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Integration of IoT Technology for Assessing the Quality Part of 3D Printed Parts

Teo Wei Hao[1], Omar Mohd Faizan Marwah[1,*]

[1] *Department of Mechanical Engineering Technology, Faculty of Mechanical and Manufacturing, University Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia*

*Corresponding Author: mdfaizan@uthm.edu.my
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Abstract

IR4.0 is getting more and more popular since it change the manufacturing process especially with 3d printing and IoT. In order to achieve good quality in 3D printed part IoT which is a new technology that can be used to monitor the parameter and control the printing process. PLA filament is used in this studies since it is the most common material used in 3D printed but due to its poor quality, it hasn't been widely use in industries.Therefore, a IoT monitoring system is used to ensure the parameter fulfill the setting and the quality and properties (surface roughness, dimension deviation ,tensile stress) has been studies. The main factor that affect these responses is layer height. The optimum parameter for surface roughness is 0.1 in layer height, 220 printing temperature and 40 printing speed, for dimension deviation is 0.2 in layer height, 220 printing temperature and 40 printing speed while tensile stress is 0.3 in layer height, 200 printing temperature and 60 printing speed. Then an optimisation and verification process has been done. The difference between prediction and experiment is below 10% Overall, IoT is a good tool that help to monitor and improve the quality of the 3D printed part.

1. Introduction

The phrase "Internet of Things" which is also shortly well-known as IoT is coined from the two words i.e. the first word is "Internet" and the second word is "Things". [1] The concept of IoT involves extending connectivity beyond traditional electronic devices. In summary, IoT connect the digital and physical world by integrating network capability into other items.[8] This could help the items to be remotely monitored, controlled and interact through Internet. This type of integration can help to increase the important part of a production to ensure the quality of the product.

In the past decades, IR 4.0 has been a growing trend in manufacturing sector, which include the use of IoT and additive manufacturing (AM). AM, or 3D printing (3DP), is a recent paradigm evolution of manufacturing methods. With this innovative method, a digital model or blueprint is used as a guide to carefully build a three-dimensional object layer by layer.

Quality control of the AM parts has gained wide attention from the industries to ensure parts fabricated for functional use satisfy specific requirements, particularly in quality and reliability. [2] One significant concern is the adhesion between layers, as weak bonds or delamination can compromise the structural integrity of printed components. Achieving a smooth surface finish and high resolution is another hurdle, with issues such as layer lines and rough surfaces affecting both aesthetics and functionality. Proper balancing of print speed and cooling is crucial to prevent overheating and warping. Some problems are flaws, uneven mechanical quality because of the limited materials, high prices, and a low number of units made. [3] Material quality and other challenges are due to nozzle clogging, inconsistent extrusion, and material deposition. Determining the optimal print orientation and addressing supports for specific geometries are important in order to having better printing quality of 3D printed part so it can be widely use in industries. Additionally, challenges such as overhangs, bridging, and maintaining dimensional deviation for 3DP part are also common in 3D printing process. These challenges must be investigated through understanding of the technology, meticulous parameter optimization, and ongoing advancements to ensure the successful production of high-quality 3D printed parts.

Therefore, the objective of this research is to develop an IoT system, analyse 3DP machining parameter, and evaluate the optimization process parameter.

Besides that, the accuracy of previous study is not so accurate since the internet connection in previous generation still occur limitation where there is a delay due to network induced. [4] When the abnormal machining parameter has been detected, it will be a delay in response time therefore, the action taken also will be delayed.

In this research, the Response Surface Methodology (RSM) is used to analyse the surface roughness, dimensional deviation and material properties of the 3D printed part which produce using PLA by the integration of IoT in monitoring and controlling the printing parameter and process. The optimal parameter is lastly obtained and monitor again by IoT integration and compare with the experimental data. The experimental data are adapted from previous study that investigate the surface roughness, dimensional deviation and tensile properties of 3D printed part made with different process parameter and with and without the integration of IoT.

