The Application and Evaluation of Creality's Sonic Pad for Ender 5-S1 3D Printers

by

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ABSTRACT

This thesis explores the integration of the Creality Sonic Pad with the Ender 5 S1 3D printer, focusing on identifying and resolving connectivity, print quality, and reliability issues. The study systematically examines key problems, including frequent disconnections, premature filament extrusion, poor first-layer adhesion, excessive stringing, and print failures. Through hands-on testing, analysis, and troubleshooting, the research identifies the primary causes of these issues, such as degraded USB-C cables, improper cable placement, firmware mismatches, and inadequate startup GCODE configurations.

Several targeted solutions were proposed and implemented, including the replacement of USB-C cables, optimization of cable placement, modifications to the Klipper firmware, adjustments to the startup GCODE, and stabilization of printer surfaces. These interventions led to major improvements in print consistency, reduced failure rates, and enhanced overall integration of the Sonic Pad with the Ender 5 S1.

The findings of this research offer valuable insights into overcoming common integration challenges and present practical solutions for users facing similar issues with the Sonic Pad. It highlights the potential of the Sonic Pad to enhance 3D printing workflows when properly integrated, while also outlining areas for future research, such as exploring alternative Klipper versions, improving rollback procedures, and gaining access to the full source code of the Sonic Pad for deeper firmware customization. With the right adjustments, the Sonic Pad can become a powerful tool for improving the reliability and performance of 3D printers in both hobbyist and industrial settings.

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LIST OF DEFINITIONS

1. Creality Ender 5 S1 3D Printer – A popular 3D printer model (Creality, n.d.E).
2. Sonic Pad – A controller designed to enhance the capabilities of Creality's 3D printer (Creality, n.d.J)
3. USB-C Cable – A type of cable used to connect the Sonic Pad to the Ender 5 S1 (USB Implementers Forum, n.d).
4. USB-A Plug – The connector used inside the Sonic Pad to interface with the USB-C cable (USB Implementers Forum, 2019).
5. Klipper Firmware – A firmware used in conjunction with the Sonic Pad that offloads the motion control tasks (GitHub, n.d).
6. Extruder – A key component of the 3D printer responsible for feeding filament into the hot end to create the printed layers. This section includes the motor, the gears, and the hot end (All3DP, 2022).
7. Heat Block – A metal block that surrounds the heating element (MatterHackers, n.d).
8. Heating Element – An electrical component that generates heat (Prusa3D, n.d).
9. Thermistor – A temperature sensing device embedded in the heat block. (Simplify3D, n.d).
10. Nozzle – A small opening through which filament is forced under pressure through (Ultimaker, n.d).
11. Heat Break – A narrow section that isolates the hot parts from the cooler parts (E3D, n.d).
12. Polytetrafluoroethylene Tube (PFTE) – A tube made out of high temperature resistant material (Filamentive, 2021).

13. Cooling Fan – A fan that is mounted above the extruder to keep the hot end cool. (3D Insider, 2020).
14. Heat Sink – A part that helps dissipate heat from the heat break (TechTarget, n.d).
15. Hot end – The part of the 3D printer that heats the filament to a molten state for extrusion. It consists of the heat block, the heating element, thermistor, nozzle, heat break, PTFE tube, cooling fan, and heat sink (MatterHackers, n.d).
16. Printer bed – The surface on which the 3D print is created (Rasie3D, n.d).
17. Z-axis motor – A motor that moves the print bed vertically on the Z-axis (Adafruit, n.d)
18. Limit Switch – A safety mechanism used to detect the boundaries of the printer’s movement (SparkFun, n.d).
19. Stepper Motors – Motors used to drive the X, Y, and Z axes (Pololu, n.d).
20. GCODE – A set of instructions sent to the 3D printer that guides the movement, temperature control, and other operation aspects of the print (Ultimaker, n.d).
21. Stringing – Unwanted deposition of thin, wispy strands of filament that occur between different parts of a print (Simplify3D, n.d).
22. Webhooks Request - The Klipper received a command from the touchscreen of the Sonic Pad (Ebbert, 2023).

CHAPTER 1. INTRODUCTION

The rapid advancement of 3D printing technology has introduced increasingly sophisticated tools aimed at improving print quality, speed, and user experience (3D Printing Industry, 2024; Bebhardt & Hotter, 2016; Norck, 2024). One such tool is the Creality Sonic Pad, a touchscreen device powered by Klipper firmware, designed to enhance performance on a range of Creality printers, including the Ender 5 S1. While the Sonic Pad promises faster print speeds and more accurate results, many users have reported a large number of integration issues that hinder its effectiveness (Buttriss, 2023; David, 2023; Smith, 2022). This research investigates the challenges encountered when pairing the Sonic Pad with the Ender 5 S1, a high-performance 3D printer, in an effort to identify the root causes of these problems and propose actionable insights.

Existing Issues

The purpose of this research focuses on finding solutions to improve the integration of the Sonic Pad into Creality's 3D printers, however, the existing issues must be explored before determining the next steps in how to improve the system. There was a long list of existing problems that had been observed while the systems were in use. These include randomly disconnecting Sonic Pads, printers failing to print the object, and the filament extruding prematurely. However, within each overarching problem, there are many underlying issues that must be discussed.

The most common issue users have been experiencing is the Sonic Pad randomly disconnecting either before the print or even during it (3D Printing for Beginners and Pros, n.d; fylith, 2023; Hawken, 2024). The Sonic Pad has a message show up that says, "Error Key 1, The Sonic Pad failed to connect to the printer," or "Error, Printer Not Found." These two errors are seen the most when the Sonic Pad stops working without a noticeable cause. However, another error message was observed while this research was being conducted, “Error, Klipper Failed to Connect,” or “Sonic Pad has lost connection with MCU.” (Wouters, 2024; Hawken, 2024). While this new message was not seen prior, it is believed that this message also relates to the Sonic Pad disconnecting. When the Sonic Pad disconnects, it then takes one of two courses of action: the printer is forced to stop the operation it is in the middle of, or the Sonic Pad forces a restart, leading to the print stopping anyway. There have been many different users reporting this exact issue through the Creality help groups and/or Reddit forums (Wouters, 2024; Hawken, 2024). While reading through many of these posts, they all followed the listed errors above, and no solutions were offered since no one could determine why it was happening.

The next known issue that was explored was the print failing to either adhere to the build plate or something stopping the print before it is completed. This issue took the most amount of time to research since there are countless reasons why this issue is happening. Some relate to the Sonic Pad, and some relate to the printer itself. In terms of the Sonic Pad causing this, three major errors that have been experienced (kroos7601, 2024; jasonius1974, 2023; AK1244, 2023). The first error that has been seen is, “Error, Extruder has exceeded maximum value in the X/Y/Z axis,” This error is very concerning to the users who experience it because it means that on one of the axis, the extruder, or build plate has gone past the limit switches that stop it from hitting the frame or plunges the build plate into the extruder.

The second error that has been given by the Sonic Pad is, “Shutdown due to webhooks request.” (Anthony1, 2024; UseLessUK, 2024). Similar to other issues that were explored throughout this work, this factor is a substantial reason why the integration of the Sonic Pad has not achieved the expected outcomes for some users. This error can be caused by many problems within the printer. The leading cause seen throughout the research was that something triggered the emergency stop procedure (Sineos, 2022; The deadestpool95, 2023). The procedure could be activated by the Sonic Pad or the Klipper, making it even harder to diagnose.

The third error that shows up when a print fails is "Error, Temperature Sensor has exceeded its maximum value." Like the previous error, this means that the temperature sensor has given the Sonic Pad a value that is higher than the extruder should be allowed to reach (Creality Store, 2024; 3mil, 2022). This has many different implications for why it could happen, but that will be discussed later in the research. All these errors are concerning when they appear because not only do they show an issue somewhere in the code or software of both systems, but they also show a physical problem with components, which could break the 3D printer itself or cause a fire.

The last known issue this research was attempting to fix is filament extruding before it is supposed to (Javitolago, 2024; MixhealOG, 2023; richard.c16, 2018). While this may not relate directly to the Sonic Pad, it wastes more filament and can lead to an error in the print sticking to the bed. Additionally, if filament is extruding when it should not, excessive amounts of stringing can occur during the printing process. However, with this issue, the Sonic Pad does not display an error, but leads to a lower quality print.

All of these complications hinder the ability for the user to integrate the Sonic Pad into their daily use in 3D printing, which leads to a technological advancement to fall through. The Sonic Pad has the ability to solve the issues involved with the printer itself, but has also added more issues than it has solved. However, through this research, solutions were discovered that could allow for the Sonic Pad to be successfully integrated into modern 3D printing.

Problem Statement

The Creality Sonic Pad has experienced connectivity issues and a decline in 3D print quality after the integration of the device with Ender 5 S1 3D printers.

Purpose

The goal of this research aims to determine and implement possible solutions into the Sonic Pad to increase the reliability and quality of the 3D printed products from the Creality Ender 5 S1 printer.

Research Questions

Many different questions were explored throughout the study that ultimately need to be answered to make the Sonic Pad more reliable. These questions, that drove the investigation, are:

1. What causes the printers to disconnect?
2. What causes the filament to extrude while the printer goes through the setup?
3. Why is the first layer not adhering properly?
4. Why is there a large amount of stringing in the product?
5. Why are the prints failing?

These questions act as benchmarks throughout the process, as each one relies on the next to form a reliable and high-quality print. Multiple settings in the printing process control these factors, including temperature, the speed which extruder moves, the levelness of the build plate, extrusion speed, retraction amount, and filament quality. Exploring each of these settings in depth allowed for a complete understanding of all the factors involved in 3D printing, which allowed for the solutions to be implemented to solve the reliability and print quality while using the Sonic Pads.

Rationale

The Creality Sonic Pads could prove to be a leap in technological advancements in the growing field of additive manufacturing if the user friendliness and reliability of the device is improved (3D Printing Industry, 2023). These devices are some of the first ones that were introduced in the world, and due to the problems associated with them, few people are even considering buying them and other companies may not be looking into building better models because of these issues. If these issues are not resolved using this type of technology, and no alternatives are developed with similar capabilities, the additive manufacturing field could miss out on crucial innovations that might shape its future (Petch, 2024; Trickyhicky, 2024).

With research providing solutions to the issues experienced with the Sonic Pad, there can be many impacts that lead to a better version of the Sonic Pads and/or competition in the market of this technology. These innovations can lead to substantially better and faster versions of this style of control. For example, if these issues are solved and Creality implements them into the Sonic Pad, more and more customers may begin buying them again, creating more interest in the field of 3D printing. Generally, the more interest there is in a particular technology, the more likely it is that major innovations will emerge to improve and advance it.

