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Comparative research of 3D printer main control parameters and characteristics utilising Klipper firmware

Abstract. 3D printing is replacing traditional machine design methods, providing manufacturers with flexibility, ease of operation, and the ability to adjust process parameters in real-time. This study focused on determining the print speed to produce high-quality models in two scenarios: without Klipper firmware and using Klipper firmware for control parameters during printing. The 3D printer used in study used a Creality Ender 3 V3 SE printer with two sample 3D models. The authors conducted the testing process with three presets of print speed: medium speed, above-average speed, and maximum possible speed (maximum print speed 345 mm/s; above-average speed 180 mm/s; average 150 mm/s). As a result of the study, it was found that the most critical problem is that the stepper motor only sometimes has time to move the table by the required number of steps. The standard acceleration values were set at the level the original equipment manufacturer recommended, and the optimal printing speed was up to 120 mm/s. During the experiments, the standard acceleration values were increased, which showed positive changes and led to better print quality and stability of this process. It has been determined that it is best to keep the default settings and settings in the case of a standard (ready-to-pack) printer, as the printer will not be able to print faster due to its hardware limitations. In contrast, special hardware firmware can help dynamically adjust print parameters while maintaining maximum quality and optimising job performance. The study results can be used in industrial production to optimise 3D printing processes, improve product quality, and reduce manufacturing costs

Keywords: printing technologies; embedded systems; automated systems; iterative system evaluation; control systems

INTRODUCTION

Modern 3D printers increasingly rely on advanced hardware and firmware solutions to enhance performance and expand functionality. Contemporary hardware-software solutions offer a distributed architecture, high-speed command processing, and fine-tuned parameter adjustment capabilities in real time. These features enable precise motion control, higher printing speeds, and a reduction in the likelihood of defects, making them highly advantageous for various applications. Comparative analysis of such systems with traditional approaches is essential to identify optimal configurations for specific usage scenarios. This contributes to advancing 3D printing technology across industrial, scientific, educational, and other fields, ensuring more efficient and reliable printing processes.

Scientific study concerning 3D printers' print quality and speed is crucial, as it can significantly improve printer

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efficiency. H. Hemminger *et al.* (2022) emphasised the importance of effective system design for low-cost 3D printers, highlighting how stability, speed, and precision influence the printing process's output quality. The researchers examined key factors, including firmware, as essential components to enhance both speed and quality. Similarly, P. Geng *et al.* (2019) studied the effects of extrusion and printing speed on the stability of PEEK filaments. Their findings demonstrated that optimal parameter tuning significantly improves process consistency and output precision.

C. Arnold *et al.* (2019) explored strategies to achieve high accuracy and smooth surface quality in 3D-printed models, even when printing at elevated speeds. Their work provided insights into how specific adjustments to process parameters impact overall model quality. Expanding on this theme, A. Jandyal *et al.* (2022) presented a broader perspective, detailing the integration of 3D printing into Industry 4.0 frameworks. Their review highlighted sustainable practices and advanced technologies such as IoT and AI, showcasing their transformative potential for industrial applications.

Technical innovations in high-speed 3D printing, particularly with Fused Filament Fabrication (FFF) systems, have also been a focus of researchers. A.S. Suiker (2022) investigated the influence of small-scale parameters like raster angle and infill density, aiming to mitigate errors and enhance reliability in low-cost printers. Their work served as a foundation for improving mechanical properties and optimising speed. Similarly, R. Afshar *et al.* (2023) conducted a detailed analysis of the mechanical properties of PLA, utilising nonlinear modelling methods to determine the optimal infill density for maximising strength and minimising material usage.

Material optimisation remains another critical area of study. For example, M. Pivar *et al.* (2021) examined shape transformation capabilities in 3D-printed structures, emphasising the relationship between printing parameters and structural adaptability. Ş. Stănciulescu *et al.* (2015) addressed the issues of requirements to modify and adjust the open source firmware for embedded devices. In another study, M.R. Khosravani & T. Reinicke (2020) analysed the impact of raster orientation and printing speed on the strength of 3D-printed components, underscoring the importance of parameter optimisation for load-bearing applications.