2. Methodology

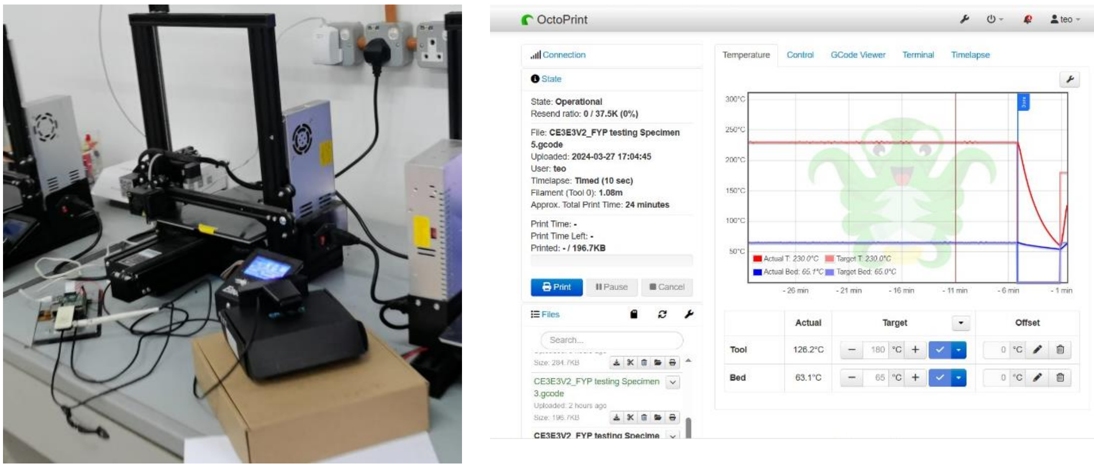
In this research, PLA filament was used for the fabrication of specimen. The test specimen is being fabricated by an FDM 3D printer named Creality Ender 3 which integrated with IoT technology. 15 test specimens were prepared according to the RSM run which generated through MINITAB software for further analysation and optimisation process. These specimens are fabricated by using PLA filament to test the surface roughness, dimension deviation and tensile testing as per ASTMD-638. First of all, the specimen model is designed by using a CAD software which is and then converted into stereolithography (STL) file and generated G-code using slicer program. The testing parameter is then set in the slicer program before G-code was generated. Finally, a verification process is done to verify the predicted optimum parameter.

Table 1 *Printing Parameter*

Variable	Minimum	Maximum
Layer Height	0.1	0.3
Printing Temperature	200	220
Printing Speed	40	60

2.1 IoT system integration printer development

To develop the IoT system in 3DP process by desktop, an important hardware has been chosen for the core of this system which is Raspberry Pi 2.0 microcomputer. This hardware can help to process the data from 3D printer and send it back to desktop monitoring system by WIFI connection. [5]. The IoT also consist of other hardware such as webcam to monitor the condition of the specimen by visual and WIFI adapter for IoT connection between the Raspberry Pi and desktop. Then a micro Secure Digital (SD) card is connected to desktop by adapter to install Octoprint operating system (OS) which is the IoT system used in this research. [6] The SD card which contain installed OS is plug in into the Raspberry Pi for installation process. The IoT monitoring system can be access by WIFI from desktop by inserting the Internet Protocol (IP) address generated from the installation of the OS. Then the G-code can be uploaded through Octoprint for monitoring and fabrication process. [4]. The IoT system can also control the movement, temperature of the printer and start, pause or stop the printing.



(a) (b)

Fig 1 *(a) IoT integration system (b) IoT monitoring system*

2.2 Specimen parameter and preparation

Next, the IoT system is ready for fabrication process by using the test run that generated from Minitab software from data from Table 1. There are many key parameters that affect the quality of the 3DP part including filling density, layer height, nozzle diameter, printing temperature, bed temperature, extrusion speed, printing speed, cooling fan speeds and filling pattern. In this study, only three parameters have been chosen which layer height, printing temperature is and printing speed. This is to study the surface roughness, dimensional deviation and mechanical properties. The experiment run is shown in Table 2. Bed temperature were set at 60°C, infill density 20%, other parameters were default setting in Creality Ender 3 printer.

