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MAKING A 3D PRINTER OF DELTA CONFIGURATION USING OPEN-SOURCE PROJECT

IZRADA 3D ŠTAMPAČA DELTA KONFIGURACIJE NA BAZI PROJEKTA OTVORENOG TIPA

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Abstract

The term 3D printing is often used as a synonym for Additive Manufacturing or Rapid Prototyping. 3D printing is the technology at the core of Additive Manufacturing, and with rapid development, 3D printers can also be used to make final products. 3D printing is based on conversion of the digital model of the product into a physical, three-dimensional object, in a layer-after-layer manner. The process of 3D printing does not require custom designed tools, while it produces custom designed products, building the object layer by layer, often directly making it on a working platform.

Here the building of a 3D printer is described, following an open-source project for the device Rostock MAX 3D printer, /1/. Components like various joints and rods and essential parts of the 3D printer had to be printed on another 3D printer. Both the printer that was made and the one used for its making have delta configuration, /2/.

After assembling the 3D printer, the calibration should be performed. Upon successful calibration, the 3D printer should be tested by printing a cube, /1/.

Izvod

Pojam 3D štampanje je često korišćen kao sinonim za aditivnu proizvodnju (eng. Additive Manufacturing) ili brz razvoj prototipova (eng. Rapid Prototyping). 3D štampanje je tehnologija, koja čini srž aditivne proizvodnje i, uz brz razvoj i projektovanje, 3D štampači mogu da se koriste i za izradu finalnih proizvoda. 3D štampanje je zasnovano na pretvaranju digitalnog modela proizvoda u fizički, trodimenzionalni predmet, izradom sloj-po-sloj. Proces 3D štampanja ne zahteva specijalno izrađene alate, a pravi finalne proizvode, u skladu sa posebnim zahtevima naručioca (eng. custom designed products), gradeći ove predmete sloj-po-sloj, često i slažući slojeve direktno na radnu platformu.

Ovde je opisana izrada 3D štampača, sprovedena na osnovu projekta otvorenog tipa (eng. open-source project) za uređaj Rostock MAX 3D printer, /1/. Komponente kao što su različiti spojevi i šipke i najvažniji delovi 3D štampača, odštampane su na drugom 3D štampaču. Oba štampača, ovaj koji se izrađuje i onaj koji se koristi za njegovu izradu, imaju delta konfiguraciju, /2/. Nakon sastavljanja i kalibracije 3D štampača, potrebno je testirati 3D štampač štampanjem kocke, /1/.

INTRODUCTION

3D printing is based on one basic principle, converting a digital model of an object into a physical three-dimensional object using layer-by-layer method of building. This way of making the products is significantly different from other types of manufacturing, e.g. casting in moulds or machining parts on CNC machines. The process of 3D printing does not require special tools, and makes the object directly on the work surface, layer by layer. 3D printing used to be the synonym for *rapid prototyping*, however, nowadays it is also used to denote *additive manufacturing*, /1/.

Nowadays, 3D printed objects tend to be more than just 3D models - some of these are finished products, too. 'If a picture is worth a thousand words, a prototype is worth a thousand pictures.'

The process of 3D printing begins with the creation of a digital model using appropriate software (e.g. AutoCAD, SolidWorks, 3D MAX, etc.). The file with the digital model is then imported into software for 3D printer that slices the model into thin 2D layers and translates them into a set of instructions that the printer needs to execute (G-code), /1/.

Here the process of making a 3D printer is described, which was made in accordance with an open-source project, as in /1/. The 3D printer of delta configuration /2/ is chosen following an open-source project for the Rostock MAX 3D printer /3-5/. Nowadays it would not be as affordable as used to be to make homemade 3D printer since complete devices of acceptable performance can be purchased for as little as 250 to 300 euros. Prices have dropped significantly over the past two years. However, making a 3D printer or other device by oneself can be a very interesting way to learn, and it is a successful example of project-based learning.

