ORIGINAL

Development of a filament auto-detection system for fused deposition modelling 3D printers

Enrique Soriano Heras, Fernando Blaya Haro, José María de Agustín del Burgo y Manuel Enrique Islán Marcos

Desarrollo de un sistema de detección automática de filamentos en impresoras 3D de modelado por deposición fundida

ABSTRACT

The purpose of this paper is to present a development to avoid extrusion failures in fused deposition modelling (FDM) 3D printers by detecting that the filament is carried forward properly. The Weighted Objectives Method is one of the most common evaluation methods for comparing design concepts based on an overall value per design concept. Taking into account the obtained scores of each specification, the best choice for this work is the optical encoder. Once the sensor is chosen, it is necessary to design de part where it will be installed without interfering with the normal function of the machine. To do it, we employ photogrammetry scanning methodology. The developed system achieve perfectly detect the advance of the filament without affecting the normal operation of the machine. Also, the primary objective of the system is achieved, avoiding loss of material, energy and mechanical wear, keeping the premise of making a low cost product that does not significantly increase the cost of the machine. This development has made it possible to use the printer with remains coil filament, which were not spent because they were not sufficient to complete an impression and printing models in two colours with only one extruder. A system architecture to avoid extrusion failures has been developed and integrated into an FDM 3D printer.

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Palabras clave
3D printers, rapid prototyping, fused deposition, extrusion failures, photogrammetry, manufacturing system.

RESUMEN

El propósito de este trabajo es presentar un desarrollo que permita evitar fallos de extrusión en impresoras 3D de modelado por deposición fundida (FDM), mediante la detección de un avance del filamento correcto. Diseño/metodología: El Método de Objetivos Ponderado es uno de los métodos de evaluación más comunes para la comparación de los conceptos de diseño, basado en un valor global por concepto del diseño. Teniendo en cuenta las puntuaciones obtenidas de cada especificación, la mejor opción para este trabajo es el codificador óptico. Una vez elegido el sensor, es necesario diseñar la estructura en la que se va a instalar, sin interferir con la función normal de la máquina. Para hacerlo, empleamos la metodología de digitalización por fotogrametría. Hallazgos: El sistema desarrollado logra detectar el avance del filamento sin afectar al funcionamiento normal de la máquina. Además, se consigue el objetivo principal del sistema, evitando la pérdida de material, energía y desgaste mecánico, manteniendo la premisa de hacer un producto de bajo coste que no aumenta significativamente el precio de la máquina. Implicaciones prácticas: Este desarrollo ha hecho posible el uso de la impresora con restos de filamentos, que se habían descartado previamente y la impresión en dos colores con un solo extrusor. Originalidad/valor: Un sistema para evitar fallos de extrusión que se ha desarrollado e integrado en una impresora FDM 3D.

