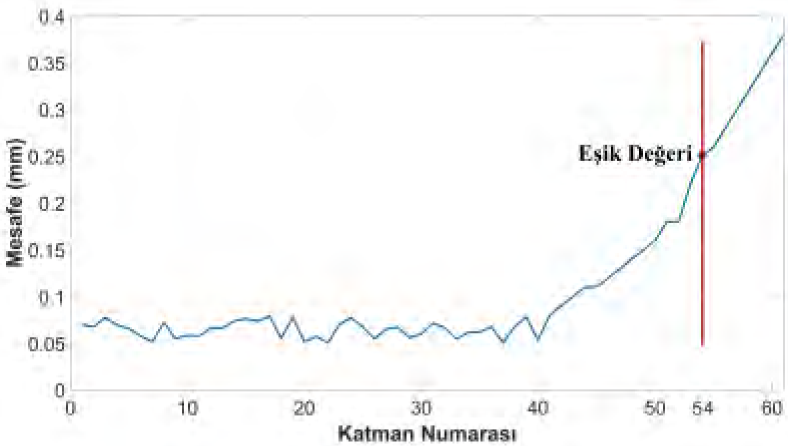


Figure 32 : Measurement of the distance between the nozzle and the print sample according to the layer number.

3.2. Results of After TUBITAK Support

As can be seen in Figure 33, a full photograph of the operating system is available. The left side screen is connected to the Raspberry Pi device. While the 3D printer is running, the Raspberry Pi and the camera take pictures at regular intervals. These photographs are subjected to some image processing processes. Photos are both saved on the Raspberry Pi device and sent over the internet to a Windows Form application written in C#. The laptop on the right in the figure is the user's computer and is connected to the internet. The Socket library is communicated between the Raspberry Pi device and the laptop.

Figure 283 : Photo of the working system

In this case, the Raspberry Pi device acts as the server and sends the photos, while the laptop acts as the client and receives the photos. The three most recent photos are displayed in the Windows Forms application. Also, according to the results of the image processing algorithms, if an alert is triggered, that photo is instantly sent via e-mail. In this way, the user has the opportunity to follow the printer without being near the 3D printer.

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A.APPENDIX

Below I leave an example of the Server(Python) and Client(C#) codes for a better understanding of the Server-Client relationship.

Server Code :

```python
import socket
import struct
import picamera
from datetime import datetime
from time import sleep

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
s.bind(('0.0.0.0', 4900))
s.listen(5)
c, addr = s.accept()
print("CONNECTION FROM:", str(addr))

camera = picamera.PiCamera()

while True:
    dateTimeObj = datetime.now()
    camera.capture('image_' + dateTimeObj.strftime("%d-%m-%Y_%H-%M-%S") +
'.jpg')
    print("Image captured.")

    with open('image_' + dateTimeObj.strftime("%d-%m-%Y_%H-%M-%S") +
'.jpg', 'rb') as image_file:
        image_bytes = image_file.read()

    image_size = struct.pack('<L', len(image_bytes))
    c.sendall(image_size)

    c.sendall(image_bytes)
    print("Image sent.")

    sleep(600)
c.close()
```

Client Code :

```csharp
using System;
using System.Drawing;
using System.Windows.Forms;
using System.Net.Sockets;
using System.IO;

namespace WindowsFormsApp2
{
    public partial class Form1 : Form
```

```
    {
        public Form1()
        {
            InitializeComponent();
        }

        private async void Form1_Load(object sender, EventArgs e)
        {
            Console.WriteLine("Trying to establish connection...");
            TcpClient client = new TcpClient();
            client.Connect("192.168.241.78", 4900);
            Console.WriteLine("Connection established.");
            NetworkStream stream = client.GetStream();

            while (true)
            {
                // Receive the size of the image
                byte[] imageSize = new byte[4];
                int bytesReceived = await stream.ReadAsync(imageSize, 0, 4);
                if (bytesReceived == 0)
                    break;
                int size = BitConverter.ToInt32(imageSize, 0);
                Console.WriteLine("Image size received: " + size);

                // Receive the image
                byte[] imageBytes = new byte[size];
                int totalBytesReceived = 0;
                while (totalBytesReceived < size)
                {
                    bytesReceived = await stream.ReadAsync(imageBytes,
totalBytesReceived, size - totalBytesReceived);
                    if (bytesReceived == 0)
                        break;
                    totalBytesReceived += bytesReceived;
                }
                if (totalBytesReceived == size)
                {
                    Console.WriteLine("Image received.");

                    // Convert the image bytes to a Bitmap and display it in the
PictureBox
                    using (MemoryStream ms = new MemoryStream(imageBytes))
                    {
                        Bitmap bmp = new Bitmap(ms);

                        pictureBox1.SizeMode = PictureBoxSizeMode.StretchImage;
                        pictureBox2.SizeMode = PictureBoxSizeMode.StretchImage;
                        pictureBox3.SizeMode = PictureBoxSizeMode.StretchImage;
                        pictureBox4.SizeMode = PictureBoxSizeMode.StretchImage;

                        pictureBox4.Image = pictureBox3.Image;
                        pictureBox3.Image = pictureBox2.Image;
                        pictureBox2.Image = pictureBox1.Image;
                        pictureBox1.Image = bmp;



                        // Set pictureBox1's SizeMode to StretchImage to scale
the image to fit in the pictureBox

                    }

                }
```

```
            }
            client.Close();
        }
    }
}
```