Lastly, the exploration of material-specific settings has advanced 3D printing processes. J. Kentzer *et al.* (2011) focused on PLA, while others, like A. Jandyal *et al.* (2022), investigated nylon and composite materials, providing insights into durability and structural efficiency. R. Zucca *et al.* (2019) presented a case of modifying and adjusting 3D printer during set-up phase to fit a specific printing task. Collectively, these studies demonstrate that optimising parameters, material selection, and leveraging technological advancements are central to pushing the boundaries of 3D printing capabilities.

The research aimed to run an experiment using two identical printers, but one of them had been improved with the Creality Sonic Pad, which uses Klipper firmware to improve the processing of motor steps.

The tasks of the research included:

1. Analysing and comparing key parameters of 3D printers, such as printing accuracy, process stability, and job speed, focusing on their dependence on printing velocity.

2. Assessing the economic feasibility of upgrading printer firmware or implementing other modernisation measures by evaluating whether the potential improvements in printer performance justify the investment.

MATERIALS AND METHODS

This research was conducted in May 2024 at the research lab of the Department of Information Technologies, National University of Life and Environmental Sciences of Ukraine. Within the scope of the study, the printing speed of a conventional 3D printer and a printer with Klipper had been compared. Considering their technical features, the two printing options were carried out on the same printers. The main difference between the two printers was using the second printer of an additional controller called the Creality Sonic Pad, on which the Klipper is installed. In the course of the work, Creality Ender 3 V3 SE printers (Shenzhen Creality 3D Technology Co., Ltd., China) were used, which did not differ from each other, except for an additionally installed tablet with Klipper firmware (Fig. 1). It should be noted that the replacement of components that could affect their further operation was not carried out.

a)

b) c)

Figure 1. 3D Printing equipment and materials
Note: a – Ender 3 V3 SE printer, b – Creality Sonic pad, c – sample yellow PLA material
Source: authors' photos

Critical to achieving high print quality was that the Ender 3 V3 SE has a sturdy aluminum frame that ensures high stability and accuracy when printing. The printer was designed to minimise vibrations, which was very convenient due to partial assembly before delivery; the setup process was greatly simplified, which lowered the entry threshold for different categories of users of this equipment.

The print area range of the Ender 3 V3 SE was quite wide and is 220×220×250 mm, which allowed one to create relatively large models without the need to divide them into parts. The heating platform of the device, which distributes heat quickly and evenly, allowed one to work with a wide range of different materials, such as PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), TPU (thermoplastic polyurethane), and others. This provided flexibility in the choice of materials and expanded the possibilities of using this printer. Note that the Bowden-type filament feeding system provides accurate and stable material feeding, which was essential for achieving high print quality even at high speeds. The use of high-precision threaded screws contributes to the accuracy of axis movement, which had a positive effect on the detail of printed models. The desktop of the Ender 3 V3 SE printer had a special coating that improves the adhesion of the first layer and makes it easier to remove finished models. This reduced the risk of deformation and damage to finished models when removed. An optional 32-bit control board provides smooth and precise control over the printing process, which was critical to achieving consistent, high-quality results. The equipment was equipped with an LCD (liquid-crystal display), which made it easy to adjust printing parameters and monitor the process. The detailed research hardware and set-up information is provided in Table 1.