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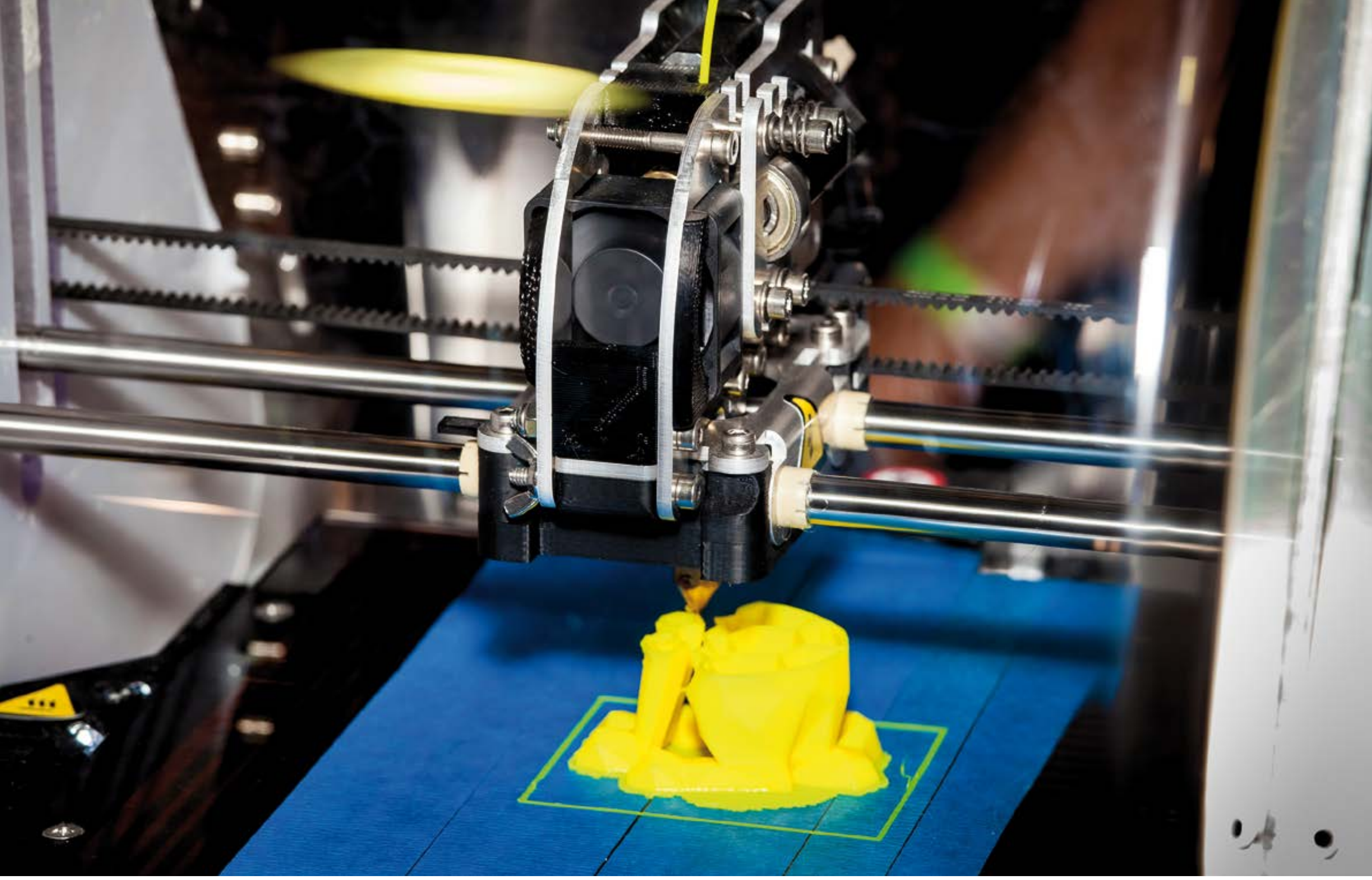
Keywords
Impresoras 3D, prototipado rápido, deposición fundida, fallos de extrusión, fotogrametría, sistema de fabricación.



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Introduction

Nowadays, the use of 3D printers in homes and small businesses is growing outside of engineers and tinkerers,[1] so 3D printers must remain 100% reliable with near zero failed prints due to mechanical and electro-mechanical malfunctions. One of the most important leading causes of print failure is filament feeding mechanism. Some researches and engineers have optimized the grip force on 3D printer filament and even have developed novel feeding mechanisms without filament.[2,3]

Extrusion failures in FDM 3D printers include those related to the extruder, hot end and filament. The main extrusion problem that occurs to FDM 3D printers arises when the filament does not move as it is desired, which produces jams in extruder or in extruder drive pulley. This problem may be due to damage, stress, dust and small debris in filament. Nevertheless, the most common problems spring from a wrong filament diameter, braking of the filament, or simply that the filament coil is over. In these cases, the printer keeps on printing but it does not deposit any material.[4,5]

Although manufacturers and researches are constantly improving polymers manufacturing process, including fiber spinning and injection molding, the product quality and production efficiency is influenced by multiple processing and material parameters, such as the nominal shear and shear history, process temperature or long chain branching, mechanisms that currently are not completely understood. The control and optimization of such operations contribute to get closer and closer to the nominal filament size but it still moves in fairly large tolerances.[6-9] Moreover, the possibility of continuously checking the deposited filament, allows to reach a better quality of the printed parts.[10,11]

In this paper, we present a development to detect the root of the extrusion failures (may be a knot coil, an extruder jamming or simply the filament coil ends). It is proposed trying to detect that the filament is carried forward properly. To reach this goal, it is initially thought of a mechanical switch that detects when the filament fails to move, but although it seems trivial to cases in which the filament breaks or runs out, it is more difficult to detect the correct advance. For this reason, we propose to use a rotation encoder driven by the movement of the filament. The printer should consult repeatedly, while printing, that the encoder is rotating and therefore the filament is going forward. In the event that no progress is detected, the machine will stop and offer the option to download the filament, reload it and continue printing not having to discard the part.

