Dataset for anomalies detection in 3D printing

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Abstract. Nowadays, the Internet of Things plays a significant role in many domains. Especially, Industry 4.0 is making significant usage of concepts like smart sensors and big data analysis. IoT devices are commonly used to monitor industry machines and detect anomalies in their work. This paper presents and describes a set of data streams coming from a working 3D printer. Among others, it contains accelerometer data of printer head, intrusion power and temperatures of the printer elements. In order to gain data, we lead to several printing malfunctions applied to the 3D model. The resulting dataset can therefore be used for anomalies detection research.

Keywords: Internet of Things, Industry 4.0, anomaly detection

1 Introduction

The use of 3D printers is becoming more and more desirable. They are used not only in professional production plants, but also among home users. As a result, methods of automatic fault detection during their operation are gaining importance. This paper presents the data that we have gathered from the 3D printer during the printing process. Among all, data samples include a temperature of working elements of the printer, intrusion force and the acceleration of printing head. The data has been gathered using two types of sources - custom-made measurement devices and the printer's internal software. In order to enable the dataset to serve as an example of anomalies detection for intelligent Industry 4.0 systems, we provoked several types of failures during the printing process. All of the files are placed in the repository[1] and can be used under the `Creative Commons Attribution 4.0 International` license.

The rest of the paper is organised as follows. Section 2 presents related work. In section 3 we describe the characteristics of the printer machine used for gathering data samples. In 4 we characterize each type of data source while printing failures that we created are presented in 5. Section 6 contains sample data analysis. The last section sums up the paper.

[1] https://github.com/joanna-/3D-Printing-Data

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2 Related Work

As interest in 3D printing increases in various applications, anomaly detection systems are gaining in importance [1]. Moreover, data sets which facilitate development of anomaly detection systems are made available, for instance as described in [2]. We can distinguish several types of systems used to monitor the operation of machines for manufacturing processes. The industrial device monitoring systems may use data from various types of sensors [3], e.g. kinematic, visual, inertial, as well as auditory [4]. Systems, which are specialized for monitoring 3D printers' operation, are also designed, developed, and described, e.g. systems based on image analysis [5–7] or on sensor data analysis [8, 9].

Proper preparation of the 3D printer and retrofitting it with sensors requires some time and equipment expenditure. In the article, we present a set of test data that were obtained using devices built using the FogDevices platform [10]. The presented set of test data can be used to develop new algorithms for detecting anomalies in the work of 3D printers and, what is important, to compare them.

3 3D Printer characteristics

The 3D printer utilized for collecting its operation data was Monkeyfab Spire manufactured by Monkeyfab[2] - its basic properties are listed in Table 1. It is a *delta printer* in which the printing head is mounted on magnetic ball joints. The Monkeyfab Spire uses the *RepRapFirmware* and is controlled over the network via *Duet Web Control*[3] interface.

Table 1: Basic parameters of the utilized 3D printer according to manufacturer's specifications.

Maximum printed object dimensions	150 mm diameter 165 mm height
Default nozzle diameter	0.4 mm
Minimum layer height	0.05 mm
Filament diameter	1.75 mm
Maximum hotend temperature	262 °C
Maximum platform temperature	120 °C

4 Data sources characteristics

The sensor data comes from two sources - (i) internal electronics that control the operation of the printer and from (ii) additionally mounted sensors. They are described in more details in the next subsections.

[2] http://www.monkeyfab.com
[3] https://duet3d.dozuki.com

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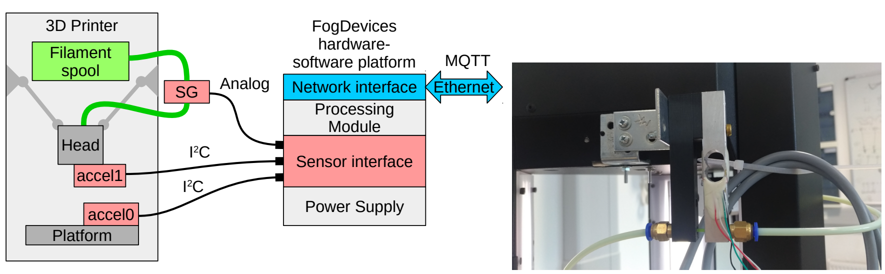
4.1 Duet Web Control

The 3D printer is controlled by the Duet3D electronics which expose user interface (UI) called *Duet Web Control Interface* that is accessible via a web browser allowing to monitor and change printer state. Among others, it includes such features as emergency stop, monitoring temperatures of printer parts, changing filament and selecting 3D models to print. The aforementioned information is also exposed via API in *json* format which can be accessed remotely via a network.