ROSTOCKMAX 3D PRINTER

A 3D printer can be seen as a robot. Like a robot it is programmed using G-code. As is the case with robots, different configurations of 3D printers exist - to name the two /2/: Cartesian and Delta configuration. Deltabot printers, also called Delta robot printers, use parallelograms in the arms like a robot and have some benefits over the Cartesian configuration. Delta configuration allows for higher speed, because the print-heads are lighter and they use shorter paths to move from one point to another, /2/.

The end - effector in delta configuration is lighter - this is why it has reduced inertia by the end of the movement. Because of this, the 3D printer is able to respond quickly while retaining its high accuracy. With simpler construction this reduces maintenance and costs, /1/.

Rostock MAX 3D printer /3/ is one of the derivations of Rostock 3D printer, which is a linear delta robot prototype /4/, built in 2012 by Johann C. Rocholl in Seattle, USA, and named perhaps after his town of birth. Rostock printer /5/ is considered to be relatively easy to make and assemble, having in mind it consists of less than 200 parts in total.
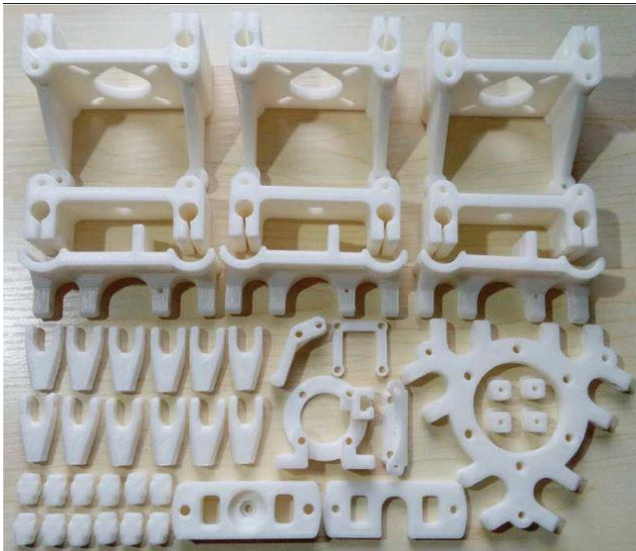

Figure 1. 3D printed parts of the RostockMAX 3D printer frame, /1, 6/ (source: https://www.thingiverse.com).

The Rostock MAX 3D printer is chosen for this project since it has stable construction, lightweight end effector with hot-end, fixed base surface, adjustable print surface (heated glass), delta configuration, and adjustable height of the print (therefore, adjustable build volume, too), /1/.

THE FRAME AND HOUSING OF THE 3D PRINTER

A variety of designs and suggestions for the items to 3D print, including the parts for building the Rostock MAX 3D printer can be found on the web, e.g. /6/. Components like various joints and rods and essential parts of the 3D printer, Fig. 1, /6/, had to be printed on another 3D printer for this project. Both the printer that is made and the one used for its making are of delta configuration.

The dimensions of plates that make up the printer housing can be either specified by the user or downloaded as a CAD document, containing blueprints with required dimensions.