Table 1. 3D printer characteristics and sample print model data

Type	Parameters	Description
Creality Sonic Pad	7’ sensor display 1024x600 pixel res. ARM Cortex-A7 1.2 GHz.	USB, Wi-Fi та Ethernet G-code and STL – file support
Ender 3 V3 SE	220×220×250 mm. (printing range) 32-bit module	PLA, ABS, TPU – materials support
Klipper	Open source firmware Raspberry Pi	OctoPrint support
3D models	Calibration Cube 3D Benchy Model	3 axes calibration cube Complex 3D model of a ship

Source: developed by the authors

In the study, the Creality Sonic Pad were used, a high-tech accessory for 3D printers aimed at improving the control and optimisation of the printing process. It should be noted that the device was equipped with a 7-inch touchscreen with a resolution of 1024×600, which provides an intuitive interface for easy setup and monitoring of printing by users. The Sonic Pad supports USB, Wi-Fi, and Ethernet connectivity, providing a wide range of options for data transfer. This allowed users to easily upload files for printing directly from their computer or other devices. The device was compatible with G-code and STL file formats, allowing for the flexibility to use various 3D printing software.

An important characteristic of the Creality Sonic Pad was its ability to upgrade firmware, allowing users to integrate new features and improvements easily. This made the printer more adaptable to new technologies and user needs. The 1.2GHz ARM Cortex-A7 processor ensured fast data processing and stable operation even when printing complex models. The Sonic Pad also supported model previews and real-time tracking of print progress. Which in turn allowed the authors to control the printing process during the study and make the necessary adjustments promptly. In addition, the device has built-in capabilities for automatic platform calibration, which reduces setup time and increases print accuracy. Figure 2 and Table 2 outline the 3D model and printing details.

For comparison, the filament from the manufacturer Fainyi was selected with a type of plastic for printing – standard PLA. Such standard plastic required an operating temperature of 215-240 degrees at the nozzle outlet and a table heating temperature of 50-60. The following parameters were used during the work: nozzle temperature – 225°C and table heating temperature – 60°C. The recommended printing speed by the manufacturer of this equipment was 40-90 mm/s; these speeds result in sufficient print quality.

To conduct experimental research, a popular 3D model of the Benchy boat was picked, which had the necessary complexity and detail and contained a sufficient number of complex elements to check the print quality. This 3D model is often used as a base model for testing print quality. The basic and experimental printers needed a .gcode file that had been created using a slicer to print. For this, Creality Print, a slicer from the printer manufacturer, was used. During the experimental work, the following basic settings of the slicer were chosen: layer height of 0.20 mm, number of wall lines – 2, number of layers of the bottom and lid of 4, and Occupancy – 15%.

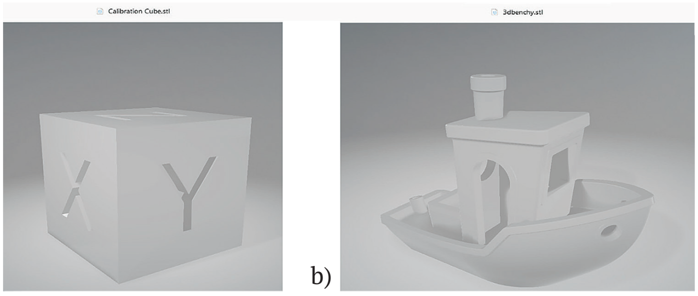


Figure 2. 3D print models
Note: a – calibration cube, b – sample research print 3D model
Source: developed by the authors

Table 2. Printing data

Components/Stage	Parameters	Description
3D printer filament *default*	PLA (Fainyi)	215 – 250C Nozzle output temperature 50-60C Print Bed temperature
3D printer filament *research set-up*	PLA (Fainyi)	225C Nozzle output temperature 60C Print Bed temperature
Printing Speed *recommended*		40-90 mm/s for optimal 3d printing model quality
3D models	3D Ship model (Fig. 2)	Designed in Benchy
3d printer slicer	1. printing tasks 2. ball height 3. number of wall lines 4. number of layers of the bottom and lid 5. occupancy	1. gcode code 2. 0.2 mm 3. 2 4. 4 5. 15%

Source: developed by the authors

In the study, Klipper, a powerful and flexible software for managing 3D printers, was used; it was necessary to improve the productivity and quality of printing. Such was an open-source firmware that leverages the computing capabilities of both the printer itself and an additional computer, usually with a single plateau such as a Raspberry Pi. The primary purpose of using the optional Klipper software was to streamline the printing process by reducing delays and improving motion control accuracy. During the work, Klipper ensured efficient task distribution: the basic calculations related to motion planning and command processing were performed on an additional computer. At the same time, the printer's microcontroller was used only for low-level tasks. This approach allowed us to achieve smoother and more precise motion control, which was especially useful when printing complex or high-speed models. With efficient motion planning and minimised latency, Klipper has made it possible to significantly improve print speeds without sacrificing quality. It was found that more precise control of the movement of the extruder and axes provides better positioning and detail of the printed models during the work.