Table 2 *Experiment run as per Response Surface Methodology*

Run Order	Layer height	Printing Temperature	Printing Speed
1	0.2	200	40
2	0.2	210	50
3	0.2	200	60
4	0.2	220	60
5	0.1	220	50
6	0.1	200	50
7	0.2	220	40
8	0.1	210	60
9	0.3	200	50
10	0.3	220	50
11	0.3	210	40
12	0.3	210	60
13	0.2	210	50
14	0.2	210	50
15	0.1	210	40

All of the specimens were designed by using Solidworks software and then exported into STL file. The slicer program used is CURA slicer which all the parameter in Table 2 are inserted to get the G-code upload to the printer through IoT system. The condition of the printing is being monitor using IoT to ensure that the extrusion condition such as clogging, deposit melt uneven and spaghetti form when printing.

2.3 Quality test

2.3.1 Surface roughness

Before dimension and mechanical properties were being test, surface roughness testing is being conducted by using Mitutoyo SJ-410. The method involves moving the stylus over the surface that is to be measured. Following that, the profile surface's Ra value will be shown on the screen. The work piece's flat and curved surfaces are utilized to measure the Ra value. The average Ra value is then used to analyse the roughness of the surface. All the data is then recorded and key in into Minitab software for analysation and optimisation process.

2.3.2 Dimensional deviation

Dimension of the tested part is being measure using basic measuring tools such as Vernier calliper. Proper setup is necessary before measuring, making sure the instruments are clean and operating at their best. Then, zeroing is important to adjust for any offset that may exist. To acquire an accurate reading while using a Vernier calliper, place the object tightly between the jaws and precisely align the Vernier scale with the main scale. Accuracy is improved by taking multiple measurements at different D points on the part. As part of the documentation process, measurements are methodically recorded, units are specified, and necessary part information is recorded. Multiple measurements are taken by Vernier calliper to guarantee uniformity, and checked against predetermined tolerances which the design drawn by using SolidWorks. In this study, ISO 13385-2:2020 are used for the measurement method of tolerance of the 3D printed part.

2.3.3 Tensile test

The tensile tests were carried out on a 5kN Autograph-AGS universal tester at a fixed loading speed of 5 mm/min at room temperature of 25°C according to the ASTM D638 standard. Test data were recorded and stored. All specimens were tested for each parameter and the dimension of each specimen were measured using a digital Vernier calliper before testing. The data including percentage strain at maximum load, stress at maximum load, elongation at break and maximum force of each specimen were recorded and statistically analysed using Minitab software.

2.4 Optimisation and validation process

The measurement is then obtained from quality analysis part based on the experimental run with three parameters. Analysis of Variance (ANOVA) are used to determine the optimum parameter of FDM on response variable. In the ANOVA, the alternative hypothesis is based on the existence of at least one significant parameter, whereas the null hypothesis states that there is no significant difference among the parameters. It is calculated to get the F-ratio and the corresponding probability value (p-value). The FDM parameter variable has a considerable impact on surface roughness, dimensional deviation, and mechanical properties if the p-value is less than 0.05. For RSM method, mean effect plot has been used to determine the mean and the relationship between parameter and quality analysis and predict response variable. [7] These data are used to find the optimum parameter for lower surface roughness, higher dimension deviation and higher tensile stress the product can achieve. Then the experiment is repeated to validate the quality of the 3DP part from the optimum parameter that analyse by Minitab software.

3. Result and Discussion

This study investigates the use of IoT system monitoring is 3 parameters of 3DP which will affect the quality of the build part. In the literature review, previous study only investigates about the surface roughness, surface roughness combines with dimensional deviation or the mechanical properties alone. Therefore, this study is presented a new type of monitoring system which is IoT to investigate the effect of quality of build part when monitor by IoT system. [8] Studies that used statistical analysis to the current study's only considered surface roughness [9] [10] or dimensional deviation [9]. No studies consider mechanical properties, surface roughness and dimension deviation as a group of analysis factor. Most of the study uses Taguchi for analyse and optimised purpose. Therefore, RSM is used in this study as a statistical analysis tool.

The effect of 3DP parameter and IoT monitoring system on quality of printed part were thoroughly investigate in this study. Direct comparison between the result obtained and previous study will be big differences since the control parameter and dimension of the printed part are different, especially when there is major parameter which brings major impact to the quality is not considered in the studies. Therefore, a similar trend of result is expected when comparing with previous study with different control parameter.