Review of extruder-filament sensors used for current 3D printers

Mechanical sensor

Mechanical sensors have been widely implemented in 3D printers, the majority of them use a mechanical button to stay on while filament is detected could easily detect filament end or breakage to stop the printing. It is possible to find some detection systems using mechanical filament breakage sensors, but this kind of systems does not solve the main problem, which is a filament jam, as the state of the switch would not change.

Load cell sensor

As the extruder feeds the filament to the hot end, the extruder is effectively pushing against the filament causing the extruder to apply extra load on the load cell. Load cells have strain gauges attached that change in electrical resistance when under different loads. This resistance change provides small voltage levels that can be amplified and then read by an analogue to digital converter.[12] Unfortunately, load cell sensor could make it difficult to calibrate without a suitable weighing platform and stand.[13]

Rotary encoder

A rotary encoder, also called a shaft encoder, is an electro-mechanical device that converts the angular position or motion of a shaft or axle to an analog or digital code.[14] There are two main types: absolute and incremental ones. The output of absolute encoders indicates the current position of the shaft, making them angle transducers. The output of incremental encoders provides information about the motion of the shaft, which is typically further processed elsewhere into information such as speed, distance and position. Encoder may have mechanical problems due to the high accuracy that must be taken to fabricate them. Environmental pollution can be a source of interference in optical transmission. They are particularly sensitive to shock and vibration devices, and their operating temperature is limited by the presence of electronic components.

Mechanical encoder

Mechanical encoders have an axis that spins internally activating, thus, different pins depending on the direction of rotation and speed. Although this type of encoder firstly seems easy to use, the resistance of the rotation axis is considerable, and it is not desired to increase the resistance of the filament feed because it could affect the proper operation of the extruder.

Optical encoder

The principle of operation of an optical encoder is based on the so-called photo couplers. These are small chips consisting of a diode as a photo emitter and a transistor which performs the tasks of photoreceptor (see Figure 1). This element is responsible for detecting the presence/absence of light through a concentric axis. It is manufactured with slots that allow the light to go through the disc to obtain the final measure.[15]

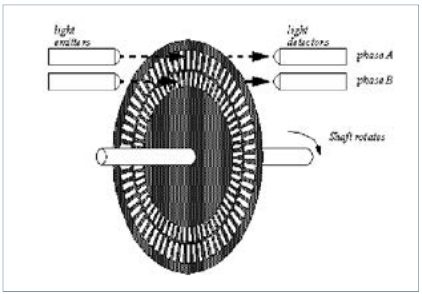

Figure 1. Optical encoder: Principle of operation.

Filament auto-detection system development

Election of the sensor

The Weighted Objectives Method is one of the most common evaluation methods for comparing design concepts based on an overall value per design concept.[16] The biggest disadvantage of using other methods like the Datum method or the Harris profile is that the scores per criterion cannot be aggregated into an overall score of the design alternative. This makes a direct comparison of the design alternatives difficulty. The Weighted Objectives Method does exactly this: it allows the scores of all criteria to be summed up into an overall value per design alternative.

The Weighted Objective Method assigns scores to the degree to which a design alternative satisfies a criterion. However, the criteria used to evaluate the design alternatives might differ in their importance. For example, the cost price can be of less importance than appealing aesthetics. The Weighted Objectives Method involves assigning weights to the different criteria. This allows the decision-maker to take into account the difference in importance between criteria.

The selected criteria and compared in Table 1 are the following:

E1. Filament detection (yes-no)
E2. Detecting the advance of the filament
E3. Not interference with normal movement of the filament
E4. Adaptability of the output signal
E5. Price
E6. Durability

Taking into account the scores (see Table 2), and as expected, the sensor that best meets the specifications is the optical encoder. In this work, an inexpensive bi-directional optical incremental encoder is used.