RESULTS AND DISCUSSION

It has been found that during the operation phase, Klipper supported a wide range of functions, including the ability to control several extruders, which made it possible to print simultaneously from several materials and colors when performing work. Various printing settings, including acceleration, speed, and other characteristics, could be easily adjusted, which helped achieve optimal research results. Compatibility with popular 3D printer management software, such as OctoPrint, provided a user-friendly web interface for monitoring and managing the printing process.

As a result of the research, the equipment was utilised to its full capacity, including software and performance characteristics. After identifying the main features of different printers, it was possible to proceed to a practical comparison and test two different technologies (Klipper and standard firmware). During the work, the print quality was compared on two printers with the same technical component, but one was equipped with an additional device that should improve printing at high speeds. Therefore, during the study, the authors planned to study what speed indicators guarantee the printing quality and compare the work of two printers: the basic configuration and the improved version with Klipper retrofitting.

During the experiment, it the initial print speed settings were based on the previous experience and research reports. For the initial testing the default print speed had been set up, as expected the output model had been in high quality (Table 3). One of the research questions was to evaluate at what speed there would be a noticeable deterioration in print quality and how much worse the quality would be when using a basic printer. Accordingly, during the experiment, the following settings for the print speed in mm/s were set (Table 4).

Table 3. Print iterations velocity data

Iteration number	Perimeters, mm/s			Filling, mm/s			Bridge, mm/s	Fill-in gaps, mm/s	Press, mm/s	First layer speed, mm/s
	normal	small	external	normal	solid	top solid				
1	70	50	60	90	40	70	25	30	150	30
2	80	60	70	100	50	80	25	30	150	30
3	10	90	90	120	70	100	25	120	150	30

Source: developed by the authors

Table 4. First print iteration speed parameters (average speed)

Setting	Print speed	Top/Bottom layer speed	First layer movement speed	Acceleration of the top/bottom layer	Speeding up the printing of the first layer
Value	150 mm/s	75 mm/s	33 mm/s	2500 mm/s^2	500 mm/s^2

Source: developed by the authors

It should be noted that the other research models had already been printed using these printer settings, and the output print quality had been sufficient. There was no need to interfere with the print acceleration setting, and the print time on both printers was 1 hour and 28 minutes. The print output model is highlighted in Figure 3. The next phase of the research was to significantly increase the printing speed and adjust the acceleration parameters (Table 5).

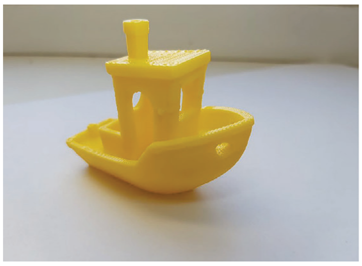
a)  b) 

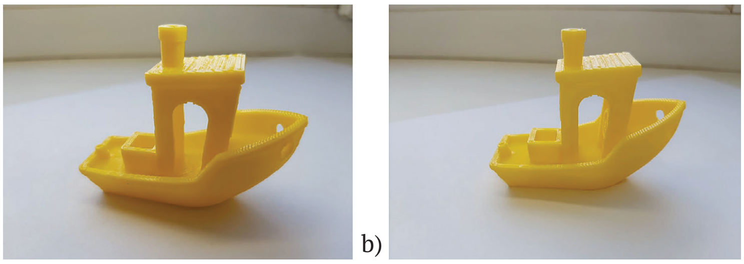
Figure 3. Ship model result during the first iteration
Note: a – without using Klipper, b – with using Klipper
Source: developed by the authors