4.2 Data acquisition hardware

The printer has been equipped with additional custom sensors developed as part of the FogDevices[4] research project. Data from the sensors were collected using a device assembled using modular hardware components.



(a) Data acquisition system (b) Filament feeding force sensor

Fig. 1: Sensors attached to the printer

The printer has been equipped with two inertial measurement unit (IMU) sensors LSM9DS1 that can measure acceleration, angular rate and magnetic field in 3 axes but only linear acceleration was used. First of the sensors, called *accel0* is attached to the printing platform and *accel1* is on the print head. Both sensors use the I^2C digital interface and are connected to the FogDevices hardware platform.

The method of measuring the filament feeding force is based on indirect measurement of the force acting on the Bowden tube during printer operation as presented in Fig.1b. This was possible since the extruder is located on the printer's body, not at the print head. Therefore, a force sensor *SG* based on a strain gauge was developed. Its operation is based on the Wheatstone bridge and it produces small voltage output. The voltage is amplified in FogDevices sensor interface module with INA128 instrumentation amplifiers and then measured using an analog-to-digital converter (ADC) with 12-bit resolution.

[4] http://fogdevices.agh.edu.pl

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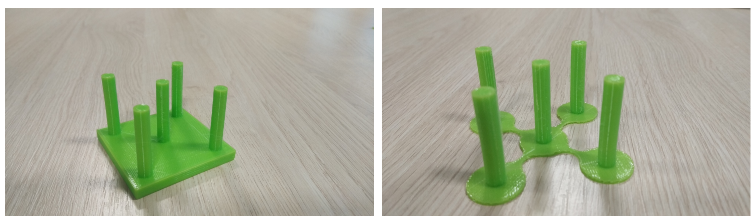
Block diagram of the hardware is presented in Fig. 1a. The FogDevices hardware platform has been utilized to collect data from three sensors: *SG*, *accel0*, and *accel1*. Data collected by the device was being sent through the MQTT protocol over the Ethernet interface. The data were then saved by a data logger running on a PC. The acquisition system collects and processes 200 samples per second[5].

5 Test prints

We have used two variants of the same five towers print to collect data. In the variant (a), presented in Fig. 2a, towers have printed base that is an integral part of the print and in variant (b) presented in Fig. 2b, towers do not have a base - they are placed only on the raft.



(a) towers with the base - photo (b) towers without base - photo

Fig. 2: Models used in the experiments

For both variants, we have collected data from the undisturbed, properly made print. Apart from that, we provoked six printing anomalies presented in figure 3:

1. **variant (a)**:
   - 3b - printer ran out of plastic before the print was finished;
   - 3c - part of the print unstuck from the printing base, but the rest of print remained undisturbed;
   - 3d - the speed of the retraction has been set too low (to 0.5);
   - 3e - during the printing, the Bowden tube fell out from its place;
   - 3f - during the printing, the arm of printer head has been detached from magnets holding it in the place;
2. **variant (b)**:
   - 3a - during the printing, part of the print has been removed.

[5] Additional sensors and devices are provided by the FogDevices platform. The video showing printing process is available online https://youtu.be/SFBInVsVDgk

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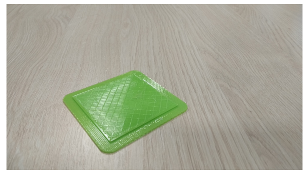
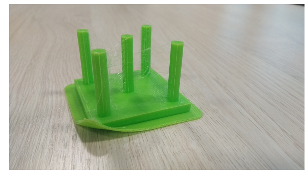
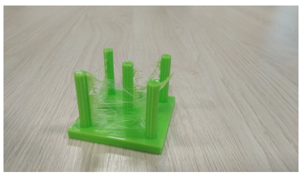
(a) removal of the part of the print