Hardware assembly

Assembly part design

Once the sensor is chosen, it is necessary to design the part where it will be installed. It must be taken into account that it cannot interfere with the normal function of the machine. To do it, we will employ photogrammetry scanning methodology since it will be possible to do it in a precise way.[17] This method uses reverse engineering thus allowing to reduce the costs of the development.

Sensor	E1	E2	E3	E4	E5	E6	Amount	Compensation	Weight	%
E1	X	0,0	0,0	1,0	0,5	0,5	1,5	2,5	0,167	16,67
E2	1,0	X	0,5	0,5	0,5	0,5	2,5	3,5	0,233	23,33
E3	1,0	0,5	X	1,0	0,5	1,0	3,0	4,0	0,267	26,67
E4	0,0	0,5	0,0	X	0,5	0,0	1,0	2,0	0,133	13,33
E5	0,5	0,5	0,5	0,0	X	0,5	1,5	2,5	0,167	16,67
E6	0,5	0,5	0,0	1,0	0,5	X	2,5	3,5	0,233	23,33
Total							9,5	14,5	0,967	96,67

Table 1. Evaluation of filament detection sensor specifications.

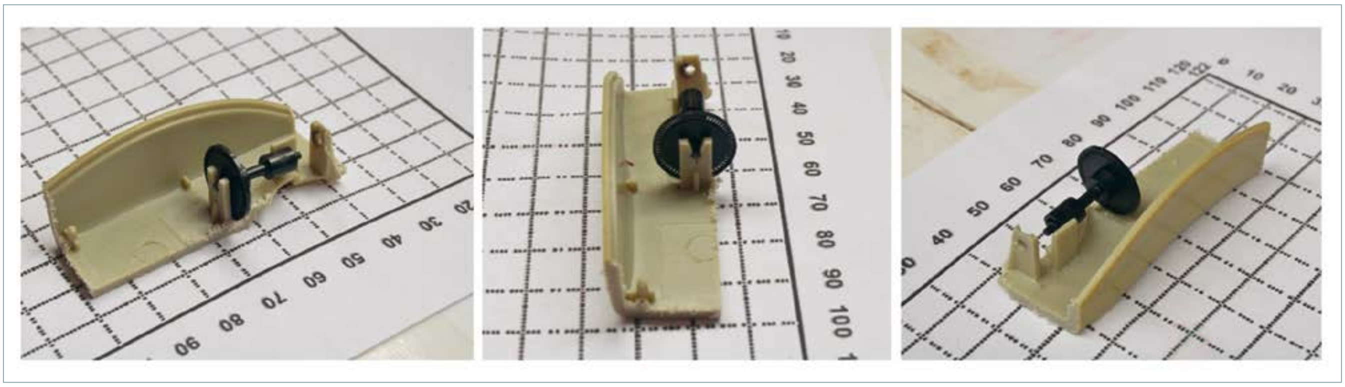

Figure 2. Photogrammetry images.

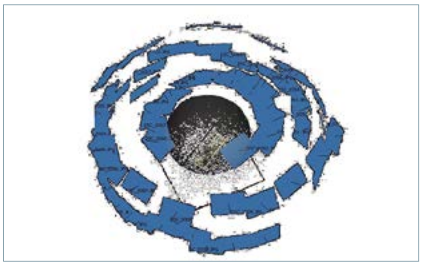

Figure 3. Orientated pictures.

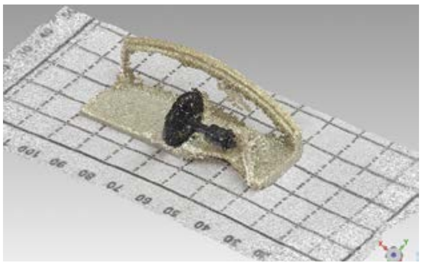

Figure 4. Points cloud of the object.