Another impact of this research is that it could lead to competition in this area of technology. As seen throughout the history of 3D printing, especially in 2005 with RepRap, the more competition, the lower the prices of devices become (“From Exclusive to Accessible”, 2025; Williams, 2016). This benefits the consumers and even people who are interested but cannot afford to buy the top-of-the-line expensive items. With more competition in the field, more companies push for even better versions of the device which can lead to even better technological advancements and better products that may benefit the field of additive engineering. Overall, this research has the potential to make a large positive impact, benefiting both consumers and the field of additive engineering as a whole.

Summary

This chapter serves as the foundation for investigating the integration challenges and potential of the Creality Sonic Pad, a touchscreen interface powered by Klipper firmware, designed to enhance the performance of Creality 3D printers, particularly the Ender 5 S1. While the Sonic Pad promises improvements in print speed and accuracy, user reports highlight major integration issues, undermining its effectiveness. The chapter identifies several recurring problems, including random disconnections, print failures, premature filament extrusion, poor adhesion to the build plate, and inconsistent temperature readings. These issues, attributed to software malfunctions and hardware miscommunications between the Sonic Pad and the printer, complicate the user experience and hinder the device's utility in 3D printing workflows.

The problem statement articulates the core issue: the Creality Sonic Pad, despite its innovative design, introduces instability in connectivity and performance, which detracts from the overall reliability and quality of prints. The research purpose was to identify the root causes of these integration issues and propose actionable solutions to enhance the reliability and quality of prints when using the Sonic Pad with the Ender 5 S1. The chapter outlines five central research questions that guide the investigation: (1) What causes the printers to disconnect? (2) What leads to premature filament extrusion during setup? (3) Why is the first layer not adhering properly? (4) Why is there a large amount of stringing in the prints? (5) What causes print failures? Each of these questions addresses a critical factor in achieving consistent, high-quality 3D prints, and their resolution is central to optimizing the Sonic Pad’s functionality.

The rationale highlights the importance of resolving these issues to maximize the potential of the Sonic Pad as a tool in 3D printing. By improving its reliability and user experience, the Sonic Pad could stimulate greater interest in its application, fostering innovation and competition in the market. The chapter draws parallels to the disruptive effect of the RepRap movement in 2005, which, through increased competition, led to advancements in 3D printing technology and made it more accessible. The research thus holds substantial implications for both the development of more reliable versions of the Sonic Pad and the broader impact on the 3D printing industry by encouraging innovation and reducing device costs through market competition.

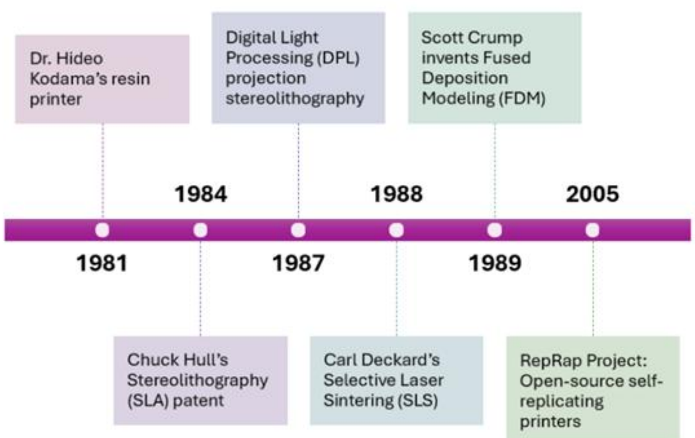
CHAPTER 2. LITERATURE REVIEW

Additive manufacturing is a relatively new form of production compared to the other fields involved (McBagonluri et al., 2025). This type of production is most easily defined by the process of 3D printing, which comes in many different styles. Without knowing the history and anatomy of 3D printing, the research and improvement within the thesis cannot be fully understood. For this reason, the history of 3D printing, 3D printing components, and a Sonic Pad will be discussed in detail for the research to make sense.

History of Additive Manufacturing

Figure 1

Timeline of Additive Manufacturing



Note. Created by the author.

The first historical example of 3dimensional (3D) printing came to light in 1981 by Dr. Hideo Kodama with a resin 3D printer for use in the medical field (Hellenic-CAM, n.d). His version of additive manufacturing used a photosensitive polymer, which when exposed to UV light, hardens in place, thus forming a single layer of a 3D print (Marine Corps Community Services Libraries, 2022; UltiMaker, n.d). This was a huge breakthrough in manufacturing because before this resin printer, only subtractive manufacturing existed. According to Enterprise

Resource Planning (ERP) Information, “Subtracting manufacturing is a traditional method involving starting with a solid block of material and removing or ‘subtracting’ unwanted portions to create a desired shape or product.” (Informer, 2024). Based on the previous definition, it is obvious why Dr. Hideo Kodama’s resin printing process is a completely new form of manufacturing. After the invention of the first resin printer and the creation of additive manufacturing, Dr. Kodama was quickly followed up by other inventions to make his version of the resin printer more efficient (3d Printer Power, n.d).

In 1984, employees from the French General Electric company began the patent paperwork for a process they called Stereolithography. Three weeks later, Chuck Hull filed for a patent for the same concept (Slusarczyk, 2025). General Electric ultimately abandoned its patent proposal, so it was given to Chuck Hull. Hull’s theory of stereolithography states that photosensitive liquid materials cured by ultraviolet light can be used to produce products layer by layer (Marine Corps Community Services Libraries, 2022). This form of 3D printing is also most associated with the term “rapid prototyping.” This follows the same concept seen in Dr. Kodama’s invention. Hull describes that using a laser beam and scanning over the required areas of the current layer of the product will cure the material and produce the hardened layer of the print (UltiMaker, n.d). While following this method of stereolithography, it can be imagined that it would take a long time for that single layer to cure since the light needs to hit every single area in a linear pattern. This leads to the next innovation in additive manufacturing.

Additive manufacturing still follows the concept of stereolithography but was officially named projection stereolithography (Zhao et al., 2015). The process of projection stereolithography was invented by DLP Technology in 1987 and uses a digital light projector, similar to the concept of a television projector, to cure the material. As opposed to a laser following a designated path to cure the material, this projects the ultraviolet light across the whole layer, curing it all at once (Stratasys, n.d). This sped up the 3D printing process, although it also had its drawbacks. For this process, the print quality relied mostly on the projection quality (3D Systems, n.d). If the projector has a poor resolution, the result would be a decrease in the print quality. Also, as the print size increased, the resolution would degrade even more, ultimately resulting in very poor-quality prints, mostly due to the projector.

Despite these earlier advancements, each carrying their inherent limitations, new technologies continued to emerge to overcome these shortcomings. One such advancement came in 1988 by Carl Deckard called selective laser sintering (Marine Corps Community Services Libraries, 2022). This revolutionized the world of 3D printing because it no longer required a material curable by ultraviolet light. This method of 3D printing uses a laser to sinter a powdered material. Some of the powdered materials included nylon, polystyrene, aluminum, and stainless steel. This sintering action would fuse this material into a solid structure, thus creating the product. With the invention of a new 3D printing format, people began exploring other ways to produce products quickly through additive manufacturing. This led to one of the most common forms of additive manufacturing currently employed.

In 1989, the most commonly used form of 3D printing in the world today was produced by Mr. Scott Crump. He patented a form of printing that uses a plastic filament as a material to print, and this became known as fused deposition modeling (FDM); however, it can also be considered as fused filament fabrication (FFF) (Marine Corps Community Services Libraries, 2022). This printing process is the most popular form companies still use today. It relies on a material fed through an extruder, a critical piece of the printer, that heats the filament to a semi-liquid state so that it can begin flowing through the small nozzle (3D Systems, n.d). This material will then be deposited along a designated path and laid initially on the build plate and then on the previous layer of material. With the material being hot, it adheres to whatever it is melted on, and as it cools, it forms the solid layer for the next pass of the nozzle.

The final critical point to discuss relates to the history of 3D printers occurred in 2005. This is when the RepRap project, created by Adrian Bowyer, was introduced (Marine Corps Community Services Libraries, 2022). The RepRap project was one of the most successful advancements in the production of today's 3D printers because it focused on replicating rapid prototypers (Jones et al., 2006). This means that 3D printers were able to print the majority of the parts needed to build a new 3D printer, replicating themselves. The goal of this project was to get relatively cheap 3D printers to anyone who had an interest in additive manufacturing (Sells et al., 2009). Likely the most important aspect of this project was the open-source code available for everyone to access (Bowyer, 2014). Throughout this project, there was a large increase in the number of companies producing 3D printers, which created market competition, forcing companies to sell their printers for cheaper, compounding the effects of the project as a whole (Sells et al., 2018).

Creality is a very popular company that many new users lean towards for their first printers, since they are cheaper than most of the other big brands (Creality, n.d.A; Bryant, 2025). However, they also produce many different products outside of 3D printers, which aids the efficiency and quality of their services. The first product that they introduced to make 3D printing easier was the Creality Slicer.

A slicer is an essential software tool that serves as the bridge between a digital 3D model and the physical printer. It takes a 3D model file, such as STL, OBJ, or 3MF, and slices it into hundreds or thousands of horizontal layers (All3DP, 2024). Once sliced, the software translates these layers into G-code, a set of precise instructions that tell the printer exactly how to move, how fast to print, how much filament to extrude, and what temperatures to use. In addition to generating this code, slicers allow users to fine-tune a wide range of print settings, including layer height, print speed, infill density, support structures, and temperature controls. Most slicers also offer a preview feature, enabling users to simulate the entire print process and catch potential issues before printing begins. Popular slicers include Cura, PrusaSlicer, Creality Slicer, Bambu Studio, Simplify3D, and SuperSlicer. Ultimately, a slicer is what transforms a 3D design into a printable set of instructions, making it a vital part of the 3D printing workflow (All3DP, 2024).

While these other companies released their own slicers, Creality's slicers were directly connected to the settings of their printers, making this slicer much easier to use since you only needed to make minor changes depending on the issues the user experienced. This was very popular when it was first released due to its ease of setup in any Creality printer (Creality, n.d.B). However, Creality pushed the additive manufacturing world even further with the release of the Creality Sonic Pad in 2022.