Figure 2, /1/, shows the blueprint of the base and top of the housing of a 3D printer, also available in open-access on the Internet. The housing should be made of solid and firm materials such as metal, wood panels, or PVC (polyvinyl chloride). Wood panels are chosen here since they meet the specified criteria: these are affordable, easy to process and to obtain. Depending on the thickness of the wood plate and the budget available, panels can be cut on a CNC machine or by hand, where precision is very important, /1/.
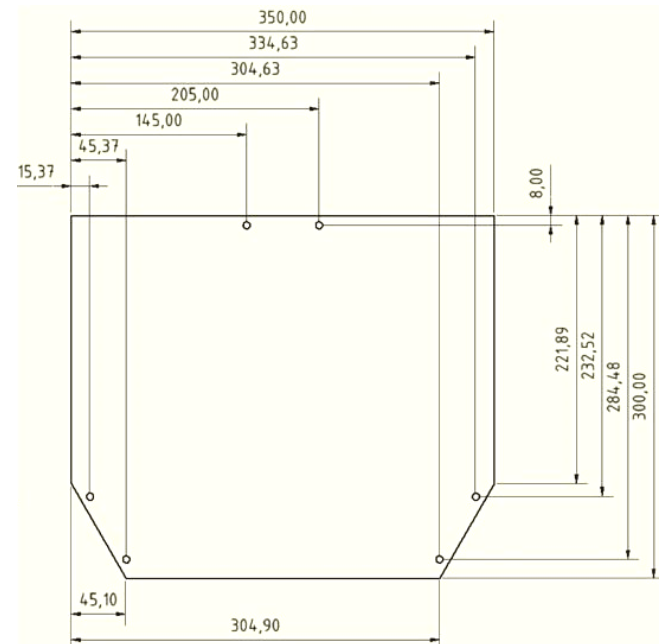

Figure 2. Blueprint of base and top of the 3D printer casing, /1/.

Some of the parts can be purchased in stores for hobbyists, like rods made out of stainless steel and carbon tubes for robot's arms. In order to complete the 3D printer housing, smooth stainless steel bars from cold-rolled steel are needed, having 8 mm diameter. These bars hold the housing plates and provide a specified height of the 3D printer and serve as leads for printer arms. These bars are mounted through the wooden boards and brackets which are 3D printed in advance. After assembling the frame of the housing, the arms and printer brackets are to be mounted. The wrists (hinges) and support for the extruder should be 3D printed in advance. The printer arms can be 3D printed or made of various light materials (wood, aluminium, plastics, etc.). The best choice for arm material are carbon tubes, as they are strong enough, and at the same time extremely light. In Serbia, these can be found in several stores that sell materials and equipment for modellers. After the length of the arms is determined and the joints and hinges put into place, arms are assembled with the head support (for extruder) at one side, and with the hinges connecting them to lead rods at the other side. This concludes the first phase of this project.

ELECTRONIC COMPONENTS FOR THE ROSTOCK MAX 3D PRINTER

Electronic components for the Rostock 3D printer can be bought separately, but the cost-effective choice is to buy the electronics in a set from many available online stores, /7-

14/, etc. Data sheets and mounting instruction can be found online, too. One available kit is on the photo in Fig. 3, /8/.

Figure 3. Kit with electronic components for the Rostock 3D printer, /8/.

RAMPS 1.4 is one of the most commonly used control electronic boards for RepRap machines since 2014. RAMPS stands for RepRap Arduino Mega Pololu Shield. RAMPS 1.4 consists of a RAMPS 1.4 case, an Arduino Mega 2560 board (or its clone) and a maximum of five Pololu stepper motor driver carrier boards. RAMPS 1.4 has numerous pins which provide power for and receive signals from stepper drivers, heat bed, hot-end, end-stops (limit switches), and contains resistors and other passive electronic components that enable synchronized operation of 3D printers, /1, 10/.

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 microcontroller. It has 54 digital input/ outputs, 15 of which can be used as PWM (pulse width modulated) outputs, 16 analogue inputs, 4 UARTs (universal asynchronous receiver transmitter), 16 MHz crystal oscillator, USB (universal serial bus) port, power supply connector (a power jack), ICSP (in circuit serial programming) header, and a button for master reset /11/. The Arduino Mega 2560 board is to be mounted to the back side of the RAMPS 1.4 board using provided pins, /1/.

Stepper motor drivers are specifically designed to drive stepper motors capable of continuous rotation with precise position control, even in systems without feedback. Pololu stepper motor driver carrier boards offer adjustable current control and multiple step resolutions and have built-in translators that allow the stepper motor to be controlled by two inputs - number of steps and rotation direction. Here, the Pololu stepper motor driver A4983 carrier boards are chosen. These modules are generally basic carrier boards for various stepper motor driver ICs (integrated circuits) that offer low-level interfaces such as inputs to directly initiate each step. An external microcontroller is usually required to generate these low-level signals, /1, 13/.