Table 5. Second print iteration speed parameters (higher speed)

Setting	Print speed	Top/Bottom layer speed	First layer movement speed	Acceleration of the top/bottom layer	Speeding up the printing of the first layer
Value	300 mm/s	250 mm/s	16.67 mm/s	3500 mm/s^2	1500 mm/s^2

Source: developed by the authors

There were no particular differences in print quality; both models had sufficient quality. With the increase in print speed and acceleration, the quality of both printers did not deteriorate, but certain work features were revealed. At this stage, there was already a noticeable difference in printing time between the two printers. A standard printer printed a part in 1 hour and 13 minutes, and a printer with a clipper in 51 minutes and 33 seconds. This result was unexpected and required determining its reason because the slicer displayed the approximate printing time as 48 minutes. Based on previous experience, the printing time using firmware was always less than the standard settings printing time by 3-5 minutes, which fits into the printing time of a printer with a clipper but is significantly different from a regular printer (Fig. 4). This could happen due to the insufficient processing power of a conventional printer, which does not have time to process each next step for a stepper motor. Accordingly, it led to the conclusion that the printer had certain architectural limitations that did not allow it to print at higher speed. The printer's printing speed with the Clipper was unexpected during the second attempt. It was clear, based on the printing process, that printing new layers becomes complex layers. The printer operated at a much higher volume than under normal conditions prior. At the same time, it should be noted that despite the mentioned issues, the printer continued its process, and the print speed was still significantly ahead of the competitor's. The main point of this experiment was to reduce the actual printing time. The goal was to reduce the printing time to at least 40 minutes. However, achieving such a goal took a great deal of effort. As a result, the final print time was reduced to 42 minutes. In order to achieve and maintain the speed, the layers' movement speed had been significantly increased. The printing time of the model was 1:13 on a regular printer, which was the limit for this printer, and 46:24 on a printer with a clipper.



a) b)

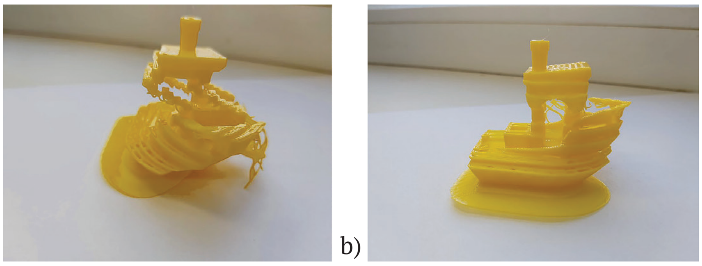
Figure 4. Ship model result on higher print speed
Note: a – without using Klipper, b – with using Klipper
Source: developed by the authors

Table 6. Third print iteration speed parameters (maximum speed)

Setting	Print speed	Top/bottom layer speed	First layer movement speed	Acceleration of the top/bottom layer	Speeding up the printing of the first layer
Value	345 mm/s	350 mm/s	45 mm/s	5000 mm/s^2	4000 mm/s^2

Source: developed by the authors

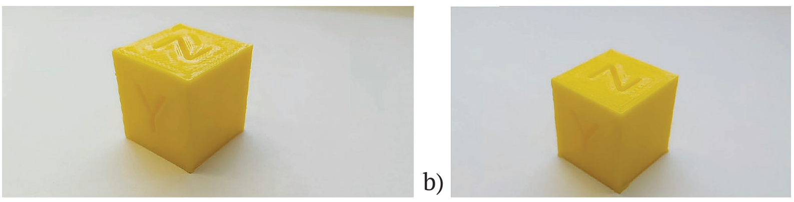
The numerical results showcased in the data table appear good (better than before); however, the original objective of the study was to evaluate the output model quality, which in this case could have been better (Fig. 5). The resulting model was of poor quality. It was now a minor flaw – the model of such quality can be used in practice under any application. It can only be used to highlight the results of scientific research. It was determined that the main reason for poor output quality was due to the printer engine. The engine did not have enough time to move the pin, and due to this fact, the engine skipped several preliminary steps altogether.



