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IMPLEMENTATION AND OPTIMIZATION OF THE DELTA 3D PRINTER CONTROL SYSTEM

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Abstract: *This paper deals with the implementation of a control system for a Delta 3D printer, which was carried out to enable its use in educational applications. A detailed diagnostic was performed on essential hardware components of the Delta 3D printer, including the Arduino MEGA, RAMPS 1.4 board, stepper motors and their drivers, micro switches, display module, and other electronics. A customized version of the Marlin firmware, adapted for a Delta configuration, was then installed on the Arduino MEGA microcontroller. Key parameters such as build plate dimensions, print height, Delta radius, motor microstepping, and maximum motor speed and acceleration were configured. To optimize stepper motor performance, reference voltages were adjusted, and TL smoothers were installed to ensure stable and quieter operation. The final system evaluation included measuring motor voltage levels, verifying filament flow rates, checking the dimensional accuracy of printed parts, and validating the parameter setup. After hardware and firmware calibration, various slicing software tools available online were tested and compared. The aim of the analysis was to identify the most suitable slicing software for the optimized Delta system, as well as the optimal configuration of its parameters, in order to achieve the highest possible print quality.*

Keywords: *Delta 3D printer, Marlin firmware, Arduino, TL smoother, RAMPS 1.4, Slicer*

1. INTRODUCTION

Additive manufacturing technologies are experiencing rapid and continuous advancement, reflected in diverse design solutions, a wide range of available materials, and improved device performance. Among the available configurations, the Delta design stands out, utilizing parallel kinematics to achieve high speeds and increased print height. Aside from hobbyist and professional applications, the unique motion geometry and construction of Delta printers make them particularly interesting for educational purposes. For this reason, this project involved the complete hardware reconstruction and software customization of an outdated, non-functional Delta 3D printer, with the goal of integrating it into the university's curriculum. The project was carried out as part of an initiative to enhance practical education in additive technologies, where the optimized device is used for laboratory exercises and the development of practical skills in working with different 3D printer configurations.

The project employed *Marlin firmware* for hardware control, with the Arduino IDE development environment used for optimizing the control code. An Arduino MEGA board was utilized to transmit the necessary control signals.

The implemented technology belongs to the material extrusion process, which, according to the ASTM F2792-12a standard, is one of the seven fundamental categories of additive manufacturing. This method, also known commercially as FFF (*Fused Filament Fabrication*), is based on the controlled deposition of molten material onto a build plate or previous layer through a nozzle [1]. This technology supports the use of various polymers, including PLA, PETG, ABS, ASA, and others.

1.1 An Overview of 3D Printer Configurations Used in FFF Technology

The fundamental 3D printer configurations used in FFF technology are Cartesian, Delta, Polar, and SCARA, shown in Figure 1 [2].

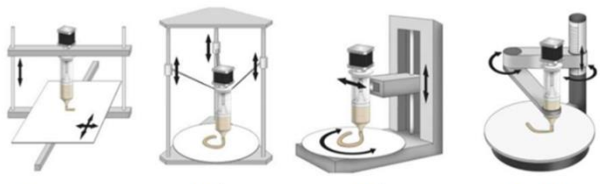


Figure 1. The fundamental 3D printer configurations for FFF technology

Cartesian printers operate based on a rectangular (Cartesian) coordinate system, where linear movement occurs along the mutually perpendicular X, Y, and Z axes. Their rectangular base and simple motion geometry make them easy to construct, which contributes to their widespread use in the market.

Delta configuration printers achieve extruder head movement through three synchronized pairs of rods. The extruder head remains parallel to the build plate at all times. Delta systems are characterized by higher printing speeds, greater build heights, smooth motion, and complex kinematics.

In polar configuration printers, printing is achieved through coordinated movement of the build platform and the extruder head. Typically, the build platform rotates while the extruder head moves along a radial path (spherical motion). A drawback of such systems is the complexity of the motion geometry, resulting in more complex control software. Platform rotation can cause dimensional inaccuracies in larger models and complicate the implementation of a heated build plate, which is essential for printing materials such as ABS.

SCARA (*Selective Compliance Articulated Robot Arm*) configuration printers control the extruder head using two jointed mechanical arms. This setup provides high flexibility and enables fast printing. However, due to the complexity of the motion mechanics, the control system development is challenging.

Many studies emphasize the advantages that Delta kinematics offer in 3D printing compared to traditional Cartesian configurations. In paper [3], it is indicated that the main advantage of delta kinematics is the high speed of the extruder head, enabled by the parallel motion of the platform connected through three pairs of rods. Paper [4] presents a performance comparison between Cartesian and Delta 3D printers. Similar observations can be found in paper [5], and both studies show that parts printed with Delta 3D printers exhibit smoother surfaces and higher overall print quality.