3.1 IoT System Integration

From figure below we can observe there is a fluctuation detected at the setting temperature at the beginning of the printing. This can help us to detect the error of the printing temperature. To ensure that the temperature is printing as setting parameter, we can pause the printing and wait until the temperature is stable before starting the printing process. So, the relationship between response and variable in this study is obtained more accurate. In Figure 2(b), the flatness of the graph indicate that the temperature is controlled accurately in the setting temperature. Besides that, the temperature indicator show that the temperature detected is in 1 decimal place which is more accurate than the 3D printer's indicator which only show the integer temperature.

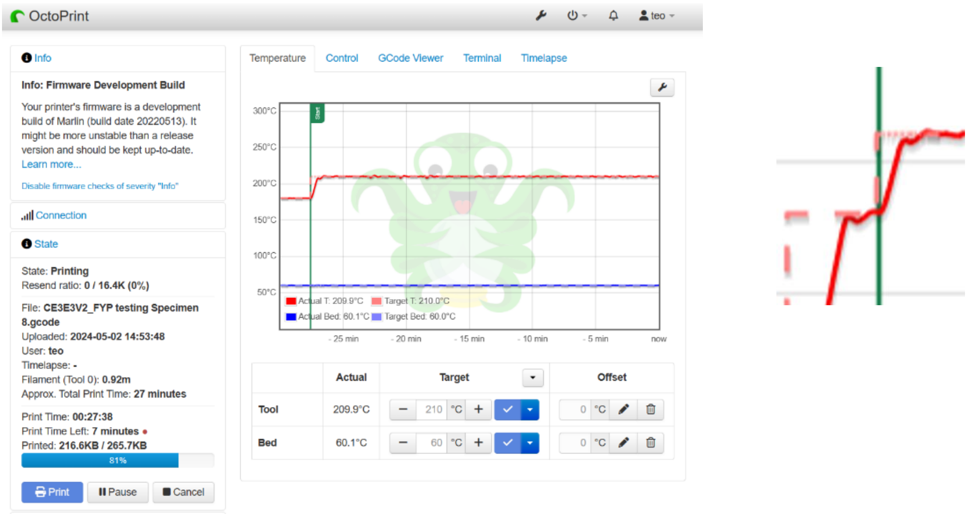


Fig 2 *(a) IoT monitoring system (b) Zoom towards setting parameter*

3.2 Surface Roughness

ANOVA in Figure 3 shows that the significant difference in group mean for interaction between layer height and printing temperature. Since the p-value of the model is smaller than significance value which is 0.05, which shows that there is significant mean difference between parameter and surface roughness. The regression model for surface roughness is presented in Equation 1 and the R-sqr coefficient is 61.32%. Figure 4 shows the main effect plot for surface roughness in (Ra). It was obtained by surface roughness tester. Two measurement for each run is obtained to ensure the precision and consistency of the result. There are significant differences in the value, therefore the value is put into statistical analytic software for further analysis. The measurement can be obtained in Table 3. The Pareto chart in Figure 2 shows the main factor that influence the surface roughness is interaction between layer height and printing temperature, follow by layer height interacting with layer height and finally printing speed. Observation by [9] [10] [11] [12] also state that the surface roughness is related to layer height. While the trend of the mean effect plot of surface roughness in term of parameter is similar to previous study as expected. It shows that the optimum parameter for surface roughness is 0.1 in layer height, 220 printing temperature and 40 printing speed.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.202689	0.022521	0.88	0.592
Linear	3	0.068271	0.022757	0.89	0.507
layer height	1	0.011250	0.011250	0.44	0.536
printing temperature	1	0.020706	0.020706	0.81	0.409
printing speed	1	0.036315	0.036315	1.42	0.287
Square	3	0.040946	0.013649	0.53	0.679
layer height*layer height	1	0.038887	0.038887	1.52	0.272
printing temperature*printing temperature	1	0.002285	0.002285	0.09	0.777
printing speed*printing speed	1	0.002377	0.002377	0.09	0.773
2-Way Interaction	3	0.093472	0.031157	1.22	0.394
layer height*printing temperature	1	0.085264	0.085264	3.33	0.127
layer height*printing speed	1	0.007396	0.007396	0.29	0.614
printing temperature*printing speed	1	0.000812	0.000812	0.03	0.866
Error	5	0.127848	0.025570		
Lack-of-Fit	3	0.085312	0.028437	1.34	0.455
Pure Error	2	0.042536	0.021268		
Total	14	0.330538			