Sensor 1	Mark	Satisfaction	Final mark
E1	16,67	100%	16,67
E2	23,33	0%	0,00
E3	26,67	100%	26,67
E4	13,33	100%	13,33
E5	16,67	100%	16,67
E6	23,33	75%	17,50
		Total	73,33

Sensor 2	Mark	Satisfaction	Final mark
E1	16,67	100%	16,67
E2	23,33	100%	23,33
E3	26,67	25%	6,67
E4	13,33	75%	10,00
E5	13,33	75%	10,00
E6	16,67	75%	12,50
		Total	79,17

Sensor 3	Mark	Satisfaction	Final mark
E1	16,67	100%	16,67
E2	23,33	100%	23,33
E3	26,67	100%	26,67
E4	13,33	75%	10,00
E5	13,33	75%	10,00
E6	16,67	50%	8,33
		Total	95,00

Table 2. Final marks.

After taking numerous pictures of the object, they are processed using a computer software so that common points are identified on each image. A line of sight (or ray) can be constructed from the camera location to the point on the object. It is the intersection of these rays (triangulation) that/which determines the three-dimensional location of the point.

The result of the process is a digital tridimensional object which can be used as a model to design the rest of the parts. It is interesting to include graphic scales to get the correct dimensions of the digital model. Figure 2 shows a sample of a total of 74 images involved in the process.

The software locates the pictures and shapes a points cloud of the scanned object. The process is showed in Figure 3 and 4, where it is possible to see the pictures completely orientated and the formatted points cloud.

As it is possible to notice in Figure 4, there are some defective parts. This is due to the brightness of the object, so it is necessary to perform a repair of the digital model. Thus, a model as similar to the real as possible can be reached. To achieve this, first of all a filter of the points is performed to remove the noise eliminating points spaced of the set a specified size. After this, different holes are detected. In this case a total of 698 of holes which 670 are closed automatically since have a small size. The remaining 28 holes are manually closed to keep the original form. An automatic reparation of errors is carried out, and finally, we get the digital solid model. Figure 5 shows an image of the process and the final model.

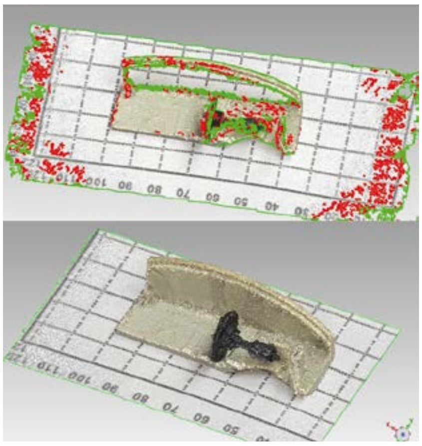

Figure 5. Digital model reparation.

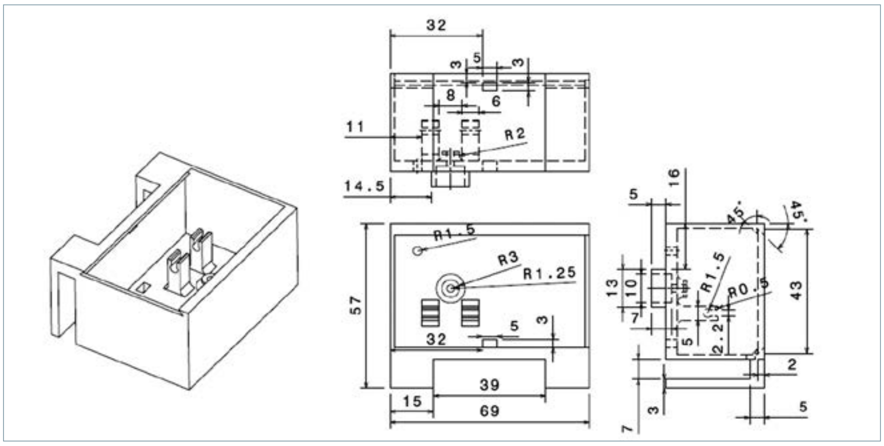

Figure 6. Assembly part dimensions.