1.2 An Overview of Available Firmware

The two most commonly used firmware options for configuring 3D printers are Marlin and Klipper. **Klipper** is a newer, faster, and more modern firmware solution for 3D printers, offering a wide range of advanced features and a high customization potential. In contrast, **Marlin** is the most widely adopted and traditional firmware, known for its stability, broad hardware compatibility, and strong support from 3D printer manufacturers. While it may be less flexible in some advanced use cases, it remains the standard in many commercial and hobbyist 3D printing setups. Marlin firmware was used in this project, and its customization is presented later in the paper.

1.3 Comparative Analysis of Available Delta Configuration Printers

Additive technologies have become a crucial step in the product development process. Delta 3D printers have undergone significant development and optimization. From devices originally intended solely for hobbyists, they have evolved into professional machines tailored to the needs of industry today.

The first commercial Delta 3D printer was introduced in 2012, marking the start of this printing technology's development. Initially popular for hobby use due to its speed and precision, early models such as the *Anycubic Kossel* and *Monoprice MP Delta* were limited by factors including small build volume, restricted material compatibility, and manual calibration requirements, which reduced their suitability for professional and industrial applications. Advancements in motion mechanics, software solutions, and material compatibility have transformed Delta printers from hobbyist tools into professional systems. Modern Delta printers offer larger build volumes, higher speed and precision, as well as automated bed leveling. Additionally, current models support a broader range of materials, including engineering plastics, composites, metals, and ceramics.

Models such as *FLSUN V400* and *FLSUN S1*, equipped with a temperature-controlled chamber, represent examples of new generation Delta printers successfully used in industry as well as in advanced research and educational institutions. However, as noted in [6], perhaps the primary reason why Delta printers are still predominantly used for hobbyist applications is their limited print accuracy compared to Cartesian systems, due to the relatively lower positioning precision of the extruder head. Cartesian printers have demonstrated smaller deviations from the original CAD models [4].

Table 1 presents a comparison of key characteristics between an earlier-generation Delta 3D printer, the *Anycubic Kossel Plus*, and a modern model, the *FLSUN S1 PRO.*

Table 1. Performance comparison between earlier-generation and modern Delta 3D printers

characteristic	Anycubic Kossel Plus	FLSUN S1 PRO
max. print speed	up to ~150 mm/s	up to ~1200 mm/s
max. print acceleration	up to ~3000 mm/s^2	up to ~40 000 mm/s^2
chamber	no	yes
max. extruder temp.	260 °C	350 °C
print bed temp.	110 °C	120 °C
build volume	Ø230 x 300 mm	Ø320 x 430 mm
dimensions	△380 x 680 mm	550 x 595 x 1030 mm
weight	~7 kg	41 kg
positional accuracy	X/Y axis: 0.0125 mm	X/Y axis: 0.0125 mm
	Z axis: 0.0025 mm	Z axis: 0.0004 mm
price range	$150 – 200	$1 000 – 2 000

The Cartesian Bambu Lab P1 series, priced below $1 000, is comparable in terms of available features to professional Delta printers such as the FLSUN S1 Pro. While the FLSUN S1 Pro is more advanced and professional, both systems include a wide array of features: touchscreen interface, integrated monitoring camera, filament presence and run-out detection, filament tangle and clog detection, vibration compensation, debris and spaghetti detection, automatic shutdown, power-loss recovery, first-layer inspection, and smart zone heating. In contrast, most Delta printers priced below $1 000 typically lack this level of advancement.

2. SOFTWARE OPTIMISATION OF DELTA 3D PRINTER

A detailed diagnostic was performed on the Delta 3D printer. The stepper drivers, motors, micro switches, RAMPS 1.4 board, Arduino MEGA, and display were tested for functionality. Faulty components were identified and replaced.

During the testing phase, several parts were printed, revealing poor surface quality characterized by a ripple effect. This issue was resolved by adding TL smoothers – electronic modules that reduce vibration and noise in stepper motors. This resulted in stable and quieter operation, and improved print quality.

Figure 2 shows the printed parts before and after the installation of TL smoothers. The improvement highlights the importance of proper hardware–software alignment in achieving high print quality.