Fig 3 *ANOVA for surface roughness*

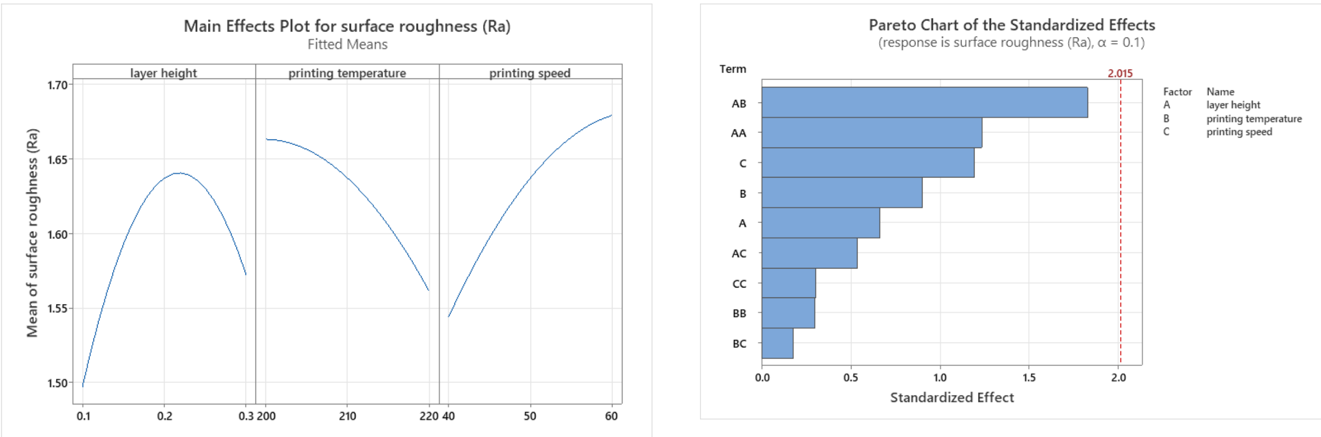


Fig 4*(a) Main effect plot for surface roughness (b) Pareto chart of the standardized effect of surface roughness*

$$
\begin{aligned}
surface\ roughness\ (Ra) = & -16.9 + 33.0\ layer\ height + 0.136\ printing\ temperature \\
& + 0.053\ printing\ speed - 10.26\ layer\ height * layer\ height \\
& - 0.000249\ printing\ temperature * printing\ temperature \\
& - 0.000254\ printing\ speed * printing\ speed \\
& - 0.1460\ layer\ height * printing\ temperature + 0.0430\ layer\ height * printing\ speed \\
& - 0.000143\ printing\ temperature * printing\ speed
\end{aligned} \tag{1}
$$

Table 3. *Parameter with overall experiment measurement*

Run Order	Layer height	Printing Temperature	Printing Speed	Surface roughness (Ra)	Dimension Deviation	Tensile Stress
1	0.2	200	40	1.520	0.150	13.3246
2	0.2	210	50	1.711	0.240	14.5458
3	0.2	200	60	1.819	0.303	13.4072
4	0.2	220	60	1.625	0.203	13.3164
5	0.1	220	50	1.670	0.296	9.8711
6	0.1	200	50	1.416	0.450	10.3288
7	0.2	220	40	1.383	0.200	11.8838
8	0.1	210	60	1.357	0.453	10.2371
9	0.3	200	50	1.641	0.303	14.8327
10	0.3	220	50	1.311	0.250	13.7463
11	0.3	210	40	1.575	0.256	13.2139
12	0.3	210	60	1.660	0.253	14.1146
13	0.2	210	50	1.731	0.303	12.4090
14	0.2	210	50	1.469	0.303	12.5655
15	0.1	210	40	1.444	0.500	10.2632