Mechanical endstops are chosen for limit switches. This is the simplest type of endstop: a mechanical switch set to

trigger when the 3D printer's axis reaches the end or start position of its motion - here the top position of arm's shoulder along vertical bars. Mechanical switches are cheaper and less complicated to implement than optical end-stops because they use only 2 wires to connect and do not require a separate printed circuit board for control, /1, 14/.

Bill of materials (BOM) includes also /1/: four NEMA 17 stepper motors, LCD (liquid crystal display), extruder, hot-end, thermistor (one or two), power supply, timing belts and pulleys, and heat bed.

LCD is an electronic display module and finds a wide range of applications and the one used here has 16×2 form, 16 characters in 2 rows, /1/.

A stepper motor is an electromechanical device that converts electrical pulses into discrete mechanical movements.

Extruder is a set of parts that handle the feeding and extrusion of filament - printing materials. It consists of two subassemblies: a cold end for feeding-in the thermoplastic filament and pulling it out of the wound spool, and a hot-end that melts and squeezes the thermoplastic filament. Hot-end refers to the part of extruder which is heated up high enough to melt plastics, or other printing materials. The hot-end is made of materials that can withstand heat up to ~240 °C. The 'hot-end' usually refers to the very tip of the extruder because it should be the hottest part, /1/.

Thermistors are resistors that change resistance with a change in temperature. In most 3D printers, the thermistor detects the temperature of the hot-end. Often another thermistor is used to detect the temperature of the heat bed. The good property of a thermistor is a predictable, accurately known value of its resistance at any temperature in its operating range. Thermistors can be either PTC (with positive temperature coefficient) or NTC type (negative temperature coefficient), /1/.

The most important part to ensure that the 3D printer will operate is power supply. The standard minimum output power for 3D printers is usually 240 W (12 V voltage at 20 A current). Power supply taken out of computers or for LED lighting can be used as well /1/.

Regarding the use of 3D printers, accuracy is a key to get good results. When the timing belt (transmission) for a 3D printer is adjusted, it is very important to make sure that its movements are controlled and accurate as much as possible. Using a stepper motor can help provide advanced control, but it is useless if the timing belt falls off. That is why 3D printer belts are often made to fit into gears, with many notches on one or both sides. The drive gear (leading barrel) is attached to the stepper motor, and the belt fits into the teeth of the gear, preventing it from slipping, and allowing it to rotate with the stepper motor shaft.

The heat bed is an optional 3D printer module; however, it is strongly suggested that it should be added. The heat bed provides better printing results by making cooling process of 3D printed materials controlled. The heat bed also prevents problems such as poor adhesion of the printed object to the working platform, poor adhesion between layers of the printed object, heat loss during printing, and bending of the final product, /1/.

CONNECTING ELECTRONICS AND PRINTER ASSEMBLY

After all necessary components are gathered, connecting the electronic components should be done as well as connecting the electronics to the mechanical parts of 3D printer.

All electronic components are to be connected to the RAMPS 1.4 control board, to appropriate ports, which is relatively easy to complete following instructions and data sheets for RAMPS 1.4 board and the connection and wiring diagram shown in Fig. 4, /1, 10/.

It is important to choose the right connection diagram. Having in mind that there are several models of 3D printers, this should be in accordance with the design of the printer that is being built (here Rostock MAX). For Rostock MAX 3D printer, 4 step motors with step drivers are necessary, one

step motor for each axis (X, Y, and Z) and one step motor for the extruder. Three mechanical endstop switches are needed, one for each printer arm. There are two thermistors (temperature sensors), one for the hot-end, and another for the heat bed. These are basic components. Optional components often are one or two cooling fans and an auto levelling switch, /1/.