5. VITA

europass

Oğuzhan Telli

Date of birth: [redacted]

Nationality: Turkish

Gender: Male

CONTACT

Balatçık mahallesi 8911/7 Ciğli kat:2 no:3, 35000 IZMIR, Turkey **(Home)**

[illegible]

[redacted]

https://www.linkedin.com/in/oguzhan-telli/

ABOUT ME

I was very impressed by Nuri Fırat Ince's speech at the 2019 EEMKON. That's why I want to study neuroscience. I continue my development in the field of coding. Working, researching and developing in Neurotechnology or a similar field are among my biggest goals.

WORK EXPERIENCE

26/09/2021 – CURRENT Izmir, Turkey

Volunteer Intern Biomechanic Laboratory in Izmir Katip Celebi University

Researching 3D printers, microcontrollers and signal processing. I've been working on Raspberry Pi imaging lately so I'm more inclined towards this and Python at the moment.

2209-A University Students Research Projects Support Program Application
Topic : 3D Printing Defect Detection System Design Based on Machine learning Using Recyclable Materials

IEEE TURKEY-SPA-Signal Processing applications 2022 Application
Topic : A system Design for Detecting Printing Troubleshoot utilizing Recyclable Materials in 3D Printers

01/08/2021 – 26/08/2021 Manisa, Turkey

Intern BoneGraft

Production internship in cleanroom conditions.

EDUCATION AND TRAINING

08/2018 – CURRENT Izmir, Turkey

Biomedical Engineering Student Izmir Katip Celebi University

Address Balatçık Mah. Havaalanı Sosese Cd. No:33/2, 35620 [illegible] Çiğli Izmir, Turkey | **Website** https://www.ikcu.edu.tr/ | **Field of study** Biomedical Engineering | **Final grade** [illegible] | **Thesis** Real-Time Detection System for Printing Problems of Three-Dimensional Printers

08/2016 – 03/2017 Antalya, Turkey

Computer Engineering Student Alanya Alaaddin Keykubat University

I learned some algorithm skills and I quit the school for some causes

Address [illegible] Cd., 07450 Alanya/Antalya, Antalya, Turkey | **Website** https://www.alanya.edu.tr/

LANGUAGE SKILLS

MOTHER TONGUE(S): Turkish

Other language(s):

English

Listening	Reading	Spoken production	Spoken interaction	Writing
B2	B2	B1	B1	B2

German

Listening	Reading	Spoken production	Spoken interaction	Writing
A2	A2	A1	A1	A2

Italian

Listening	Reading	Spoken production	Spoken interaction	Writing
A1	A1	A1	A1	A1

DIGITAL SKILLS

Microsoft Office | Programming Languages: C, C++, Python, Matlab | Solidworks (Professional Proficiency) | Proteus PCB Design & Simulation | Fritzing | Microcontrollers (Arduino ESP32 Raspberry pi) | 3D printer | COMSOL MULTIPHYSICS | ANSYS | FPGA programming with Xilinx ISE

SOFT SKILLS

Decision-making | Critical thinking | Written Communication | Leadership | Problem Solving | Good listener and communicator | Creativity | Organizational and planning skills | Team-work oriented | Motivated | Analytical skills | Strategic Planning | Responsibility | Research and analytical skills | Reliability

ADDITIONAL INFORMATION

Driving Licence

- **Driving Licence:** AM 26/10/2015 – 25/08/2030
- **Driving Licence:** A1 26/10/2015 – 25/08/2030
- **Driving Licence:** A2 26/10/2015 – 25/08/2030
- **Driving Licence:** A 26/10/2015 – 25/08/2030
- **Driving Licence:** B1 26/10/2015 – 25/08/2030
- **Driving Licence:** B 25/08/2020 – 25/08/2030

Hobbies and interests

- **Skill Highlights** Popular sciences reading / Chess / Football,basketball and volleyball / Ping pong / Swimming / Fishery / Billiards / Travelling / Jogging / To invest / Taking photo / Solve puzzles / Archery / Backgammon / Cycling / Take a walk / Tennis / Table Tennis

CERTIFICATES AND CONFERENCES

- **15/11/2019 – CURRENT**
  PEARSON ENGLISH PREPARATORY PROGRAMME
- **Angiography Device Training-MEDCAMP | EMBS&PHILIPS**
- **EEMKON 2019**
- **IMAGING TRAINING SERIES - MR AND CT IMAGING | BEYKENT UNIVERSITY&SIEMENS**