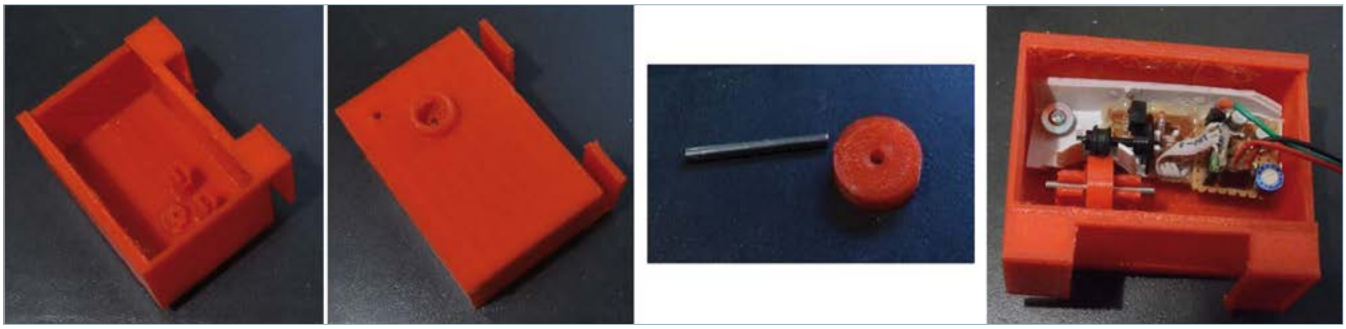

Figure 7. Electronic assembly.

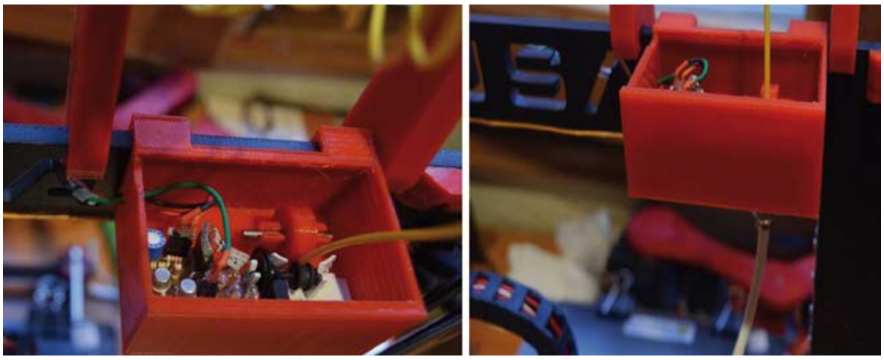

Figure 8. Installation of the system.

Once the three-dimensional solid model is obtained, it is exported to a 3D design program for modeling the part where it will be assembled. In this way, it is possible to avoid design errors to be made too many times to iterate to find the optimal model. In Figures 6 and 7 the dimensions of the modeled part and the real product made with a 3D printer are showed.

System assembly

The whole system is installed on the top of the printer, so that the filament goes through the sensor. The filament is leaded through a Teflon tube to the hot-end, analogously to Bowden system.

After checking that the system does not interfere in the normal function of the machine, it is connected to the main electronic board of the printer (an Arduino Mega board). Figure 8 shows the system installed.

Firmware modifications

Once the system is installed, it is necessary to modify the firmware of the machine, so it is possible to get the sensor signal and act accordingly. Since the encoder works asynchronously, it is necessary to use program interruptions to get the signal correctly. These interruptions will detect whether the filament is moving or is blocked. Moreover, it will be possible to calculate the speed at which the filament is advancing in order to be sure about the quantity of material deposited.

However, after repeated tests, it is observed that the interruptions take place very frequently, which interferes with the operation of the printer. That is why we finally choose for attending interruptions every 5 seconds, regardless when interruptions occurs the rest of the time. After several tests, it is proposed that after 10 seconds it will have produced at least one interrupt of the filament if it is proceeding correctly, and otherwise, 10 seconds without detecting an interruption should be sufficient to stop printing due to an error in filament advancing. A new pause menu is also implemented, since error filament was not previously available.

Once an error in advancing filament is detected, the printer activates the implemented pause mode because of filament error, from which it is possible to load and unload the actual filament to continue printing avoiding to lose the piece.

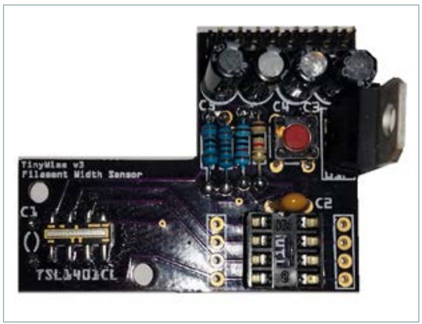

Figure 9. Sensor used.