The Sonic Pad is a new device within the 3D printing community. It is a tablet that allows the user to control up to four printers from one singular device (Creality, n.d.C). The printers are hooked up to the device using a USB to USB-C cable running directly from the printer into one of the four USB ports in the Sonic Pad. The Sonic Pad allows for extremely fine tuning during the printing process itself, including changing the z-axis offset by 0.001 mm, the temperature, the speed of the motors, and the flow rate of filament (Creality, n.d.D). This tablet also allows remote access using Creality Cloud to adjust, stop, or start prints from anywhere, rather than at the printer itself. However, Creality seemed to prematurely release this device because most customers who purchased these sonic pads have encountered problems that ultimately cause the printers to be unreliable and even produce poor quality prints when they do function properly (3D Print Beginner, 2023; GitHub, 2023; Klipper Discourse, 2022).

System Design

This section outlines the system design of the Creality Ender 5 S1 3D printer, the Sonic Pad, and the Klipper firmware, detailing how these components interact to enhance printing performance. It begins by breaking down the hardware architecture of the Ender 5 S1, including key components such as the extruder, hot end, motors, and build plate. The Sonic Pad is then described as an external controller that offloads processing tasks from the printer, improving responsiveness and control. The integration of Klipper firmware is also discussed, emphasizing its advanced motion planning features and how it leverages the Sonic Pad's hardware to optimize print speed and quality. Together, these technologies form a cohesive system aimed at maximizing reliability, precision, and efficiency in 3D printing.

3D Printing Files

To truly understand how a Creality Ender 5 S1 3D printer (illustrated in Figure 2) works, the process of obtaining the code to send to the printer is critical (Creality, n.d.F). This code is crucial because it tells all the hardware exactly what to do. The code that is used by the printer is a .GCODE file, a file that acts as instructions for the hardware by slicing the surface profile of an object into layers (Marlin Firmware, n.d). From these layers, the .GCODE determines the exact tool path to produce the object and then transforms these paths into coordinates following the Cartesian coordinate system. However, there is a very strict process on how to obtain a .GCODE. The user must save their software-generated, parametric solid model as a .STL file first. An STL file, also known as a stereolithography file, describes the surface geometry of the object the user created using triangles for the .GCODE software (the slicer) (lancu, 2018). Once the user uploads the code into the printer, the 3D printing process can begin.

3D Printer

Figure 2

Creality Ender 5 S1 3D Printer

Note. Ender 5 S1 3D Printer. From Creality, n.d.E, Creality, https://www.creality.com/products/ender-5-s1-3d-printer

The Creality Ender 5 S1, illustrated in Figure 2, has many different parts involved with its function, including an extruder, two fans, a feed system, leveling nuts, three motors, a filament detector, limit switches, a USB-C port, the computer circuit, and a power switch (Viola, 2024). Focusing on the hardware side of the printer, the process of 3D printing is relatively simple. The most important parts to discuss about the printer are the motors, the extruder, and the hot end (McClements, 2022).

Motors

Figure 3

X, Y, and Z-Axis Motor.

Note. This is an image showing what the four motors on an ender 5 S1 look like. From Creality3DParts, n.d, https://www.creality3dparts.com/product/42-34-motor-x-axis-and-z-axis-ender-5s1/

Focusing on the motors (illustrated in Figure 3), the printer has four of them. The first motor to discuss is the z-axis motor since the z-axis is the most critical one in 3D printing (PrintPal, n.d). Some 3D printers move the extruder up and down to print, but the Ender 5 S1 is the opposite; it moves the build plate up and down to the extruder to form the different layers (Creality, n.d.G). The z-axis motor spins a screw which the build plate is attached to move the plate down based on what the code tells it to do. The motor is attached to a coupler, a part that tightens on the motors drive shaft on one side, and the ling screw on the other. This is attached using set screws that can lock on to whatever the coupler is attached to.

The exact distance the z-axis moves is based on the quality settings of the slicer the .STL was put through. There is a wide range of quality settings that can be found within the slicer: low quality, standard quality, and high quality (Grames, 2024). For the low-quality resolution, the z-axis is broken into 0.4 mm layers, resulting in a quicker print but a decrease in the finer details. For the standard quality, the z-axis is broken up into 0.2 mm layers, and the high quality breaks the z-axis up into 0.1 mm layers. The two other motors within the 3D printer control the location of the extruder on the X-axis and Y-axis. These motors must be in sync with each other throughout the entire process because any curve or non-linear shape requires both motors to move at different speeds to create a smooth shape. While these three motors focus on the location of the print bed and the hot end, the fourth motor is located in the extruder (Mensley & O'Connell, 2023).

Extruder

The next hardware component in the Ender 5 S1 is the extruder, which functions as the mechanical system responsible for feeding filament into the hot end to form the printed object. The extruder is composed of three main parts: the motor, which drives the filament forward; the gear set, which regulates the pressure and movement of the filament; and the hot end, where the filament is melted and deposited layer by layer onto the build surface (Mensley & O'Connell, 2023). These elements work together to deliver accurate material extrusion and maintain print quality.

Motor and Gear Set

Figure 4

Gear set for the Ender 5 S1

Note. This is an image showing what the gear set looks like in the Ender 5 S1. From A7Lab, n.d, https://www.a7lab.xyz/en/home/extruders-and-hotends-en/creality-sprite-extruder-gears-kit/?v=491e5cdaf579

The motor and the gear set go hand in hand within this assembly. The motor is a very standard piece where the electricity that enters the 3D printer activates the motor when it is required to turn the gear set. On the other hand, the gear set, illustrated in Figure 4, is more complicated. It consists of two separate gears, the drive gears and the shoulder bolts to attach these gears (Mensley & O’Connell, 2023). This gear system is considered a dual-gear system since it contains two gears that work together to feed the filament. Each gear is considered to be a 3.5:1 gear ratio, thus producing more torque over speed (Creality, 2024). The actual gear itself attaches to the motor to allow for the opposite side of the gear to force filament through.

The side that interacts with the filament is a flat surface with grooves so that it has some grip on the filament. These two gears are offset by 1.7 millimeters, which is slightly less than the diameter of the filament at 1.75 mm, which allows the use of friction to feed the filament (Creality, 2024). This can be seen as any leftover filament that was pushed into the extruder but not melted, comes out with visible grooves, suggesting that the gears force material through (O’Connell & Maillioux, 2025). While these two parts are similar to other aspects, the printer cannot function if one or both parts break or stop functioning properly. While these two components are dedicated to feeding filament through, the next section melts the filament down so the object can be printed.

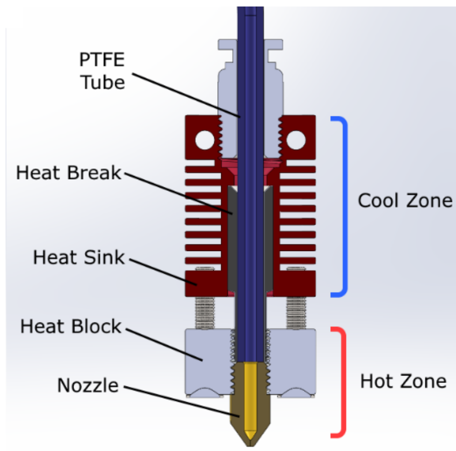
Hot End

The hot end, illustrated in Figure 5, melts the filament and extrudes the thin line of material to produce the layers of the product (Mensley & O’Connell, 2023). The hot end in the Ender 5 S1 is made from titanium alloy with a copper throat, which allows for the nozzle to handle the high temperatures that are needed to melt the plastic. The biggest reason that it is made from titanium alloy is to resist heat creep. Heat creep is defined by Dean McClements as

"The process of unsteady heat transfer throughout the hot end and melts the filament too early, before the melt zone." (McClements & Lichtig, 2024). To understand how the hot end works, the specific zones throughout the end need to be described. This includes the PTFE tube, the heat break, the heat sink, the hot end fan, the heat block, and the nozzle. To focus on these parts of the hot zone, the path of the filament from the extruder to the build plate will be followed.

Figure 5

Hot End Assembly Diagram



Note. This is an image showing what the hot end assembly looks like in the Ender 5 S1. From Creality Experts, n.d, https://www.crealityexperts.com/bimetallic-heatbreak-install-hot-end

Cool Zone

The first section of the hot end, in terms of the path of the filament, is referred to as the cool zone. This zone includes the PTFE tube, the heat break, the heat sink, and the hot end fan (Mensley & O'Connell, 2023). These components have no way to heat up the filament which is why it is considered the cool zone. These parts all make sure that the heat does not reach the filament before it reaches the melting zone. If the filament melted prior to entering this zone, it will most likely cause a clog (Maker.io, 2022). A clog forms because the filament heats up and then cools down prior to extruding, thus forming a ball of plastic that blocks the entrance to the hot end. Clogs are a huge issue in additive manufacturing because it takes the printer out of operation until the clog gets cleared and the cold zone gets cleaned. When examining each individual component, it became evident that all played a deliberate and coordinated role in maintaining proper thermal isolation and ensuring consistent filament feeding.

PTFE Tube

Figure 6

PTFE Teflon Tube

Note. This is an image showing what the PTFE Tube looks like in the Ender 5 S1. From TMYPN, 2025, https://www.amazon.com/TMYPN-Capricorn-PC4-M10-Pneumatic-Fittings/dp/B0CSNMTDD9

The PTFE Tube, the blue tube in Figure 6, is the simplest part within this section since it is exactly what the name says. This part is a tube made from PTFE, and acts as a guide to feed the filament in a straight line into the extruder (Mensley & O’Connell, 2023). There are several reasons why this material is used for the tube, including its temperature resistance (up to 500 degrees Fahrenheit), chemical resistant, and non-stick properties. While this tube is very simple, it leads to a much smoother process, as the filament will not contact any parts that it is not supposed to touch.

Heat Break

Moving on to the heat break (illustrated in Figure 7), this part serves one of the most important roles in the cool zone. The role of the heat break is to ensure that all the heat from the hot end never enters the cool zone (Mensley & O’Connell, 2023). If the heat is permitted to enter the cool zone, a clog will form, rendering the 3D printer inoperable. The heat break is made from the same titanium alloy as mentioned earlier. According to Advanced Materials Technology, “Today’s titanium alloys are specified for a maximum service temperature of 600 degrees Celsius.” (Advanced Materials Technology, n.d). This is an extremely high temperature, and 3D printing usually only reaches a third of this, thus, it is an extremely effective material for a heat break. Another critical property of this material is that it is a very poor conductor of heat (Titanium Metals Corporation, n.d). This means that the heat it interacts with from the hot zone will not pass through this material easily. This allows the titanium alloy to cool off faster than it heats up. This leads us into the next part, the heat sink.