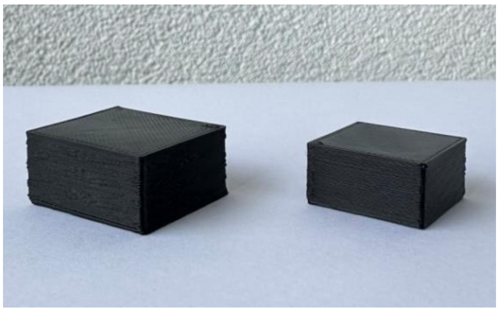


Figure 2. Surface quality before and after adding TL smoothers

A cooling fan was also added to improve airflow over the electronics and ensure thermal regulation of both the electronic components and the stepper motors.

As mentioned, the deployed control software was Marlin, which is an open-source firmware that, when combined with the Arduino Mega board, offers extensive configuration flexibility. Marlin allows users to customize the printer to their specific needs by adjusting parameters such as build volume, maximum speed and acceleration, filament sensor settings, and more. It was necessary to adjust the parameters in Marlin firmware to suit the parallel kinematics of the Delta configuration and the available components of the printer.

In the initial setup phase, it was necessary to define the type of control board using the function **#define MOTHERBOARD BOARD_RAMPS_14_EFB**, where E stands for extruder, F for fan, and B for heated bed. This configuration provides the necessary positions for implementing the part cooling and bed heating.

The next step involves defining the type of drivers. Using the directives **#define X_DRIVER_TYPE A4988**, **#define Y_DRIVER_TYPE A4988**, **#define Z_DRIVER_TYPE A4988**, and **#define E0_DRIVER_TYPE A4988,** all four stepper motors were defined, where the first three are used for positioning the extruder head along the X, Y and Z axes, while the fourth controls filament feeding.

The directive **#define TEMP_SENSOR_0 7** was used for specifying the temperature sensor type, which will enable precise temperature regulation of the extruder head. Since the printer does not include a heated bed, this was indicated by the function **#define TEMP_SENSOR_BED 0**, where 0 denotes the absence of a bed heating system.

The build volume is defined by the base radius and height, using the following lines of code: **#define DELTA_PRINTABLE_RADIUS 87** and **#define DELTA_HEIGHT 260**. To ensure accurate positioning it is necessary to define the rod length, which is done with the function **#define DELTA_DIAGONAL_ROD 210**. This means that the value of rod length is set at 210 mm. The key design dimensions of the Delta printer are shown in Figure 3. Due to positional tolerances, manual assembly cannot guarantee perfect horizontal alignment among all three micro switches, which together define the extruder's home position.

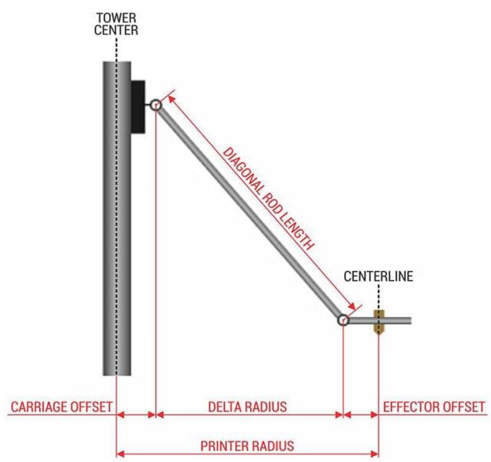


Figure 3. Key dimensions of the Delta printer

This is compensated by using the function **#define DELTA_ENDSTOP_ADJ { 0.0, 0.0, 0.0 }**, where corrected values for X, Y, and Z towers can be inputted in the brackets, respectively.

One of the key factors in maintaining the ideal parallelism between the extruder head and the print bed is a parameter known as the delta radius, which was defined using the directive **#define DELTA_RADIUS 105**, setting its value to 105 mm. The delta radius represents the horizontal distance between the centers of spherical joints located at rod ends, when the extruder head is positioned at the center of the build area. This is illustrated in Figure 3.

Due to angular tolerances, the towers of a Delta printer might not be positioned in the ideal configuration of exactly 120° between each tower, but could be slightly rotated with respect to one another. This can be corrected by implementing the function **#define DELTA_TOWER_ANGLE_TRIM { 0.0, 0.0, 0.0 }**, which allows the precise angular adjustment of the towers. The values in the brackets correspond to the angular corrections for the X, Y and Z towers, respectively.

The following lines of code are used for defining the home position, which in Delta configurations represents the maximum position of the printer's towers. These lines specify the pin to which each micro switch is connected for the respective towers. When a micro switch is triggered, the system recognizes that the corresponding carriage has reached its top position, marking it as the home position for that tower. The code lines mentioned above are: **#define USE_XMAX_PLUG**, **#define USE_YMAX_PLUG**, and **#define USE_ZMAX_PLUG**.