The temperature at the hot-end is a very important parameter of the 3D printing process. This is why the hot-end is equipped with thermistor and with a fan, too. Adding layer upon layer of semi-molten plastics can create a weak point in a 3D printed part. If the temperatures of the hot-end are too low for extruding the filament material, this may result in a poor layer bonding strength. Both problems cannot always be detected until harm is done and those situations experienced. Experimentation and research are necessary before 3D printing produces a usable item, /15/.
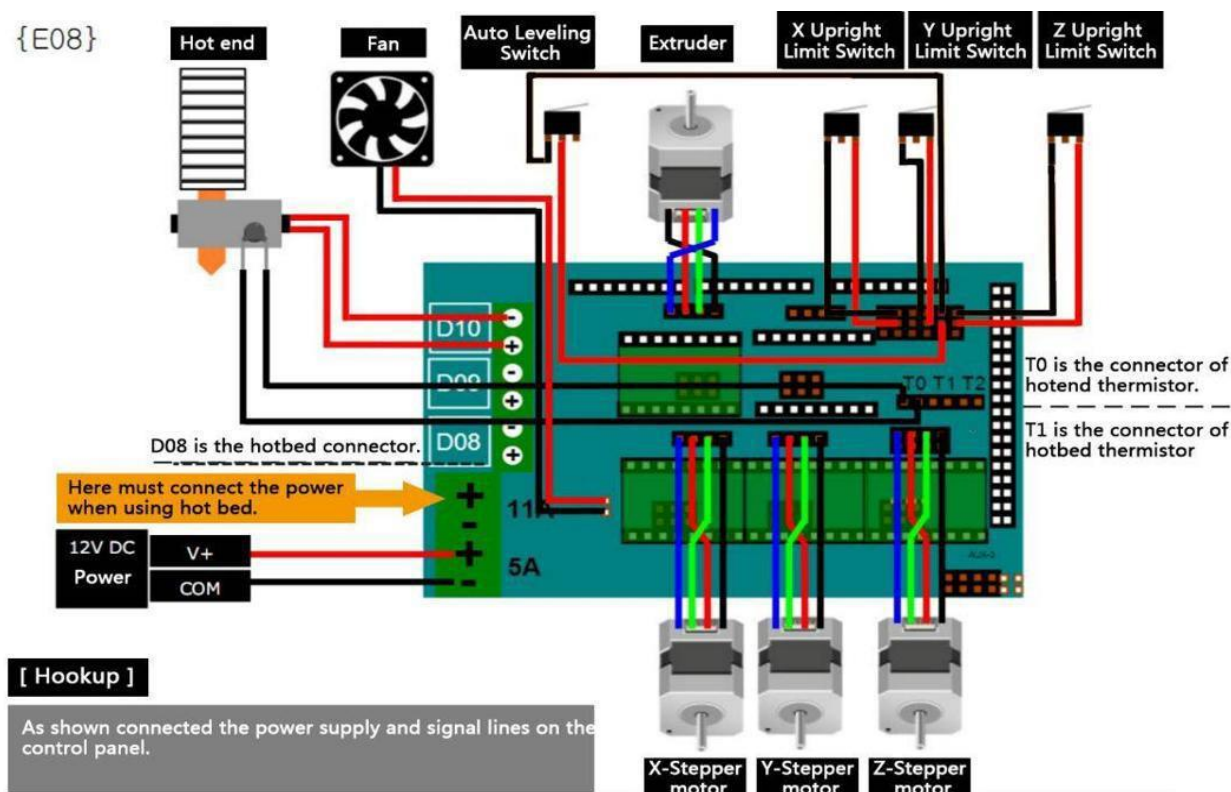

Figure 4. RAMPS 1.4 wiring and connection diagram (source: www.reprap.org).