Figure 7

Ender 5 S1 Heat Break

Note. This is an image shows the heat break in the Ender 5 S1. From Tiny Machines, n.d, https://www.tinymachines3d.com/products/titanium-heat-break-for-cr-10-smart-pro-sprite-extruder?srsltid=AfmBOorWRJIhdKgim8Z7K9KZ3BpecwnUIfTgC7HAp8uxkPa3WVCzg4TD

Heat Sink

The heat sink, illustrated in Figure 8, is integral in the cool zone because any heat that is introduced into this zone needs to be removed instantly. While the heat sink is extremely effective in stopping the heat from transferring into this zone, no component is ever perfect. The heat sink will begin heating up as the nozzle reaches the appropriate temperature to print, and then the cool zone relies on the heat sink to dissipate this heat. The heat sink is made from aluminum because it is a good heat conductor. This means it pulls the heat out and away from the other components in the cool zone (Oscar, 2024). The heat sink features horizontal fins, giving it a much higher surface area exposed to air, which helps to remove any heat that enters the material.

Figure 8

Ender 5 S1 Heat Sink

Note. This is an image shows the heat sink in the Ender 5 S1. From AliExpress, n.d.A, https://www.aliexpress.us/item/3256803472842932.html?gatewayAdapt=glo2usa4itemAdapt

Hot End Fan

Figure 9

Ender 5 S1 Hot End Fan

Note. This is an image shows the hot end fan in the Ender 5 S1. From AliExpress, n.d.B, https://www.aliexpress.us/item/3256805654308704.html?gatewayAdapt=glo2usa4itemAdapt

On top of the heat sink, the hot end fan (illustrated in Figure 9) also helps to remove any unwanted heat in the cool zone. The hot end fan is primarily directed at the heat sink, which often surprises users who assume, based on its name, that it would be aimed at the parts of the hot end that generate heat (stepinwolf, 2021). By having constant outside air, air from outside the printer's internal system, cooler air is blown directly onto the components designed to absorb and dissipate most of the heat. With the heat sink having horizontal fins and constant cool air being blown on it, all the heat that escapes into the cool zone is effectively eliminated.

Hot Zone

The next portion of the hot end that the filament feeds through is the hot zone. The hot zone is the section of the 3D printer's hot end where the filament is actively melted and prepared for extrusion onto the build surface. This zone contains the heating element, a temperature sensor, the melting chamber, and the nozzle.

Heating Element

For this study, the heating element was unable to be opened. However, it was assumed that it was the newest form, a spiral heater (illustrated in Figure 10). A spiral heater consists of a wide variety of parts. These parts include a heater pipe, insulation powder, heating wire, core insulator, sealing material, insulation tube, and an induction insulator (Tempco, n.d; Holroyd Components, n.d). A spiral heater works by converting electrical energy into heat through a coiled resistive wire wrapped around a heating component. When the current flows through the coil, it generates consistent and evenly distributed heat which allows for precise thermal control (Dyze Design, 2020).

Temperature Sensor

Figure 10

Ender 5 S1 Spiral Heating Element

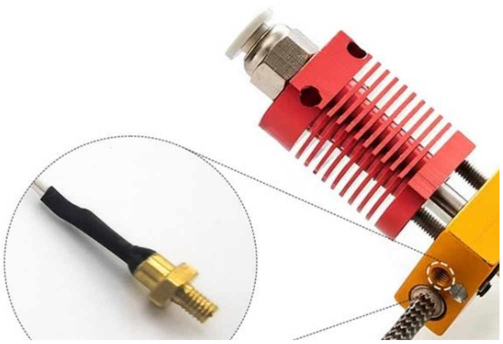
Note. This is an image shows the spiral heating element in the Ender 5 S1. From POLISI3D, 2023, https://www.amazon.com/Cartridge-Temperature-Thermistor-Compatible-Accessories/dp/B0CM9MQFXM

Moving on to the temperature sensor (illustrated in Figure 11), a thermistor is attached to the heating element to ensure that the temperature remains constant for the filament to melt smoothly (Douglas, 2021). Thermistors are very sensitive temperature gauges because they rely solely on the movement of electrons (Murata Manufacturing Co., n.d). For example, when the heat in the hot end gets warmer, the electrons move faster, allowing for more current to flow through the thermistor. For the thermistor in the 3D printer, there is a specific line of code that states that when the thermistor says that the temperature reaches x degrees, the controller should turn the heating element off until the temperature drops below another set value. This is critical in the 3D printer because without something limiting the temperature that the hot end reaches, it could easily catch fire. This has been determined to be the leading cause for fires related to 3D printing (Stevenson, 2025; 3Dnatives, 2022; Tiertime, 2019).

Melting Zone

Figure 11

Ender 5 S1 Thermistor



Note. This is an image shows the thermistor in the Ender 5 S1. From Ubuy, n.d, https://www.liberia.ubuy.com/product/ICCNXM4OW-m3-stud-thermistor-100k-3d-printer-ntc-thermistor-3950-ender-3-v2-thermistor-temperature-sensor-compatible-for-ender-3-ender-3-pro-ender-5

The next component of the hot zone is the melting zone. This is where the filament melts into the semi-liquid state for printing (Sculpteo, n.d). This chamber is heated to the designated temperature from the heating element and must stay relatively consistent while the print is happening. Within this melting zone, the filament slowly gets fed through for a very specific length of time to ensure all the filament leaving this zone is the same consistency (All3DP, n.d). However, when the filament melts, it tends to stick to the sides of this component. This is why the unmelted filament must enter this component at the beginning to force the melted filament out at a smooth pace.

Nozzle

Now that the filament has gone through the entire extruder, it needs to be formed into the thin lines seen throughout all 3D prints. This is where the nozzle (illustrated in Figure 12) comes into play (Formfutura, 2023). The nozzle in the Ender 5 S1 is a 0.4 mm nozzle. This means that the opening where the filament is fed through has an opening of only 0.4 mm. This forms the thin line that sticks to the build plate to begin printing the actual part (Gibson et al., 2015). The nozzle is made of brass since it has excellent thermal conductivity. This is critical because it allows the nozzle to heat up quickly and evenly, which stops the melted filament from sticking to it (Formfutura, 2023). It also ensures that the filament does not solidify until it meets the build plate, otherwise, the nozzle would clog and be unusable until it is cleaned.

Figure 12

Ender 5 S1 0.4 mm Nozzle

Note. This is an image shows the 0.4 mm nozzle in the Ender 5 S1. From Flora Livings, n.d, https://www.floralivings.com.au/products/creality-3d-printer-nozzle-high-speed-m6-nozzle-ender-3v3-se_ender-5-s1-ender-8

Build Plate

The final major piece of hardware in the Ender 5 S1 is the build plate. This is the platform which a 3D print will be printed. For this 3D printer, the build plate is 220 mm x 220 mm. However, with a test line of filament printed to clean the nozzle of any extra filament, the total size of the 3D print possible is 210 mm x 220 mm on average. The max print size depends on how and where the cleaning lines are printed. The build plate consists of a powder coated Polyetherimide (PEI) plate and the bed leveling screws (MatterHackers, n.d).

PEI Plate

Figure 13

Ender 5 S1 Print Bed

Note. This is an image shows the PEI build plate on the Ender 5 S1. From ChiTu Systems Store, n.d, https://www.amazon.com/Official-235x235mm-Creality-Ender-S1/dp/B0C9CNX37C

The powder-coated PEI plate, illustrated in Figure 13, is arguably the most important part of the build plate. This is the surface that the filament will stick to on the first layer to ensure the quality and ability for the part to be printed (MatterHackers, n.d). This plate is made from PEI due to many of its desirable properties. These include thermal properties, mechanical strength, flame resistance, electrically insulated, and resistance to chemicals (Loyfluoro Ltd, 2024). Another major reason why this material is used as a filament for a 3D printer, making it cheap and easier to make, since it can just be printed (LulzBot, n.d). Finally, the PEI self-releases the print as it cools down, making removal of the printed parts extremely easy and requiring no tools to break free. The PEI plate is also bendable, creating an easy way to free the part by bending it back and forth.

Bed Leveling Screws

Figure 14

Bed Leveling Screws for the Ender 5 S1

Note. This is an image shows set of four bed leveling screws for the Ender 5 S1. From DGZZI, n.d, https://www.amazon.com/DGZZI-Upgraded-Leveling-Creality-Geeetech/dp/B08C7BSWPF

The final part of the print bed are the leveling screws (illustrated in Figure 14). This is important because if the bed were unlevel, the print would never successfully stick to the build plate (Simplify3D, n.d). These screws sit under the four corners of the heating element and use the threads to either raise or lower the build plate above it (ALL3DP, 2024). There are also springs between the screw head and the build plate to ensure there is always tension on the screws to ensure they do not move unless intended to. These screws, while easily overlooked, are the reason why the Ender 5 S1 can print the object that is sent to it.

Sonic Pad and Klipper

According to Creality's website, "Creality's Sonic Pad is a hardware and software-integrated control system designed to run Klipper firmware to enhance 3D printing performance by offloading computational tasks from the printer's mainboard to a high-performance processor." (*Creality Sonic Pad*, n.d.K).

Figure 15

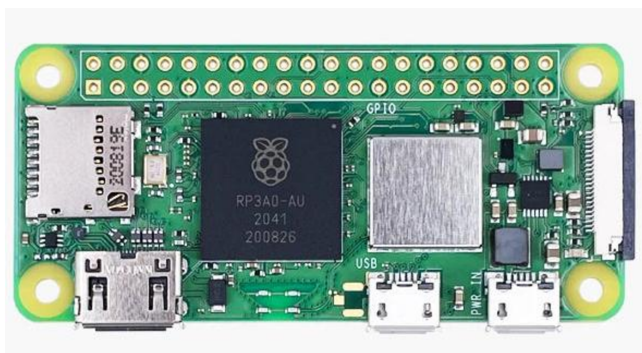
Creality Sonic Pad

Note. This is an image shows what the Sonic Pad looks like. From Creality Sonic Pad, n.d, https://www.creality.com/products/creality-sonic-pad

Hardware Architecture

Figure 16

1 GHZ Quad-Core Arm Cortex



Note. This is an image shows what the Quad-Core Arm Cortex looks like. From MS Codes, n.d, https://ms.codes/blogs/computer-hardware/1ghz-quad-core-64-bit-arm-cortex-a53-cpu

Focusing on the hardware architecture, the Sonic Pad, illustrated in Figure 14, is powered by a quad-core ARM Cortex-A53 processor (ARM Holdings, 2021), illustrated in Figure 16, which enables it to handle complex motion computations that traditional 8-bit printer mainboards struggle with. It features a 2 GB DDR4 RAM (Creality, n.d.H), illustrated in Figure 17, ensuring efficient multitasking, and an integrated Mali GPU for rendering its 7-inch capacitive touchscreen. Storage consists of eMMC flash memory for the operating system, along with microSD card support for firmware updates and additional storage (Creality, n.d.I). The Sonic Pad includes multiple USB 2.0 ports for connecting printers, cameras, and external drives, as well as Wi-Fi (2.4GHz/5GHz) and an RJ45 Ethernet port, illustrated in Figure 18, for remote monitoring and control. Cool mechanisms, such as small fans and heat sinks, prevent overheating during high-speed operations (Creality, n.d.J).