To ensure correct printer operation, it is important to introduce certain hardware parameters into the software. One key parameter is the number of steps per rotation of the stepper motor, which in this case is 200. This value is used to configure microstepping, which is essential for achieving high print quality through precise control of the extruder head's movement. For Delta printers, a common microstepping setting is 1/16 of a full step. The relevant lines of code implementing these settings are as follows:

#define XYZ_FULL_STEPS_PER_ROTATION 200;

#define XYZ_MICROSTEPS 16.

The next hardware parameters that should be introduced are those related to the pulley and belt system. The following lines of code define the belt pitch and the number of pulley teeth: **#define XYZ_BELT_PITCH 2**, and **#define XYZ_PULLEY_TEETH 16**.

Once all these parameters have been defined, it is necessary to calculate the number of impulses (steps) that must be sent to the stepper motors in order to move the corresponding carriage on each tower by exactly 1 mm. This is determined using the following formula:

#define DEFAULT_XYZ_STEPS_PER_UNIT ((XYZ_FULL_STEPS_PER_ROTATION) * (XYZ_MICROSTEPS) / double(XYZ_BELT_PITCH) / double(XYZ_PULLEY_TEETH)).

The next phase involves defining velocities and accelerations, such as the maximum homing speed and acceleration, as well as the speed and acceleration of the extruder head during rapid movement (G0 command). An example of such a directive is the following homing federate setting: **#define HOMING_FEEDRATE_MM_M { (2500), (2500), (2500) }**, where the speeds for each axis is represented in millimetres per minute (mm/min). The adjusted values for these parameters are presented in Table 2.

Table 2. Adjusted speed and acceleration values

characteristic: **speed [mm/s] or acceleration [mm/s²]**	**value for stepper motor**			
	X	**Y**	**Z**	**E0**
DEFAULT_MAX_FEEDRATE *maximum speed for all three axes and filament feeding*	300	300	300	70
MAX_FEEDRATE_EDIT_VALUES *limit value of speed modifiable through the printer's display*	100	100	100	100
DEFAULT_MAX_ACCELERATION *maximum acceleration for all three axes and filament feeding*	3000	3000	3000	2000
MAX_ACCEL_EDIT_VALUES *limit value of acceleration modifiable through the printer's display*	1000	1000	1000	1000
DEFAULT_ACCELERATION *general axis and filament feeding acceleration during G1 commands*	2000	2000	2000	2000
DEFAULT_RETRACT_ACCELERATION *retraction acceleration during filament pullback*	/	/	/	1500
DEFAULT_TRAVEL_ACCELERATION *axis acceleration for non-printing (travel) moves*	2000	2000	2000	/

The default retract acceleration refers to the acceleration applied before or during travel moves, when the extruder head moves from one print section to another, helping to prevent stringing effects.

At this stage, the acceleration profile was set to S-curve acceleration, which provides a smoother transition between speed and acceleration shifts. Instead of sharp shifts, the motion follows a curved trajectory, resulting in more stable extruder head movement and reduced vibration during printing. This was done by implementing the function: **#define S_CURVE_ACCELERATION**. The differences between S-curve and trapezoidal acceleration profiles are illustrated in Figure 4.

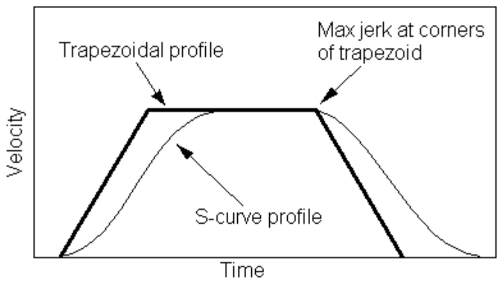


Figure 4. Difference between trapezoidal and S-curve acceleration profiles

The following directives are used to define the homing direction for each of the three towers – X, Y, and Z. The direction is defined with a value of 1 or -1, depending on whether the movement should be upward or downward. Since the home position in Delta printers is located at the top of the towers, and in accordance with previously mentioned directives **#define USE_XMAX_PLUG**, as well as Y and Z, a value of 1 is assigned to ensure that the extruder head moves upward toward the micro switches. These directives are: **#define X_HOME_DIR 1**, **#define Y_HOME_DIR 1**, and **#define Z_HOME_DIR 1**.