The very important phase in assembling a 3D printer is to connect the electronics to the printer body. The first step here that can be done is mounting the extruder and hot-end on the brackets. The extruder is mounted on the printer housing, and since it stores and feeds the hot-end with the filament, it is important to leave enough spare space between the extruder and the nozzle, because in this case the extruder is fixed, and the nozzle moves during printing. For better printing quality and to avoid filament feeding problems, the floating extruder can be used. The extruder is not mounted on the housing in this kind of implementation, but directly above the hot-end, and in order to avoid the weight overload on the nozzle, the string is connected to the upper part of the extruder with a counterweight on the other side. By applying this method, the floating extruder moves together with the hot-end, always maintaining the same distance between the

two. The counterweight cancels the weight of the extruder making it easier to move and more manoeuvrable, /1/. The floating extruder is shown in Fig. 5, /16/.

The next component to be mounted is a hot-end with a thermistor. It is mounted on a pre-printed bracket that is attached and connected to the arms of the printer. The hot-end is placed into this bracket in a specified position and attached with screws. It is very important that the hot-end remains firmly mounted on this bracket, /1/.

Heat bed or heated bed is mounted on the lower part of the printer and at the lowest level reached by the hot-end. Before the heat bed is fixed in its place, a thermistor is mounted on the backside of the heat bed, fastened with a Kapton tape. The Kapton tape has large range of temperature stability as well as ability to make electrical isolation. The thermistor is electrically connected to a specific input of the

RAMPS 1.4 board. Heat bed is fixed to the 3D printer with screws on previously drilled holes in the lower plate of the printer housing frame, as is shown in Fig. 6, /1, 16/.

Figure 5. Floating extruder with hot-end (photo and 3D printer made by M. Aleksandrović), /16, 17/.
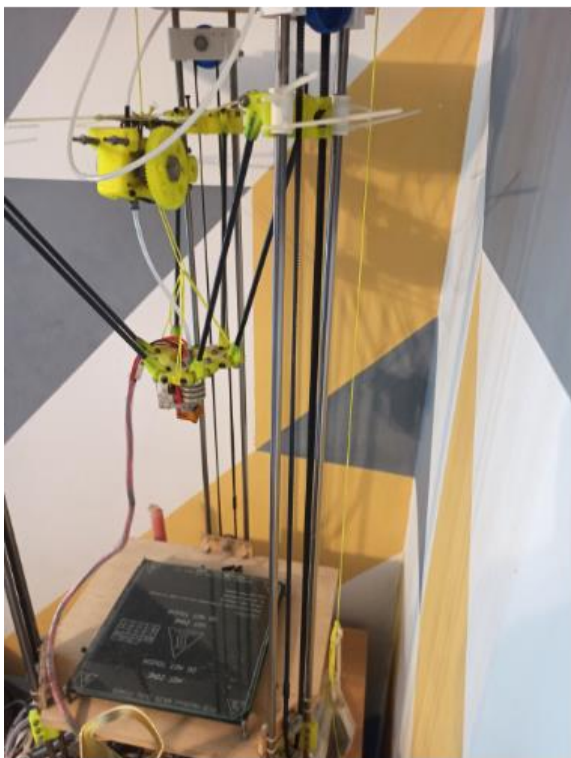

Figure 6. Home-made 3D printer Rostock MAX completed - heat bed is visible at the base of the printer (photo and 3D printer made by M. Aleksandrović), /16, 17/.

The three mechanical endstops are placed in the upper part of the printer, to detect when the brackets reach the top position on the gliding bars. When activated, endstops halt the operation of the stepper motor, which has to happen when the shoulders of robot arms reach the maximal vertical position. Endstops are mounted close to the gliding bars, using pre-printed brackets, and are electrically connected to the RAMPS 1.4 board, /1, 16/.

Three NEMA 17 stepper motors are mounted using pre-printed brackets, at the bottom of the gliding bars of the 3D printer. Each of the three stepper motors controls gliding of brackets along one of three bars, providing positioning of the extruder and the tip of the printer nozzle. The bodies of the three motors are turned inwards, while the motor shafts are pointed out, to provide mechanical coupling to gears (toothed pulleys) and timing belts. The fourth stepper motor is feeding the filament to the extruder, /1, 16/.