Figure 17

KingSpec 32 GB DDR4 RAM

Note. This is an image shows what the DDR4 RAM looks like. From KingSpec, n.d, https://www.amazon.com/dp/B0D1XNWP2N

Software Architecture

Figure 18

Creality Sonic Pad's USB-A and Ethernet Plugs

Note. This is an image shows what connections the Sonic Pad has looks. From Creality Cloud, 2023, https://www.crealitycloud.com/post-detail/642fd199beabd37fe23bfa22

Moving on to the software architecture and Klipper firmware, the Sonic Pad runs a Linux-based operating system optimized for real-time task execution, with system-based process management ensuring smooth operation of the Klipper and the touch screen interface (Creality, 2024). Klipper firmware is an advanced open-source motion control system that replaces traditional firmware like Marlin. Instead of executing G-code line-by-line on the printer's microcontroller unit (MCU), the Klipper shifts the computational load to the Sonic Pad's powerful central processing unit (CPU), enabling faster step rates and better motion planning.

The Klipper's motion planning algorithms use techniques such as input shaping, which reduces vibrations and eliminates ringing in prints, and pressure advance, compensating for extrusion lag, improving flow consistency (Klipper, 2024). The Sonic Pad's software stack includes a G-code parser, a real-time motion planner, and an error logging and diagnostics system. A built-in web interface allows users to monitor, and control prints remotely, with Over-The-Air (OTA) firmware updates to ensure compatibility with future improvements. Application programming interface (API) and WebSocket support allow for customization and integration with third-party applications.

Literature Pertaining to the Sonic Pad

As of 2025, information regarding the Creality Sonic Pad remains somewhat limited outside of Creality's official website. Much of the available feedback has been shared through online communities, such as Facebook groups and Reddit subpages, where users discuss their experiences with the device. There has been minimal formal research available publicly about the Creality Sonic Pad, making it difficult to know or provide what has already been accomplished or explored.

Summary

Chapter 2 of this thesis provided a comprehensive overview of the historical development, technological advancements, and system design of 3D printing, with a particular focus on Creality's products. The chapter began by tracing the evolution of key additive manufacturing technologies, including resin printing and fused deposition modeling, which have profoundly transformed the industry. It then examined the Creality Ender 5 S1 3D printer, highlighting the functionality of its core components that collectively ensure precise and reliable printing. The chapter then shifted to the Creality Sonic Pad, a device designed to optimize 3D printing performance through the Klipper firmware integration, which offloads computational tasks to improve speed and print quality. The chapter concluded by addressing the current state of research on the Sonic Pad, noting the paucity of formal academic studies and the reliance on user-generated feedback from online communities.

CHAPTER 3. MATERIALS AND METHODS

The purpose of this research was to find ways to increase the reliability and quality of 3D prints on the Ender 5 S1 using the Sonic Pad. There were several areas to explore to determine possible solutions, including temperature, speed, levelness of the build plate, extrusion speed, retraction amount and speed, and filament quality. While all these settings directly impact the quality of the 3D print, printer connectivity issues needed to be solved before the print quality could be assessed. Without communication with a printer, there would be no print to determine the quality. Therefore, the following research questions were investigated and used to drive the study,

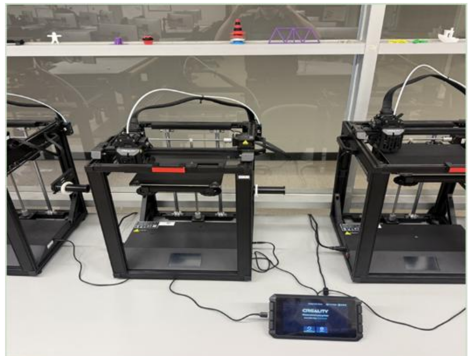
1. What causes the printers to disconnect?
2. What causes the filament to extrude while the printer goes through the setup?
3. Why is the first layer not adhering properly?
4. Why is there a large amount of stringing in the product?
5. Why are the prints failing?

Context of the Study

The research setup was located at Millersville University, in Osburn Hall, Room 300. The lab consists of 30 desktop computers, each installed with the Creality Slicer (version 4.8.2). These computers were used to generate G-code files from 3D model files. Once the slicing was completed, the G-code files were transferred manually to Sonic Pads using USB drives. There was no direct network connection between the computers and the printing systems, all file transfers occur physically via removable storage devices.

Figure 19

A Cluster of one Sonic Pad and Three Printers



Note. An image representing what the cluster looks like in the following paragraph. Created by the author.

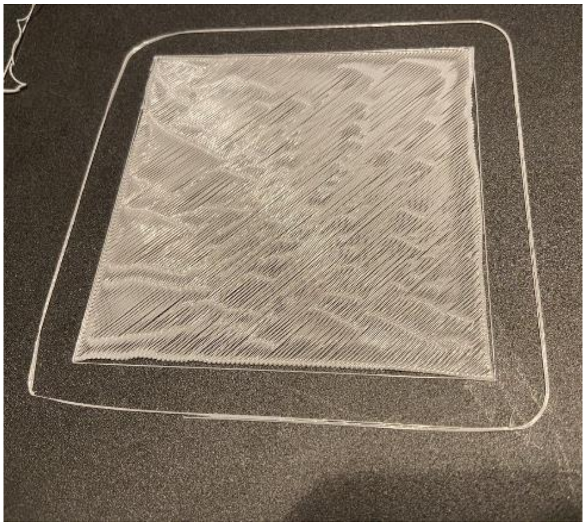
Four Creality Sonic Pads were used to manage the 3D printing process. Each Sonic Pad was physically connected via USB-C cables to three Creality Ender 5 S1 printers, forming four independent control clusters (illustrated in Figure 19). In total, there were 12 Ender 5 S1 3D printers and 4 Sonic Pads. After a G-Code file was prepared on a computer, it was copied to a USB drive and inserted into the designated Sonic Pad. The Sonic Pad then distributed the file to one of its connected printers for execution. All communication between the computers, Sonic Pads, and printers occured through manual file transfers without network-based interaction.

The testing period was scheduled during a time when the 3D printers were not required for use by any classes, students, or external projects, and access was restricted while all potential users were notified in advance to ensure they were not used during that period. This ensured that all tests conducted to analyze the effectiveness of the changes made to the Creality Sonic Pad were performed under controlled conditions without external interference. By isolating the printers from regular academic or personal use, the study maintained consistency and accuracy in its observations and results, allowing for a more reliable assessment of the Sonic Pad’s performance improvements.

Data

Figure 20

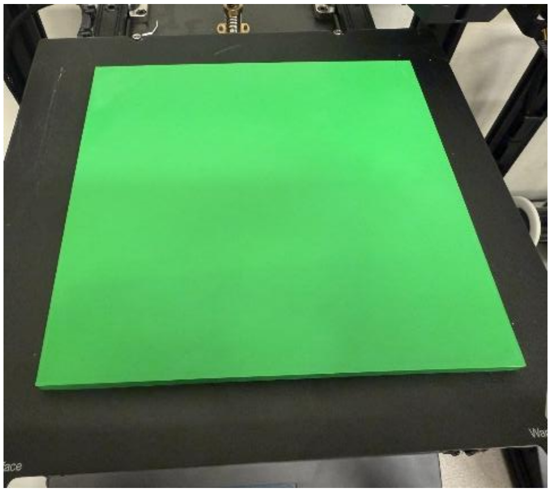
Example of a Failed Print



Note. An image representing what a print looked like when it failed mid-print. Created by the author.

Figure 21

Example of a Successful Print



Note. An image representing what a successful print looked like during testing. Created by the author.

Since this research was focused on the reliability of the 3D printer, the data that was taken relates directly to whether the 3D printer can print parts repeatedly or another complication caused the print to fail. The data that was analyzed relies on two separate data sets:

- Does the printer successfully complete the print?
- Does the print seem to be a high-quality print of the object being printed?

In this study, print completion was defined as the successful extrusion of all filament layers and the printer indicating that the print was complete. An example of a failed print is illustrated in Figure 20, and an example of a successful print is illustrated in Figure 21. After the print was determined to be successful, the object produced was examined for quality, as defined by the following criteria: all the outer walls of the print are flush with each other and there are no gaps between each layer, the amount of stringing visible on either the finished surfaces or walls, and the smoothness and consistent color of the finished surfaces.

By examining the flushness of the exterior walls, the print quality was examined and defined. Gaps and sections not flush with each other are signs of a poor-quality print, since with a high-quality print, it should be difficult to determine where one layer starts compared to the other. Examining the part for stringing helped to determine if there is excessive stringing. Lastly, by examining the smoothness and consistency of the print, it can be determined if there were any issues with filament extrusion. Together, these factors address each research question outlined in Chapter One.

Data Collection

Throughout the entire research process, data was measured from observations of twelve 3D printers over one semester. This data was then converted into numerical percentages as part of the analysis. For this research, a specific part was designed in SolidWorks that tests the quality and speed of the 3D printer. The object was a rectangle of 210 mm x 210 mm and 10 mm thick. While this seems to be an easy part in comparison to the other objects that the 3D printer can print, it tests the overall printer to its limits. By printing a part that takes up the entire bed, it tests the ability of the filament to stick to the entire build plate and tests where possible errors in the Sonic pad or printer could be located based on where the error occurred. To measure the baseline (Trial 1) of the printer's connectivity, completeness, and quality, 120 initial samples were taken, 10 subsamples from each of the 12 printers. To assess the impact of the proposed solutions based on the same criteria, 120 final samples (Trial 2) were collected, again with 10 subsamples from each printer. After the tests were completed, the print was inspected for the above criteria.