3.3 Dimensional deviation

ANOVA in Figure 5 shows that the significant difference in group mean for layer height and interaction between layer height. Since the p-value of the model is smaller than significance value which is 0.05, which shows that there is significant mean difference between parameter and dimensional deviation. The regression model for dimension deviation is presented in Equation 2 and the R-sqr coefficient is 86.30%. Figure 6 shows the main effect plot for dimension deviation (mm). It was obtained by Vernier Calliper. Length, width, and height of the specimen is measured for each run to ensure the precision and consistency of the result. There are significant differences in the value, therefore the value is put into statistical analytic software for further analysis. The measurement can be obtained in Table 3. The Pareto chart in Figure 6(b) shows the main factor that influence the dimension deviation is layer height, interaction between layer heights and follow by interaction between printing temperatures. This is because smaller layer height will cause the specimen to be printed in lower amount in one extrude therefore the PLA will cool so fast where it doesn't have enough time to move to its right position the while higher layer height will extruder large amount of filament and it will not be cool down fast enough for the specimen to be in dimension so there is a dimension deviation. Observation by [8] [11] [12] also state that the dimension deviation is related to layer height. While the trend of the mean effect plot of dimension deviation in term of parameter is similar to previous study as expected. It shows that the optimum parameter for dimension deviation is 0.2 in layer height, 220 printing temperature and 40 printing speed.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.119117	0.013235	3.50	0.091
Linear	3	0.060382	0.020127	5.32	0.051
layer height	1	0.050721	0.050721	13.41	0.015
printing temperature	1	0.008256	0.008256	2.18	0.200
printing speed	1	0.001405	0.001405	0.37	0.569
Square	3	0.050076	0.016692	4.41	0.072
layer height*layer height	1	0.034831	0.034831	9.21	0.029
printing temperature*printing temperature	1	0.010917	0.010917	2.89	0.150
printing speed*printing speed	1	0.000685	0.000685	0.18	0.688
2-Way Interaction	3	0.008659	0.002886	0.76	0.561
layer height*printing temperature	1	0.002550	0.002550	0.67	0.449
layer height*printing speed	1	0.000484	0.000484	0.13	0.735
printing temperature*printing speed	1	0.005625	0.005625	1.49	0.277
Error	5	0.018907	0.003781		
Lack-of-Fit	3	0.016261	0.005420	4.10	0.202
Pure Error	2	0.002646	0.001323		
Total	14	0.138024			