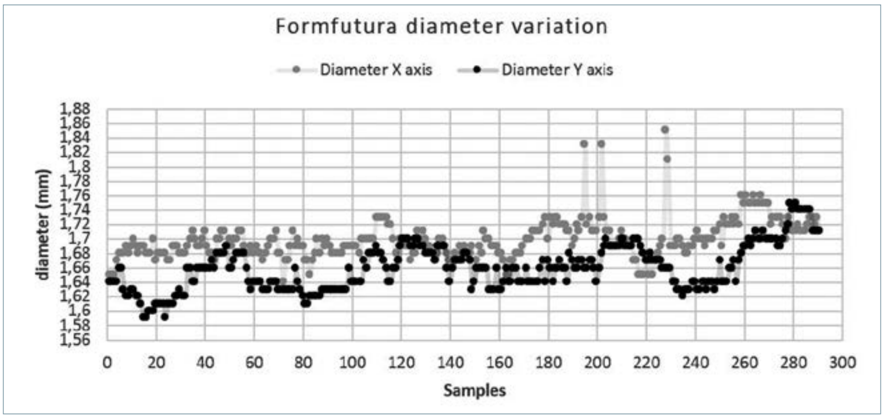

Figure 10. Filament samples: Formfutura.

Results and discussion

Filament defects

Although most of filament producers for 3D machines are constantly developing and improving their products, the manufacturing method has so far prevented achieving a filament with a constant diameter. This excess in diameter is sometimes too much for the machine, causing bad finishing models, jamming of the extruder, or even it could damage the extruder. To check the filament diameter of different producers, 03 meter samples were taken, every centimeter of filament using a sensor with a resolution of 0.01 mm.

The sensor used is shown in Figure 9, and in Figures 10 to 13 the variation of diameter (whose nominal value is 1.75 mm), in X and Y axis.

By analyzing these samples (see Table 3), it is possible to see that the diameter varies from 1.59 mm to 1.85 mm, with an average of 1.68 mm in one case, and from 1.67 mm to 1.8 mm, with an average of 1.75 mm in the other case. Booth filaments may obstruct the printer extruder.

Any of these failures makes that after leaving the printer in operation the piece that was being created is lost and it is necessary to start again. In addition, by continuing printing without really extruded plastic, the machine consumes energy and produces an unnecessary wastage. Due to this reason, the operator must be aware of the machine as long as it is operating, ensuring that the plastic flows without any problem, which is especially difficult when the piece takes several hours to be produced. Moreover, the control of the length of material extruded specially at the perimeters gets an improvement of the surface finish.[18]

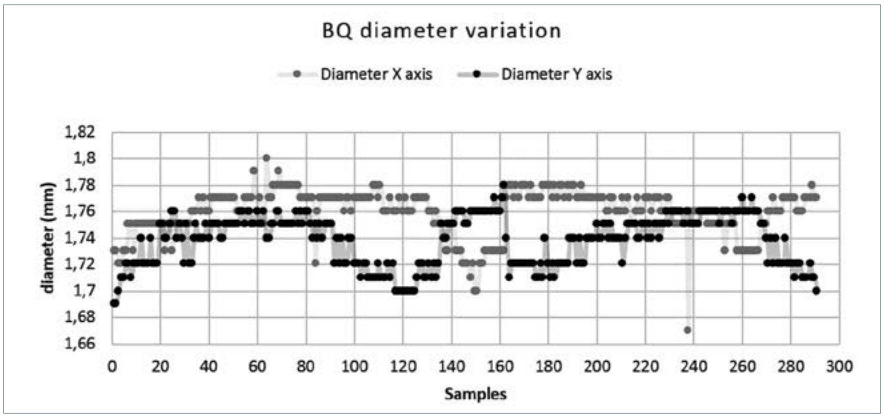

Figure 11. Filament samples: BQ.