The process for inspecting the quality of each 3D print involved a structured visual and physical inspection. Once a print was completed, it was allowed to cool and then carefully removed from the build plate to prevent any damage that might interfere with analysis. The first step was to evaluate the flushness of the exterior walls by visually inspecting the alignment of each layer and running a fingertip lightly along the surface to detect any protrusions or indentations. Close attention was given to corners and vertical surfaces, where misalignments are most likely to occur. Next, the part was examined for stringing by using a bright light to highlight thin strands or wisps of filament. Finally, the smoothness and color consistency of the surface were assessed by observing the object from multiple angles and under uniform lighting to detect rough textures or discoloration that could indicate extrusion inconsistencies. Each of these inspection steps was applied uniformly across all prints to ensure consistent evaluation throughout the research.

Once the print was inspected, the results were compiled into a Microsoft Excel file to ensure that the results can be viewed and analyzed later for a comparison between the existing 3D prints and the prints after the discovered solutions are implemented.

Limitations

This experiment does have some unavoidable limitations. The biggest limitation of this research was that the quality of the 3D prints relies on several different factors, some of which include the quality of the filament being used, the temperature and humidity of the surrounding environment, and the quality of the build plate. While some of these factors are controllable, the researcher did not have access to a thermostat that controlled the temperature and humidity of the lab. Also, the researcher was limited to using the filament that was stored within the lab for printing the test part. These factors limit the assessment of whether a specific change helps or harms the efficiency and quality of the 3D prints.

Another limitation was that the collected data was analyzed and interpreted by a single individual, which may introduce personal bias and limit the objectivity of the findings. While every effort was made to remain neutral and consistent in data gathering and analysis, having only one researcher involved reduces the opportunity for multiple perspectives to determine the data. As a result, the insights derived from research may reflect the researcher's perspective more than a collective or balanced viewpoint. This limitation should be considered when interpreting the results and their broader applicability.

A final limitation was the willingness of Creality to release source code and other specifications about the Ender 5 S1. This includes questions about how the printer operates on its own, as well as, how its functionality is affected or enhanced when used with the Sonic Pad. This will severely limit the ability to diagnose issues and identify potential solutions to improve the integration of the Sonic Pad. Since there is minimal access to the code involved in the Sonic Pad, most of the solutions must be reliant on physical changes rather than coding a change, which could provide better solutions.

Summary

Chapter 3 outlines the research process aimed at improving the reliability and quality of 3D prints using the Creality Ender 5 S1 printer with the Sonic Pad. The study addressed various factors such as temperature, speed, retraction, and filament quality, with a primary focus on resolving connectivity issues to ensure proper communication between the printer and the Sonic Pad. Conducted at Millersville University, the research involved isolating the printers from external use to maintain a controlled testing environment. Data was collected based on two main criteria: print completion and quality, which were assessed through factors like flushness of exterior walls, stringing, and surface smoothness. A specific test part was designed to evaluate the printer’s performance under maximum load, with baseline data collected from 120 samples and post-intervention data used to assess the impact of proposed solutions. The chapter also discusses limitations such as environmental factors, filament quality, and restricted access to the source code, which hindered further improvements. Despite these constraints, the study provided valuable insights into optimizing the integration of the Sonic Pad with the Ender 5 S1.

CHAPTER 4. RESULTS

The study aimed to identify and address the challenges associated with optimizing the Sonic Pad into Creality's 3D printers, particularly the Ender 5 S1 3D printer. Through systematic investigation and testing, the primary causes behind the connectivity issues, print failures, excessive stringing, and filament extrusion problems were identified. The implementation of targeted solutions substantially improved the stability and reliability of the 3D printing process. This section discusses the findings concerning each research question and evaluates the effectiveness of the following proposed solutions.

Baseline Data

The following baseline data was taken before any changes or solutions were implemented into the Sonic Pads. Each printer had a total of ten test prints attempted, 120 tests total, to determine if there were connectivity, print completion, and print quality issues. Below is the data collected from the first printer.

Table 1

Example Baseline Data Taken for Printer 1

#1 Ender 5 S1 3D Printer				
	Connectivity Issues? (Y/N)	Successful Print? (Y/N)	High-Quality Print? (Y/N)	Experienced Issues
Test 1	Y	N	N/A	Lost Connection Mid-Print
Test 2	N	Y	N	Stringing, surface roughness
Test 3	Y	N	N/A	Printer not detected
Test 4	N	N	N/A	Extruder exceeded maximum position error
Test 5	N	Y	Y	N/A
Test 6	N	Y	N	Visible layer separation
Test 7	Y	N	N/A	Restart required after crash
Test 8	N	N	N	Shutdown due to Webhooks Request Error
Test 9	Y	N	N/A	Freeze during setup
Test 10	Y	N	N	Restart required after crash
Totals	5	3	1	

This collection sheet was used for the remaining 11 printers within the lab, following the same process, see Appendix A. The results of all twelve printers are as follows:

- Connectivity issues were experienced for 63 of the 120 tests, 52.5%.
- A successful print was achieved for 54 of the 120 tests, 45%.
- A high-quality print was produced for 5 of the 54 successful prints, ~9.25%.

Proposed Solutions

To address the various challenges encountered during the research, a series of targeted solutions were developed and implemented to improve the reliability and performance of the Sonic Pad with the Ender 5 S1 3D printers. These solutions focused on mitigating connectivity issues, preventing extruder positioning errors, reducing emergency shutdown occurrences, enhancing temperature stability, and optimizing print quality. All the solutions were the results of independent brainstorming, experimentation, and testing conducted by the researcher. By incorporating hardware upgrades, firmware modifications, and slicer adjustments, these measures aimed to create a more stable and efficient 3D printing setup. The following sections outline each solution in detail, explaining its optimization and the expected impact on overall print consistency and reliability.

Connectivity

To address the Sonic Pad's connectivity issues, the researcher implemented three targeted solutions. First, replacing the USB-C to ISB-A cable with a high-quality, durable alternative was prioritized. USB-C cables tend to degrade over time, often lasting only a year before failure (Consumer Reports, 2023). To prevent yearly replacements, the researcher investigated USB-C cables with longer lifespans and better construction, minimizing connectivity disruptions.

Second, the cable placement was optimized to prevent unnecessary strain and disconnects. Ensuring that no part of the cable was positioned under the printer while it was active reduced vibrations that could lead to intermittent connectivity issues. Third, while replacing the USB-A plugs inside the Sonic Pad was a complex technical task, the research explored potential methods for reinforcing these connections. The current low-quality USB-A plugs contribute to unstable connectivity, so alternative solutions such as external adapters or improved plug securing methods were investigated.

After these three solutions were implemented, the ten tests were performed on each of the printers again, specifically focusing on the connectivity issues. As seen in Table 2, the connectivity issues experienced during this testing process decreased from 63 to 3 instances.

Extruder Positioning

To prevent the “Error, Extruder has exceeded maximum value in the X/Y/Z axis,” two key interventions were implemented. First, the 3D printers were placed on a stable surface to eliminate misalignment issues caused by vibrations. The researcher observed that a moving desk contributed to a bent limit switch, leading to inaccurate extruder positioning. By relocating the printers to a more stable platform, extruder misalignment was considerably reduced.

The second proposed solution was the implementation of Klipper firmware modifications to adjust the maximum allowable extruder movement distance. The researcher identified that on lines 107 and 119 in the configuration file required a modification from “position_endstop: 220” to “position_endstop: 215” to prevent the extruder from moving beyond its allowable range. Updating this parameter ensured that the extruder stays within its operation limits, eliminating potential damage to the build plate.

After these changes were made, the ten tests were performed on each of the printers again, primarily focusing on the “Extruder Exceeded Maximum Value” error. As seen in Table 2, initially, there were twelve errors related to the extruder’s position, however, once the above solutions were implemented and the test was run again, zero errors were experienced.

Emergency Shutdowns and Webhook Requests

Several solutions were implemented to address frequent shutdowns due to webhook requests. First, adjusting the Sonic Pad’s screen timeout settings reduced most of the accidental activations of the emergency stop button. This change minimized the unintended shutdowns while maintaining accessibility for necessary emergency stops. Second, ensuring that the Sonic Pad firmware is consistently updated prevents the command mismatches between the Sonic Pad and Klipper firmware. The researcher observed that outdated firmware led to repeated errors, which were resolved after applying the latest updates on the Sonic Pad. Implementing a scheduled update procedure should prevent future discrepancies. Third, a solution that was implemented dealt with temperature sensor irregularities. A wire leading to the sensor was getting pinched when the extruder was at the maximum Y-axis position. This caused inaccurate temperature readings and trigger emergency shutdowns.

While each of these solutions helped with limiting the Sonic Pad from giving this error, only one of them showed a considerable impact towards mitigating the issue. When the sensor wire was relocated and secured to a safer part of the printer, as seen in Table 2, only one instance of this error was observed throughout the second testing process. However, while testing the screen time out and the automatic updates, 14 of these errors were observed. Suggesting that the wire was the leading cause of this error.

Overheating and Temperature

To prevent the error message “Error, Temperature Sensor has exceeded its maximum value,” the researcher implemented two key solutions. First, activating the print cooling fan helped to maintain stable extruder temperatures. Although often overlooked, this fan creates airflow that aids in temperature regulation, reducing the likelihood of overheating. Second, addressing the wiring issues that were related to the temperature sensor further enhanced thermal stability. The researcher relocated the sensor wire to prevent the pinching caused by the Y-axis limit, ensuring that accurate temperature readings are sent. As seen in Table 2, there were 7 initial errors related to the temperature sensor; however, once these solutions were implemented, zero errors were observed.

Filament Control and Layer Adhesion

To reduce the amount of filament stringing and improve the first-layer adhesion, the researcher implemented a revised startup GCODE sequence in the Creality Slicer. The new sequence introduced controlled temperature adjustments that prevent premature extrusion and improve adhesion. The following highlighted GCODE lines were added to the existing startup sequence on the right:

```
M140 S65; Print Bed Temperature Set
M190 S65; Wait for Bed Temp
M104 S140; Set Extruder Temperature
G28; Home
G29
M109 S140; Wait for Extruder Temp
G92 E0; Reset Extruder
G1 Z2.0 F3000; Move Z-Axis Up
M104 S180; Set Extruder Temp
M109 S180; Wait for Extruder Temp
```

M104 S210; Set Extruder Temp

G1 X10.1 Y20 Z0.28 F5000.0; Move to Start

G1 X10.1 Y200.0 Z0.28 F1500.0; Draw Line

G1 X10.4 Y200.0 Z0.28 F5000.0; Move to the Side

G1 X10.4 Y20 Z0.28 F1500.0 E30; Draw a Line

G92 E0; Reset Extruder

G1 Z2.0 F3000; Move Z-Axis Up

This updated sequence introduces gradual heating steps, ensuring that the filament does not prematurely extrude during the startup process. Additionally, the controlled movements at the start help to improve first-layer adhesion by optimizing extrusion speed and placement.