Fig 5 *ANOVA for dimension deviation*

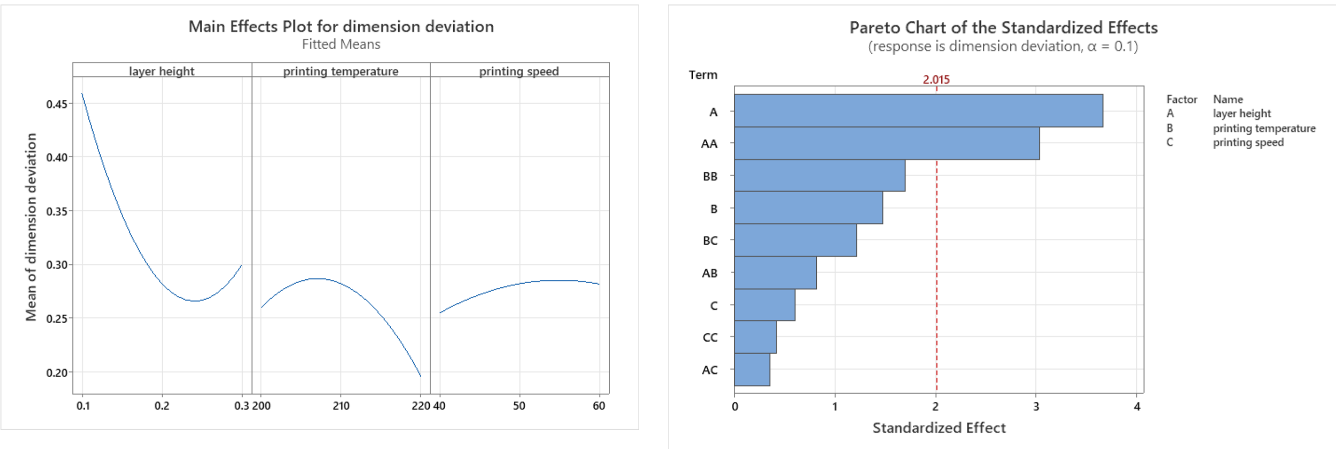


Fig 6 *(a) Mean effect plot for dimension deviation (b) Pareto chart of the standardized effect of dimension deviation*

$$\begin{aligned} dimension\ deviation =\ &-25.6 - 10.53\ layer\ height + 0.239\ printing\ temperature \\ &+ 0.0915\ printing\ speed + 9.71\ layer\ height * layer\ height \\ &- 0.000544\ printing\ temperature * printing\ temperature \\ &- 0.000136\ printing\ speed * printing\ speed + 0.0252\ layer\ height * printing\ temperature \\ &+ 0.0110\ layer\ height * printing\ speed - 0.000375\ printing\ temperature * printing\ speed \end{aligned} \quad (2)$$

3.4 Tensile Stress

ANOVA in Figure 7 shows that the significant difference in group mean for layer height and interaction between layer height. Since the p-value of the model is smaller than significance value which is 0.05, which shows that there is significant mean difference between parameter and tensile stress. The regression model for tensile stress is presented in Equation 3 and the R-sqr coefficient is 91.73%. Figure 8 shows the main effect plot for tensile stress (N/mm). It was obtained by 5kN Autograph-AGS universal tester. Maximum stress of the specimen is measured for each run. The value is put into statistical analytic software for further analysis. The measurement can be obtained in Table 3. The Pareto chart in Figure 4 shows the main factor that influence the tensile stress is layer height, interaction between layer heights and follow by printing temperature. This is because higher layer height will cause the specimen to be printed in less times in terms of layer. This can reduce the number of bonding needed between layer therefore the printed part is more rigid and strong. Observation by [13] [14] [15] also state that the tensile stress is related to layer height. While the trend of the mean effect plot of tensile stress in term of parameter is similar to previous study as expected. It shows that the optimum parameter for tensile stress is 0.3 in layer height, 200 printing temperature and 60 printing speed.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	35.3974	3.9330	6.17	0.030
Linear	3	30.8041	10.2680	16.10	0.005
layer height	1	28.9077	28.9077	45.32	0.001
printing temperature	1	1.1825	1.1825	1.85	0.231
printing speed	1	0.7139	0.7139	1.12	0.339
Square	3	3.8242	1.2747	2.00	0.233
layer height*layer height	1	3.7090	3.7090	5.81	0.061
printing temperature*printing temperature	1	0.0020	0.0020	0.00	0.957
printing speed*printing speed	1	0.1691	0.1691	0.27	0.629
2-Way Interaction	3	0.7692	0.2564	0.40	0.758
layer height*printing temperature	1	0.0988	0.0988	0.15	0.710
layer height*printing speed	1	0.2147	0.2147	0.34	0.587
printing temperature*printing speed	1	0.4556	0.4556	0.71	0.437
Error	5	3.1893	0.6379		
Lack-of-Fit	3	0.3520	0.1173	0.08	0.963
Pure Error	2	2.8373	1.4187		
Total	14	38.5867			