a) b)

Figure 5. Ship model result during third speed-test iteration
Note: a – first try, b – third try, both using Klipper
Source: developed by the authors

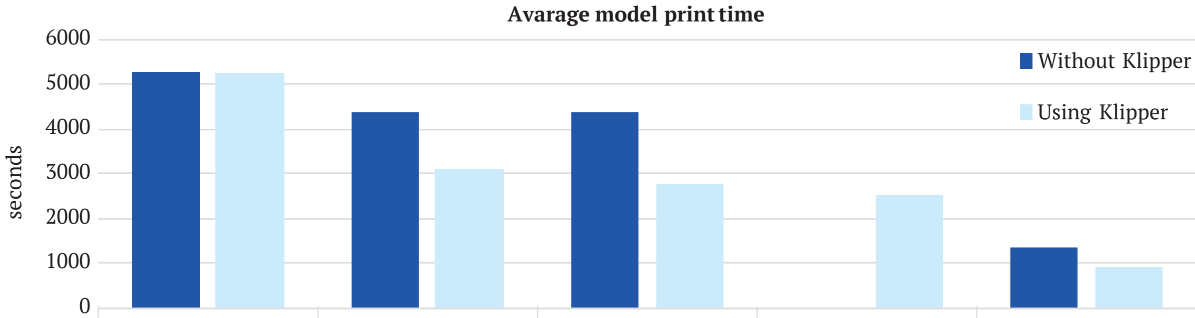
The next step of the research was to print the XYZ calibration cube (Fig. 6). It was decided to keep the print settings the same and determine if the printer could handle the model quality at high printing speed. The projected printing time was 14 minutes, but the printer with the Clipper coped with it in 15 minutes, and the regular printer in 23 minutes and 1 second. Surprisingly, judging by the print quality alone, a default settings printer had output a lower quality model than the Clipper. The model can be determined to be quite simple in terms of geometrical details and has few complex elements. At the same time, the printer with the Clipper produced a high-quality model, as it showed with more complex models in previous research iterations.



a) b)

Figure 6. XYZ calibration cube printing at highest speed
Note: a – without using Klipper, b – with using Klipper
Source: developed by the authors

After conducting a series of experimental studies and comparing the main parameters and characteristics of a conventional 3D printer and a printer retrofitted with Klipper, increasing printing speeds, it was found that the print quality is independent of the use of standard printer firmware or Klipper. In most cases, the study experiments had determined that in case when the equipment and its software parameters are set correctly, temperature and speed, acceleration values are selected correctly, the print quality does not change critically (not significantly) with an increase in print speed (Fig. 7). In some cases, degradation of the output printing model was detected. It should be noted that the changes were insignificant. However, if the parameters are set-up beyond the recommended print speeds, it could be stated that a printer with standard firmware does not have time to process the required steps for stepper motors and does not print faster, even if this was programmed in the slicer settings.



	Iteration 1	Iteration 2	Iteration 3	Max. speed (Fig. 5a)	XYZ cube (max. speed)
Without Klipper	5280	4380	4380		1381
Using Klipper	5280	3093	2784	2520	900

Figure 7. Iterations speed comparison charts – without and using Klipper firmware
Source: developed by the authors