Once these solutions were implemented, out of the 120 tests ran, 10 for each printer, premature extrusion was only experienced twice. As seen in Table 2, this error was observed 113 fewer times compared to the baseline testing. However, after determining why the premature extrusion occurred, it was discovered that there was a clog within the nozzle that accumulated enough filament to ooze out at lower temperatures. Also, once this code was implemented, as seen in Table 2, layer adhesion failures decreased from 52 to 2. Most likely, these were caused by outside factors, for example, unclean build plates and humidity levels.

Summary of Improvements

The outcomes of the proposed solutions to the Creality Sonic Pad are presented in Table 2, compares the baseline data collected prior to any modifications with the data recorded during trial 2. The baseline data, see Appendix A, and the trial 2 data, see Appendix B, led to the values presented in Table 2.

The table illustrates substantial reductions across all major categories of printing issues. Connectivity failures decreased from 63 occurrences to 3, while extruder position errors and temperature sensor errors were eliminated entirely. Webhook request errors dropped substantially from 15 to 1, and instances of premature extrusion were reduced from 115 to 2. Similarly, poor layer adhesion issues declined from 52 occurrences to 2. This data demonstrated the effectiveness of the applied solutions in improving printer performance, reliability, and print quality.

Table 2

A Comparison of the Baseline Data and the Trial 2 Data

Issue	Initial Occurrences	After Solutions
Connectivity Failures	63	3
Extruder Position Errors	12	0
Webhook Request Errors	15	1
Temperature Sensor Errors	7	0
Premature Extrusion/Stringing	115	2
Poor Layer Adhesion	52	2

Addressing the Research Questions

After studying and testing each of the proposed solutions above, the data indicated that the solutions substantially decreased the likelihood of the 3D print failing or having subpar quality. Below are what the research determined to answer the research questions.

Research Question 1

The testing conducted before and after the proposed solutions were implemented revealed that the disconnections were primarily caused by three factors: degraded USB-C cables, improper cable placement, and low-quality USB-A plugs within the Sonic Pad. The baseline data indicated 63 connectivity failures, a substantial number of which were traced back to worn-out USB-C cables. Further analysis revealed that the cable positioning underneath the printer contributed to frequent disconnections, as vibrations from the printer's movement caused the cables to disconnect intermittently. Additionally, the low-quality USB-A plugs within the Sonic Pad exacerbated these issues, as even minor disturbances in the connection led to errors. After replacing the cables with more durable alternatives, optimizing cable placement, and reinforcing the USB-A connections, the number of connectivity failures dropped substantially to 3, as shown in Table 2. This data clearly illustrates that these three factors were the reason for the disconnection issues.

Research Question 2

The data collected during testing indicated that filament extrusion during the printer's setup phase was primarily caused by temperature inconsistencies in the default startup GCODE. The high occurrence of premature extrusion, 115 instances in the baseline testing, was linked to the extruder reaching the printing temperature too early in the setup process, which caused filament to leak before printing began. The data showed a considerable reduction in premature extrusion after modifying the startup GCODE, as shown in Table 2, which suggests that the initial temperature settings in the GCODE played a key role in causing this issue.

Research Question 3

The data collected during testing indicated that poor first-layer adhesion was primarily caused by improper extruder positioning and unstable printing surfaces. The high number of extruder position errors, 12 in the baseline testing, was linked to the extruder exceeding its allowable movement limits, which led to misalignment and incorrect nozzle positioning. The occurrence of these errors decreased to zero, as seen in Table 2, after adjustments were made, suggesting that this factor substantially contributed to poor adhesion. Additionally, vibrations from unstable work surfaces were found to exacerbate the issue, as evidenced by the observed improvement in adhesion once the printers were placed on more stable surfaces.

Research Question 4

The data from Table 2 indicated that stringing was primarily caused by improper filament retraction settings, premature extruder heating before the print began, and inadequate cooling during the print. Initially, premature extrusion and stringing were observed 115 times, but after modifications to the startup GCODE, this was reduced to just 2 instances. These changes helped control the extruder's temperature during the setup phase, preventing the filament from leaking prematurely. Additionally, the print cooling fan, which was underutilized in the baseline tests, played a role in improving the overall flow consistency. Once the cooling fan was activated, temperature stability was enhanced, and filament extrusion became more consistent. These findings suggest that both improper temperature control at the start of the print and lack of cooling were substantial factors contributing to stringing.

Research Question 5

The data from Table 2 highlighted several factors contributing to print failures, including emergency shutdowns triggered by the Sonic Pad and Klipper firmware. The "Shutdown due to webhooks request" error, which initially occurred 15 times in the baseline testing, dropped to just 1 occurrence after implementing the proposed solutions. This reduction suggests that firmware mismatches and accidental emergency stop activations were key causes of the failing prints.

While these are very specific factors contributing to print failures, all the previously mentioned issues collectively played a role in causing the prints to fail. According to the criteria used to define a successful print in this research, any instance of a printer disconnection, first-layer adhesion failures, emergency stops caused by temperature sensor errors, and any other errors listed within the research, resulted in the print being considered a failure, as it was incomplete.

CHAPTER 5. DISCUSSION

This chapter presents the final analysis and insights gained from this research, summarizing the key findings and their broader implications in the context of optimizing the Creality Sonic Pad with the Ender 5 S1 3D printer. Through systematic troubleshooting and investigation, the researcher has explored several technical challenges related to the connectivity, performance, and print quality of the Sonic Pad when paired with the Ender 5 S1. The results of this research not only shed light on the specific issues encountered during the integration process but also provide a foundation for future improvements in 3D printing technologies. The findings are discussed in terms of their potential impact on the 3D printing industry, user experience, and future research directions. This chapter also highlights the study's limitations and suggests areas for further exploration that could address existing gaps and contribute to advancing the field.

Implications

This research represents an early exploration into improving the application of the Sonic Pad and aims to pave the way for further advancements needed for the Sonic Pad to become an integral part of 3D printing. By assisting users in troubleshooting and resolving common issues, the Sonic Pad has the potential to attract a more technically proficient and informed user base interested in exploring advanced solutions. Continued progress in the optimization and reliability of the Sonic Pad may contribute to meaningful advancements in technological development, economic growth, and overall user experience. From a technological standpoint, offloading motion planning to a more powerful processor allows for higher acceleration values, leading to faster print speeds without sacrificing quality (Sineos, 2023). Features like input shaping reduce vibrations, enabling high-speed printing without ringing artifacts, while pressure advancements ensure consistent extrusion. As more manufacturers recognize the benefits of implementing a Klipper, it could become a new industry standard, replacing traditional Marlin firmware and fostering universal compatibility among different printer brands. Also, real-time error detection, auto-tuning, and remote monitoring capabilities can drive the adoption of smart, IoT-connected 3D printing systems.

From an economic standpoint, the increased efficiency enabled by Sonic Pads reduces the cost per print, making high-performance printing more accessible to budget users. By allowing entry-level 3D printers to achieve professional-level print quality, the Klippers integration could disrupt the market, encouraging competitors to develop similar or improved controllers. Furthermore, high-speed, high-quality printing capabilities could expand the use of 3D printing in industrial applications such as automotive, aerospace, and medical manufacturing, making small-batch production and rapid prototyping more viable. This increased market competitiveness could push further innovation and drive down costs, making 3D printing more accessible across various sectors.

In terms of user experience, plug-and-play integration makes the Klipper’s advanced features more accessible to beginners, while experienced users benefit from extensive customization options. The open-source nature of the Klipper encourages developers and hobbyists to contribute to firmware improvements, modifications, and third-party integration, strengthening the maker community.

Limitations

Since the research was primarily conducted in one lab and in one location, the issues that were experienced could be caused by an outside factor in that specific room. 3D printing is very sensitive to the humidity levels, room temperature, filament quality, and many other factors. This will always make any of the listed solutions have different success rates when they are implemented outside of that specific room.

Another limitation of the research presented throughout this work is based on the technical knowledge available throughout the research. While there was a wide range of experience in all aspects of 3D printing, the knowledge in coding and firmware experience was lacking during much of the research. This means that most of the solutions are very basic changes that seem to help in the short term. However, long-term solutions may require a more advanced change within the code that was unable to be addressed during the research.

The final, and most likely the largest limitation of this research, is based on the concept that the Sonic Pad was designed and created to work with any of the 3D printers produced by Creality. This research solely focused on the optimization of the Sonic Pad with the Ender 5 S1 3D printer. The Sonic Pad is designed to function with every 3D printer produced by Creality and each printer has a different assembly and components so the solutions proposed within this thesis may not work for a different printer styles.

Future Research

There are many ways that this research can lead to other research areas. The primary investigation that could be done to further the study of Sonic Pad usage, this would be to determine a way to revert the 3D printers back to using their original processor, rather than strictly using the Sonic Pad's. While Creality has a forum out there that describes how to do this process, most users have reported that trying to revert the printers completely breaks it. They mention that the z-axis motor, the z-axis probe, and auto leveling completely break and are unfixable. This research would allow users experiencing issues that were either not mentioned or the proposed solutions do not fix to still have a way to revert back to when the printer was functioning properly.

Another topic that should be researched more thoroughly is changing Creality's Klipper into a more well-known Klipper version. While it was briefly mentioned, there are Klippers out there that are functioning and are open source, so users have been working on perfecting them. Creality designed their own Klipper, which is considerably more difficult to find solutions since it is different than other Klipper versions. The solutions that were mentioned for the other Klippers were tested during the research, but since Creality created one that is completely different, these solutions had no impact on any issues that were experienced. Through researching, experimenting, and implementing a well-known Klipper version into these sonic pads, it would make it much easier to diagnose problems and/or make the integration of sonic pads more successful.

The last suggestion for future directions of the research presented above focuses on recreating or gaining access to the source code of the sonic pad. During this research, there were parts of the source code that could be accessed and changed, but for the majority of it, it was unable to be located or downloaded. By creating a copy of the source code, this would allow someone with advanced coding knowledge to analyze and amend the code so they could eliminate some of the problems with the sonic pad. The solutions listed above were specific to issues that have been experienced; it is almost guaranteed that there are issues that have not been experienced yet and by examining the source code, these issues could be solved before anyone experiences them.