Fig 7 *ANOVA for tensile stress*

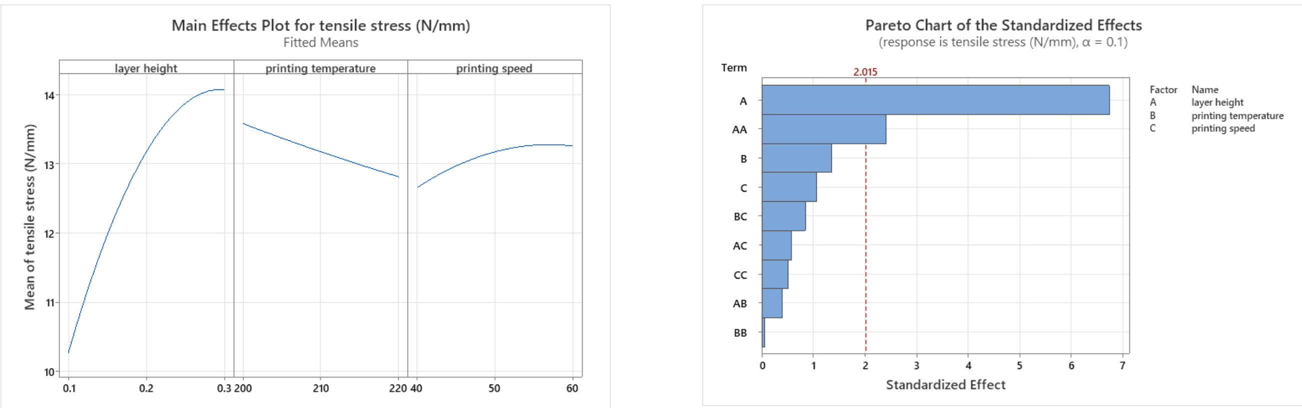


Fig 8 *(a) Mean effect plot for Tensile stress (b) Pareto chart of the standardized effect of Tensile Stress*

3.5 Optimise process

The objective response is shows as table 4 where are the optimized parameter which is being inserted into the IoT system is shown is Table 5. From table 6 we know that the difference between the experiment and prediction is below 10 percent. This is due to other factor that will also affect the response of the experiment result such as bed temperature, purity of filament and size of specimen.

$$\begin{aligned} tensile\ stress\ (N/mm) &= 48 + 80.5\ layer\ height - 0.27\ printing\ temperature \\ &- 0.511\ printing\ speed - 100.2\ layer\ height * layer\ height \\ &+ 0.00024\ printing\ temperature * printing\ temperature \\ &- 0.00214\ printing\ speed * printing\ speed - 0.157\ layer\ height * printing\ temperature \\ &+ 0.232\ layer\ height * printing\ speed + 0.00337\ printing\ temperature * printing\ speed \end{aligned} \quad (3)$$

Table 4. ***Objective Response***

Response	Goal	Lower	Target	Upper	Weight	Importance
Tensile stress	Maximum	9.87107	14.8327		1	1
Dimension deviation	Minimum		0.15	0.5	1	1
Surface roughness	Minimum		1.311	1.819	1	1

Table 5. ***Optimized parameter***

Variable	Setting
Layer Height	0.3
Printing Temperature	220
Printing speed	60

Table 6 *Prediction and result*

Response	Fit	Se Fit	Experiment result	Difference
Tensile stress	14.208	0.944	15.223	7.14%
Dimension deviation	0.2114	0.0727	0.2311	9.32%
Surface roughness	1.421	0.189	1.5433	8.61%

4. Conclusion

In this study, specimens are printed in PLA with the integration of IoT system. Different parameter has been set and monitor by the system including layer height, printing temperature and printing speed. The main conclusion in this study is as follow:

IoT integration system is develop successfully by desktop. The system can monitor the temperature, extrude speed, printing speed. It can also control the movement of the 3DP

Surface roughness (Ra) values between1.444 and 1.819 are obtained the lower the layer height, the lower the surface roughness. The surface roughness obtain are lower than previous study which indicates that with the help of IoT monitoring system, the surface roughness of 3dp part can be improve.

Dimensional deviation obtained 0.15 to 0.50. The study shows that 0.2-layer height is the optimum parameter for dimension deviation which indicates that lower layer height better dimension deviation only fulfils in certain printing condition.

Tensile stress values lie between 9.8711 and 14.8327. This study shows that the higher the layer height the stronger the 3dp part. The value obtained are different than previous study due to different design dimension.

According to multi-objective optimisation, high layer height, high temperature and high printing speed is the optimum parameter for this study. The difference between experiment and predicted responses are lower than 10 percent which is acceptable.

This present work indicates the help of IoT in 3dp is important to increase the quality of the 3dp part. The response value also indicates that different ways of experiment and design specification lead to different result but the trend of the graph is similar.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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