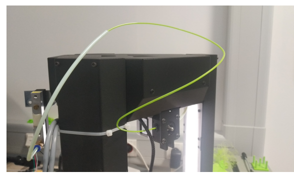
(b) plastic finish



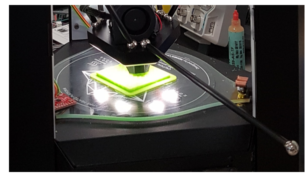
(c) print unsticking



(d) 0.5 retraction



(e) Bowden tube fallout



(f) arm failure

Fig. 3: Various malfunctions of the print

6 Sample data analysis

Provoked failures cause different symptoms that can be detected with the data analysis. Different failures may have similar symptoms depending on their type and therefore inferring the initial cause can require more complex analysis. In this section, we present very basics of analysis and show three types of symptoms related to five types of failures. The summary of failure-symptom correlation is presented in the table 2.

failure type	symptoms	brief explanation
finish of plastic	decrease of intrusion power	there is no more plastic to intrude
Bowden tube fallout		there is no friction with the print - plastic doesn't reach printed model
wrong retraction (0.5)	printing base jolting	too much plastic hooks on the next layers
unsticking of the model		printing head hooks on the rolled print
arm failure	printing head angle change	detachment of arm causes head to tilt

Table 2: Symptoms characteristic of the printing failures.

Figure 4 presents two different plots that show some of the aforementioned symptoms. Figure 4a shows the situation where the filament feeding force dropped rapidly at time 11:40. That symptom may suggest that the filament is over or there was severe mechanical problem - in this case, the Bowden tube fallout. Figure 4b shows the tilt angle of the print head during printing. Values different from 180 degrees are caused by the fact that the angle is calculated based on

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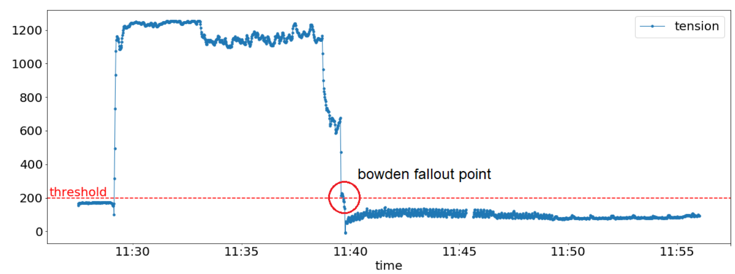
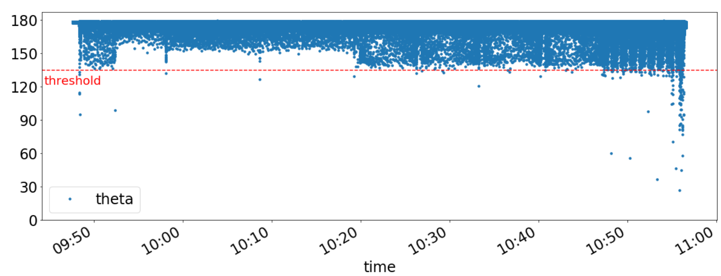
the accelerometer placed on the head, which is affected by the force of gravity and acceleration resulting from the head's movement during printing. At 11:00 a significant change in the graph's value can be observed on the chart indicating mechanical damage to the printer. In this case, the arm fixing the printing head in the delta system is damaged.



(a) Tension values for the print with Bowden tube fallout.



(b) Tilt angle values for the print with head arm detachment.

Fig. 4: Plots presenting symptoms of printing anomalies

7 Summary

The article presents data collected during the operation of the 3D printer, including typical errors observed during the printing process. The collected data can be used to develop advanced algorithms for detection and prediction of failures. The automatic detection of 3D printing machines failure can be useful for owners of printers farms allowing them to decrease the maintenance expenditures.

The paper presents also the possibilities offered by the use of IoT devices in Industry 4.0. Retrofitting machines with additional sensors and devices analyzing their work in real-time can provide valuable information about their work. IoT devices such as those offered by *FogDevices Platform* allow simplifying the process of adding sensors and analyzing data on the edge, near the sensors without sending them to the computational clouds.

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Data usage

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