Summary

This study explored five key questions regarding the Creality Sonic Pad optimization with the Ender 5 S1 3D printer. First, *what causes the printers to disconnect?* Analysis revealed that disconnections were primarily due to unstable or deteriorating USB-C cable connections, which disrupted communication between the devices. Second, *what causes the filament to extrude while the printer goes through the setup?* This was found to result from a misconfigured startup sequence that initiated heating too early, leading to premature melting and extrusion of the filament. Third, *why is the first layer not adhering properly?* The issue stemmed from the printer being placed on an unstable work surface, which interfered with accurate bed leveling and reduced adhesion. Fourth, *why is there a large amount of stringing in the product?* The excessive stringing was linked to improper retraction settings and a lack of precise nozzle temperature control. Finally, *why are the prints failing?* Print failures were attributed to firmware mismatches, unstable initialization processes, and inaccurate sensor readings that disrupted the overall printing sequence.

This study investigated the challenges associated with integrating the Sonic Pad into Creality’s Ender 5 S1 3D printers, identifying key issues such as connectivity failures, premature filament extrusion, poor first-layer adhesion, excessive stringing, and print failures. Through systematic testing and troubleshooting, several underlying causes were discovered, including degrading USB-C cables, improper extruder positioning, firmware mismatches, and inadequate startup GCODE configurations.

To address the forementioned issues, a series of solutions were implemented, including replacing USB-C cables, optimizing cable placement, modifying Klipper firmware settings, revising the startup GCODE sequence, and stabilizing printer surfaces. These interventions substantially improved print consistency, reduced failures, and enhanced overall integration of the Sonic Pad with the 3D printing system.

The key takeaway from this research is that while the Sonic Pad presents a promising tool for enhancing 3D printer functionality, its successful integration requires careful attention to hardware stability, firmware compatibility, and print optimization settings. By applying the proposed solutions, users can achieve more reliability and higher-quality prints, ensuring that the Sonic Pad serves is asset rather than a hindrance in the 3D printing process.

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Appendix A

Baseline Data Table

The following tables present the complete baseline data collected for each of the twelve Creality Ender 5 S1 printers prior to the implementation of any modifications. Each table lists the results of ten consecutive print tests, indicating the presence of connectivity issues, print success, print quality, and any observed errors. This raw data serves as the foundation for comparing pre- and post-solution performance.

Table 3

Full Baseline Data Set

Baseline Data				
Printer 1				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Lost Connection Mid-Print
2	N	Y	N	Stringing, surface roughness
3	Y	N	N	Printer not detected
4	N	N	N	Extruder exceeded maximum position error
5	N	Y	Y	N/A
6	N	Y	N	Visible layer separation

7	Y	N	N	Restart required after crash
8	N	N	N	Shutdown due to Webhooks Request Error
9	Y	N	N	Freeze during setup
10	Y	N	N	Restart required after crash
Printer 2				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Minor gaps between outer layers, slight stringing visible
3	Y	N	N	Connectivity issue during startup
4	N	Y	N	Visible gaps in outer wall layers, color inconsistencies
5	Y	N	N	Connectivity issue mid-print
6	N	Y	N	Uneven surface finish, visible stringing in several areas

7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Slight gaps between layers, rough surface finish
9	N	Y	N	Surface smoothness compromised, minor stringing
10	N	Y	N	Visible extrusion inconsistencies, rough finished surfaces
Printer 3				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Inconsistent color on surface, slight gaps between layers
3	Y	N	N	Connectivity issue mid-print
4	N	Y	N	Rough finish, visible stringing along outer walls
5	Y	N	N	Connectivity issue during startup

6	N	Y	N	Minor inconsistencies in extrusion, rough surface finish
7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Uneven surface finish with visible layer lines
9	N	Y	N	Stringing visible on finished print, slight surface roughness
10	N	Y	N	Minor gaps between outer walls, inconsistent color appearance
Printer 4				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Stringing visible on walls, minor surface inconsistencies
3	Y	N	N	Connectivity issue during startup

4	N	Y	N	GCODE successfully executed but surface roughness present
5	Y	N	N	Connectivity issue during startup
6	N	Y	N	Uneven surface finish, visible stringing
7	Y	N	N	Connectivity issue mid-print
8	N	Y	N	Minor gaps between layers, rough surface finish
9	N	Y	N	Inconsistent color appearance, minor stringing visible
10	N	Y	N	Uneven extrusion causing minor gaps between layers
Printer 5				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup

2	N	Y	N	Minor gaps between outer layers, stringing visible
3	Y	N	N	Connectivity issue during startup
4	N	Y	N	Rough finish, slight stringing on surfaces
5	Y	N	N	Connectivity issue mid-print
6	N	Y	N	Stringing visible, rough surface finish
7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Gaps between outer layers, inconsistent extrusion
9	N	Y	N	Uneven surface smoothness, visible stringing
10	N	Y	N	Inconsistent color across layers, minor gaps visible
Printer 6				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues

1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Minor stringing visible, rough surface finish
3	Y	N	N	Connectivity issue mid-print
4	N	Y	N	Uneven layer bonding, visible gaps between layers
5	Y	N	N	Connectivity issue during startup
6	N	Y	N	Rough outer surface finish, visible stringing
7	Y	N	N	Connectivity issue mid-print
8	N	Y	N	Surface not fully smooth, some visible layering
9	N	Y	N	Minor stringing visible on print surfaces
10	N	Y	N	Minor gaps between outer walls, inconsistent color

Printer 7				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues

1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Stringing visible on walls, minor surface inconsistencies
3	Y	N	N	Connectivity issue mid-print
4	N	Y	N	Uneven extrusion causing minor gaps between layers
5	Y	N	N	Connectivity issue during startup
6	N	Y	N	Z-axis calibration successful but rough surface finish
7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Surface roughness, visible stringing along outer walls
9	N	Y	N	Visible gaps between outer layers, inconsistent color appearance

10	N	Y	N	Minor stringing visible on the finished print
Printer 8				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Print completed, but visible stringing on outer surfaces
3	Y	N	N	Connectivity issue during startup
4	N	Y	N	Bed leveling successful but visible gaps between outer layers
5	Y	N	N	Connectivity issue mid-print
6	N	Y	N	Stringing visible, rough surface finish
7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Uneven surface finish with visible layer lines

9	N	Y	N	Stringing visible on finished print, slight surface roughness
10	N	Y	N	Minor gaps between outer walls, inconsistent smoothness
Printer 9				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Print completed successfully, but rough surface finish
3	Y	N	N	Connectivity issue mid-print
4	N	Y	N	Calibration completed without errors, minor stringing visible
5	Y	N	N	Connectivity issue during startup
6	N	Y	N	Smooth print, first layer adhesion good

7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Minor gaps between layers, rough surface finish
9	N	Y	N	Surface smoothness compromised, visible stringing
10	N	Y	N	Filament extrusion stable but with minor layer inconsistencies
Printer 10				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	N	Stringing visible on walls, minor surface inconsistencies
3	Y	N	N	Connectivity issue during startup
4	N	Y	N	Calibration successful but with visible gaps between layers

5	Y	N	N	Connectivity issue mid-print
6	N	Y	N	Smooth print, no issues with GCODE sequence
7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Z-axis calibration successful but rough surface finish
9	N	Y	N	Minor gaps visible between outer walls, inconsistent smoothness
10	N	Y	N	Extruder steps fine-tuned but still minor stringing visible
Printer 11				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
	Y	N	N	Connectivity issue during startup
2	N	Y	N	Gaps between outer layers
3	Y	N	N	Connectivity issue mid-print

4	N	Y	N	Surface roughness
5	N	Y	Y	N
6	N	Y	N	Stringing visible
7	Y	N	N	Connectivity issue during startup
8	N	Y	N	Minor layer misalignment
9	N	Y	N	Inconsistent color
10	N	Y	N	Slight surface roughness
Printer 12				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	N	Minor stringing
2	Y	N	N	Connectivity issue during startup
3	N	Y	N	Surface roughness
4	N	Y	N	Stringing visible
5	Y	N	N	Connectivity issue mid-print
6	N	Y	Y	N
7	N	Y	N	Minor gaps between layers
8	N	Y	N	Inconsistent color

9	Y	N	N	Connectivity issue during startup
10	N	Y	N	Uneven layer adhesion

Below is a numerical summary of the baseline data seen above:

- Connectivity issues were experienced for 63 of the 120 tests, 52.5%.
- A successful print was achieved for 54 of the 120 tests, 45%.
- A high-quality print was produced for 5 of the 54 successful prints, ~9.25%.

Appendix B

Trial 2 Data Table

The following tables compile the Trial 2 results for each of the twelve Creality Ender 5 S1 printers after implementation of the targeted connectivity, firmware, and slicer adjustments. For each printer, ten print attempts are recorded, indicating whether a connectivity failure occurred, whether the print completed successfully, whether it met the high-quality criteria, and any residual issues. These post-solution data provide a direct comparison with the baseline results (Appendix A) and demonstrate the effectiveness of the improvements in reducing connectivity failures, extrusion errors, layer adhesion problems, and other print defects.

Table 4

Full Trial 2 Data Set

Trial 2				
Printer 1				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N

8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 2				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	Y	N	N	Connectivity issue during mid-print
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N

10	N	Y	Y	N
Printer 3				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	N	N	Premature extrusion/stringing
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 4				

Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 5				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N

2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	N	N	Shutdown due to Webhooks Request Error
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 6				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N

4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 7				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	Y	N	N	Connectivity issue during startup
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N

6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 8				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	N	N	Poor layer adhesion
6	N	Y	Y	N
7	N	Y	Y	N

8	N	Y	Y	N
9	N	Y	Y	N
10	N	Y	Y	N
Printer 9				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N

9	N	Y	Y	N
10	N	Y	Y	N
Printer 10				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	N	N	Poor layer adhesion
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N

10	N	Y	Y	N
Printer 11				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N
7	N	Y	Y	N
8	Y	N	N	Connectivity issue during mid-print
9	N	Y	Y	N
10	N	Y	Y	N
Printer 12				
Test Number	Connectivity Issue	Successful Print	High Quality	Experienced Issues
1	N	Y	Y	N
2	N	Y	Y	N
3	N	Y	Y	N
4	N	Y	Y	N
5	N	Y	Y	N
6	N	Y	Y	N

7	N	Y	Y	N
8	N	Y	Y	N
9	N	Y	Y	N
10	N	N	N	Premature extrusion/stringing

Below is a numerical summary of the baseline data seen above:

- Connectivity issues were experienced for 3 of the 120 tests, 0.25%.
- A successful print was achieved for 117 of the 120 tests, 97.5%.
- A high-quality print was produced for 115 of the 117 successful prints, ~98.2%.