The pursuit of high-speed 3D printing has become a focal point of research and development within additive manufacturing, driven by the need to improve productivity without compromising quality. This research compared experimental findings on the limitations of high-speed 3D printing with critical insights from scientific studies addressing the role of process parameters, hardware improvements, and material performance. Collectively, it was explored how advancements in print speed intersect with printer mechanics, material behavior, and industrial applicability. A critical speed ceiling for standard 3D printers was identified at approximately 180 mm/s, with most operations optimised around 150 mm/s. When augmented with systems like Klipper, speeds can reach up to 249 mm/s, but these enhancements expose significant mechanical and structural challenges. Chief among these issues is the stepper motors' inability to maintain precise control at high speeds, leading to printer vibrations, misalignment along the Y-axis, and, ultimately, print failure. The research results aligned with A. Kantaros & D. Piromalis's (2021) findings emphasised that low-cost desktop 3D printers struggle with maintaining accuracy at elevated speeds due to hardware constraints, particularly mass and inertia. The referred research focused on studying the moving parts, such as printer beds. Additionally, V.G. Gokhale *et al.* (2017) highlighted the impact of errors and degraded print quality at higher speeds for low-cost 3D printers, underscoring the importance of tuning acceleration values and optimising firmware settings.

There are many limitations related to low-cost 3D printers. Some researchers used different approaches to address and overcome such limitations – modifying slicer settings or adjusting acceleration, all efforts to improve model print quality. J. Wu (2018) showcased the post-effects of optimisation parameters, such as layer height, nozzle speed, and extrusion rates, to mitigate inaccuracies at higher printing speeds. At the same time, it should be noted that the experiment results showed that the effect of the mentioned modifications had to be balanced, adhering to the physical limitations of cartesian printers. This is all because the movement of heavy components poses inherent challenges. A. Lanzotti *et al.* (2015) found that hardware and parameter tuning had to be set up so that the joint parameters set up and material picked both lead to performance optimisation in the case of PLA parts for open-source printers.

High printing speed and movement acceleration introduced an additional layer of system complexity related to material properties, particularly in thermoplastics like PLA and nylon composites. The experimental results of the referenced scientists highlighted that the stress on printer structures and motors increases with increased print speed. It can sometimes lead to issues like uneven material deposition and reduced interlayer bonding. A. Kaman *et al.* (2023) proved this statement by the research findings, stating that nylon-based composites require careful calibration of temperature and speed to maintain structural integrity. It has been proven that at elevated speeds, the thermal environment around the nozzle and the cooling rate of the material become critical factors influencing print quality.

According to I. Christodoulou *et al.* (2023), the current trend of 3D printing innovations lies in achieving reliable high-speed 3D printing utilising the Fused Filament Fabrication (FFF) system. This work showcased the improvements in print head dynamics and the inertia reduction for the moving components. Using a fused filament system enabled significantly higher print speeds than standard printers. The highlighted approach addressed issues, such as the challenges of heavy-moving beds in Cartesian systems. K. Gomathi *et al.* (2021) explored advanced error characterisation and system optimisation for 3D printer systems, presenting firmware-level interventions to mitigate the impact of rapid movements on print accuracy. The presented findings can be summarised as the importance of balancing high-speed printing with adjustments tailored to specific applications and material requirements.

The experimental results of this work set the foundation for future research, such as firmware level code modifications, using complex 3D models, and expanding the range of tested printers. This path adheres to the broader trends in additive manufacturing research, where improving printer capabilities and expanding material compatibility are vital priorities. This research goal had been proven by the research conducted by A. Albar *et al.* (2019) and D. Chen *et al.* (2013). They strongly emphasised the importance of intelligent control systems and modular hardware integration. This leads to new system designs that support a broader range of industrial applications. Similarly, it has been noted that the precision and resolution of different 3D printing technologies at high printing speeds must be at the center of the resulting 3D printed model to meet industrial standards (Kluska, 2018). Examples of industrial applications where high-speed printing can be used include aerospace, automotive, and consumer goods sectors. Reducing model (part) production times is critical for the mentioned areas.

The comparison of experimental findings presented in this work with those conducted by renowned scientists highlights the complex nature of the high-speed printing field. Many more printed issues and challenges must be addressed apart from those mentioned in this research. Using Klipper firmware and fused filament fabrication systems has solved some of the high-speed printing challenges; optimisation of printing (filling) material usage and end-model mechanical endurance will be solved. The author plans to address the presented challenges by utilising printing and material process optimisation and creating a robust software framework for high-speed 3D printers to automatically adjust system parameters based on the printing industry and the end goal of the process. Besides, it can be beneficial to study and compare various 3D printer construction technologies in the future.