In the following step, it was necessary to adjust the reference voltages (**V_{ref}**) on the stepper motor drivers to ensure stable, quiet, and reliable motor operation, as well as to prolong the service life of stepper motors. Excessively high reference voltage values may result in motor overheating and potential driver damage. On the other hand, if the reference voltage values are too low, the motors may lose or skip steps, leading to printing errors and poor print quality.

One of the final steps involved defining the type of display used, which was specified using the directive **#define REPRAP_DISCOUNT_SMART_CONTROLLER**. It was also concluded that the automatic calibration process, based on the Allen key probe, failed to achieve satisfactory results. Subsequently, this function was disabled, and it was decided that manual calibration would be a more suitable approach in this case. Up to this point, the printer's operation could only be controlled through a USB-B connection to a computer. To improve user experience, SD card support was added using the **#define SDSUPPORT** function.

Finally, the printer was personalized by assigning it a name that appears on the display when the device is turned on, using the following function: **#define CUSTOM_MACHINE_NAME "DELTA MAS PRO"**.

Following the software setup, the configuration was thoroughly tested and confirmed, resulting in successful printing of test parts.

3. AVAILABLE SLICER SOFTWARE EVALUATION

After successful testing of the Delta printer, several available slicing software options were analyzed. This included Orca, Cura, Slic3r, an older version of PrusaSlicer, and the latest PrusaSlicer version.

Figure 5 (top) shows the first printed layer using the Cura and Orca slicers, where trajectory errors of the extruder head during infill are clearly visible. In both cases, the areas surrounding the holes were not properly filled, resulting in gaps and incomplete coverage of certain printed zones. Similar issues were observed with Slic3r, where the first layer exhibited irregular extrusion paths around the holes (Figure 5, bottom left). Additionally, parts printed with Slic3r showed poor surface quality due to visible gaps between the infill lines (Figure 5, bottom right). While some issues can be addressed by tuning the print parameters, none of the slicers mentioned delivered satisfactory results using the default settings.

The older version of the PrusaSlicer also exhibited trajectory issues around openings in the initial layers (Figure 7, left), but achieved noticeably better surface quality compared to previously mentioned slicers (Figure 7, right).

Figure 5. Printing defects observed when using Cura, Orca, and Slic3r slicers

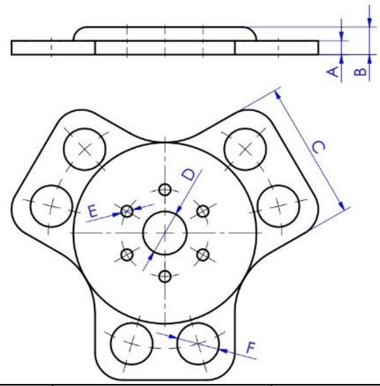
Figure 6. Surface finish obtained using PrusaSlicer

Given that slicer versions also have an impact on the overall print quality and performance, the latest version of PrusaSlicer (version 2.9.2) was installed and tested. This version produced optimal results: motion paths of the extruder head were accurate, all areas were consistently filled, and no defects were observed. Further improvements were achieved through parameter adjustments within the slicer, which offers extensive customization options for its users. A part printed using the updated PrusaSlicer is shown in Figure 8.

Figure 7. Part printed using the PrusaSlicer version 2.9.2

A dimensional analysis was conducted on the part sliced using PrusaSlicer v2.9.2. Table 3 presents a comparison between the nominal dimensions (from the CAD model) and the actual measurements of the printed part.

Table 3. CAD model and Printed Part Dimensions



dimension label	nominal value [mm]	measured value [mm]
A	4	3.98 ÷ 4.03
B	8	8.05 ÷ 8.15
C	40	39.87 ÷ 40.10
D	Ø12.5	Ø12.45
E	Ø3.3	Ø3.28 ÷ 3.41
F	Ø12	Ø11.86 ÷ 12.10

4. CONCLUSION

The Cartesian configuration is the most widely used in the market, but introducing delta printers into educational settings represents a great advantage. It gives students the opportunity to compare different printer designs and understand both their strengths and limitations. Alongside practical experience in additive manufacturing, it also helps students grasp the basics of motion system mechanics.

The goal of the project was to restore the functionality of an outdated delta 3D printer, which was successfully achieved, as parts were printed reliably, with room left for further improvement. Of all the slicers tested, the latest version of PrusaSlicer (v2.9.2) delivered the best surface quality. Dimensional analysis showed that the deviations were within acceptable limits, confirming the device's precision. It was concluded that minor dimensional variations were caused by slight warping due to the absence of a heated bed. The next step in improving the system would be the integration of bed heating to further improve print quality and dimensional accuracy

ACKNOWLEDGEMENT

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