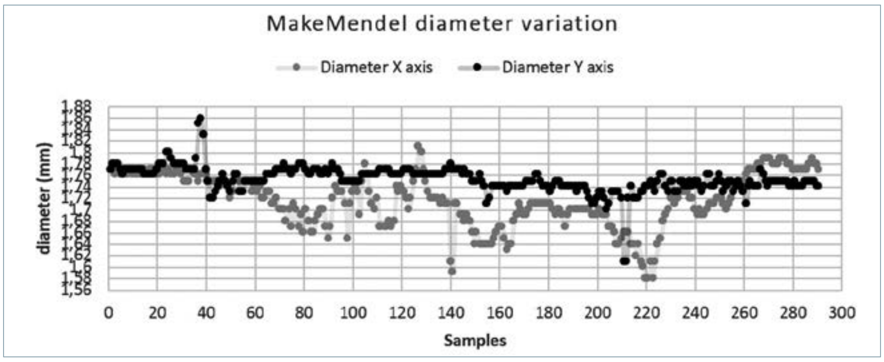

Figure 12. Filament samples: MakeMendel.

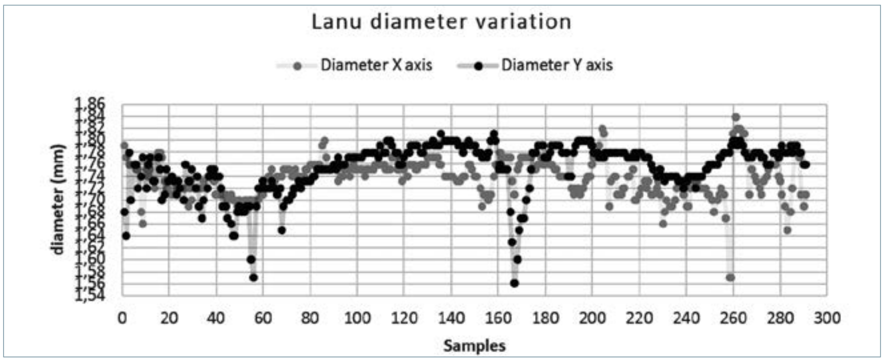

Figure 13. Filament samples: Lanu.

Brand	Maximum (mm)	minimum (mm)	mean (mm)
Formfutura	1,85	1,59	1,68
BQ	1,8	1,67	1,75
Lanu	1,84	1,56	1,75
MakeMendel	1,86	1,58	1,74

Table 3. Maximum, minimum and mean of diameters sampled.

Filament error. Push the button to change the filament.
Extract the filament when the motor stopes.
Insert the new filament and push the button.
When you see come out the filament, press the button to continue printing

Table 4. Error menu.

Figure 14. Model produced with three different filaments.

Evaluation of the implemented system

The installed system does not affect the print quality of the machine. It has been found that the time set for detecting advancing filament problems detects an error in time without producing false positives. In Table 4, the error is displayed on the printer.

In Figure 14 a piece that was printed by the filament is showed ended and continued after detecting another colour is displayed twice.

As it can be seen, the piece was completed without any problem and the adhesion of the three different filaments was correct.

Conclusions

The installed system achieved perfectly detects the advance of the filament without affecting the normal operation of the machine. The final frequency to check the advancing filament (every 5 seconds) allows to detect any problem with it, and there are no errors that can appear if the sensor is checked with a higher frequency. Although it had been raised as a possible option to detect the speed, with the sampling frequency set it is not possible to calculate it, but meets the initial objectives of troubleshooting in advancing filament.

This has made possible the use of the printer with remains coil filament, which were not spent because they were not sufficient to complete an impression. With this system, when the filament finishes, the printer enters into a standby state waiting for the user to introduce a new filament.

Therefore the primary objective of the system is achieved, avoiding loss of material, energy and mechanical wear, keeping the premise of making a low cost product that does not significantly increase the cost of the machine.

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Enrique Soriano Heras
Corresponding author
enrique.soriano@upm.es
Department of Mechanical Engineering, Chemical and Industrial Design. Technical University of Madrid (UPM). Ronda de Valencia, 3. 28012 Madrid, Spain.

Fernando Blaya Haro
Department of Mechanical Engineering, Chemical and Industrial Design. Technical University of Madrid (UPM).

José María de Agustín del Burgo
Department of Mechanical Engineering, Chemical and Industrial Design. Technical University of Madrid (UPM).

Manuel Enrique Islán Marcos
Department of Mechanical Engineering, Chemical and Industrial Design. Technical University of Madrid (UPM).