CONCLUSIONS

It had been established that the maximum print speed on a standard printer cannot exceed 180 mm/s; most often, it is about 150 mm/s. With additional equipment such as Klipper, the print speed can reach 249 mm/s, which is relatively high for printing, although it cannot be constant. At these print speeds, many properties could be improved, namely those that had to do with engine and layer functionality. In the study it was outlined that the most critical problem was the stepper motor only in some cases had time to move the table by the required number of steps. This was reflected in the appearance of a crackling sound in the printer and the vibrations of the equipment. In addition, the model was then offset along the Y-axis. After such an event, the printing process the could not continue print operations as the output model would had been damaged, and there was no point in reprinting it.

During the study, a newfound problem was identified. This issue arises when the print speed was increased – which resulted in a significant load on the engine. Due to which the structure and motors of the printer had been affected. Such loads were too significant for such classes of printers, namely those that utilise Cartesian mechanics. The main disadvantage was the movement of the table, which had a significant mass and took much energy to move. On average the printer only in a small number of cases had time to move then table. As the study showed, if one experienced a high print speed in a slicer, this would only in several occasions be considered when cutting the model because the slicer also considers the acceleration values, which are configured separately. Typically, the acceleration values were set to the OEM's recommended settings and did not require adjustments when set to optimal print speeds (up to 120 mm/s). During the experiment, the acceleration values were increased proportionally, which showed positive results.

If we take a case when the stock printer was used, like the research readings. In that case, one should refrain from interfering much with their standard parameters and settings because the printer could not print faster due to its hardware limitations. In the future, the authors plan to expand the presented research results, make manual code edits to the firmware, use more complex 3D models, and increase the variety of tested printers with a research focus on applications to several industrial applications.

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CONFLICT OF INTEREST

None.

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Порівняльне дослідження основних параметрів і характеристик системи управління параметрами 3D-принтера з використанням апаратного забезпечення типу Klipper

Анотація. 3D-друк активно замінює традиційні методи конструювання машин, забезпечуючи виробників гнучкістю, зручністю управління та можливістю реального часу налаштовувати параметри процесу. Дане дослідження було зосереджено на визначенні швидкості друку для отримання якісних моделей за двома сценаріями: без використання прошивки Klipper та з використанням мікропрограми Klipper для контрольних параметрів у процесі друку. 3D-принтером, який використовувався в дослідженні, був принтер Creality Ender 3 V3 SE з двома зразками 3D-моделей. Процес тестування проводився з трьома попередніми налаштуваннями швидкості друку: середня швидкість, вище-середнього швидкість та максимально можлива швидкість (максимальна швидкість друку 345 мм/с; вище-середнього швидкість 180 мм/с; середня – 150 мм/с). В результаті дослідження становлено, що найбільш критична проблема полягає в тому, що кроковий двигун не завжди встигає переміщати стіл на необхідну кількість кроків. Стандартні значення прискорення були встановлені на рівні рекомендованих виробником оригінального обладнання, а оптимальна швидкість друку становила до 120 мм/с. У ході проведення експериментів було збільшено стандартні значення прискорення, що показало позитивні зміни, та призвело до кращої якості друку і стабільності такого процесу. Було визначено, що у випадку зі стандартним (готовим з пакування до роботи) принтером найкраще зберегти стандартні параметри та налаштування, оскільки принтер не зможе друкувати швидше через свої апаратні обмеження, у той час як спеціальна апаратна прошивка може допомогти у виконанні завдання динамічного налаштування параметрів друку при цьому зберігаючи максимальну якість та оптимізуючи на виконання завдань. Результати дослідження можна використати в промисловому виробництві для оптимізації процесів 3D-друку, підвищення якості виробів та зменшення витрат на виготовлення

Ключові слова: 3D друк; апаратне програмне забезпечення; автоматизовані системи; контроль параметрів; ітераційна оцінка системи; системи управління