The timing belt is placed on the pulley of the stepper motor at the bottom of the printer, and on the ball bearing on the upper part of the housing and is also attached to the bracket which is gliding along bars. The part of timing belt goes through the notch provided on the bracket, which is connected using hinge to the shoulder of the robot's arm. The timing belt must be well tightened to provide the fast movement and positioning of the arms with high precision.

The power supply, RAMPS 1.4 and Arduino 2560 boards, LCD display and cables can be kept near the printer, but it would be desirable to provide a compartment for these components in the printer's base stand. With this, assembling of the 3D printer is finished. Completed home-made Rostock MAX 3D printer is shown in Fig. 6, /16/. How the printer works can be seen in a video on YouTube, /17/.

CALIBRATION OF THE 3D PRINTER

After assembling the 3D printer, calibration is performed. Calibration can be so time consuming and demanding that companies selling 3D printers are sometimes offering it as a service. Both mechanical calibration as well as software calibration has to be done, and both can be very complex and time consuming, /1/.

Mechanical calibration demands physical actions on the printer to ensure its accurate and smooth operation. The straps and timing belts have to be tightened so that they are not loose. Timing belts at the same time should not be subjected to excess tension because that may impede precise and smooth movement of the printer arms. Mechanical endstop switches must be placed at a certain height, all three at the same distance from the printer stand. The heat bed must be tuned into the best possible fit for horizontal position. The platform of the heat bed and printing base surface must not be inclined, i.e. it must be parallel to X and Y axes. This levelling is achieved by adjusting the screws that connect the heat bed to the printer stand. The last step of the mechanical calibration is to set the stepper motor operation. Stepper motors must run smoothly and quietly, without vibration and without skipping steps. These settings are made on the step drivers located on the RAMPS 1.4 board. There is a potentiometer on every Pololu stepper motor driver carrier board, which can be turned with a Phillips screwdriver and

tuned in a position where the stepper motor works smoothly. The RAMPS board is sensitive to static electricity build-up, and it is wise to use a ceramic screwdriver for this tuning, /1/.

After mechanical calibration is achieved, the 3D printer is connected to the computer and the software is uploaded to it. Software calibration can be described as giving the data to the brain to let it know all it has to know about the body it should be controlling /1/. Software calibration can be exhausting and cumbersome process for someone who is not skilful in programming. However, open-source software systems are available on the Internet, /18-21/, containing pre-configured programs which allow most relevant data to be entered or changed in accordance with the parameters of the printer to be calibrated, /1, 16/.

There are many software systems offered, either open or vendor type. Marlin from Arduino is an open-access software most suitable for software calibration of delta 3D printers. Using Marlin software, the programming and synchronizing of 3D printers are obtained after entering all relevant data, e.g.: the precise characteristics of printer's modules and parts, the length of printer arms, the height of mechanical endstop switches, the settings of maximum temperature of hot-end and heat bed, LCD specification, stepper motor synchronization (for each of all three axes and the one for extruder), and so on, /1, 16/.

CONCLUSION

The world is inevitably changing with the help of 3D printing. The use of this technology in various industries seems promising now, but what the future could bring is unknown. It is certain that 3D printing will take an important role in solving many problems. This technology has a variety of applications, and its potential is still evolving. It seems obvious that the more funding and research is dedicated to 3D printing, the more benefits from it would be obtained.

The potential and importance of 3D printing in education is obvious, especially in project-based learning or teaching the STEAM subjects (Science, Technology, Engineering, Arts, and Mathematics). A process of making a 3D printer is described here, as an example of project based learning. Open source blueprints are used for the Rostock MAX 3D printer project. Plastic parts vital for printer operation are 3D printed on another printer of the same type. After assembling the 3D printer, mechanical and software calibration is done to achieve better printing performance. Printer operation is video documented on a YouTube channel.

The assembled 3D printer was tested by the appropriate procedure. The presented project is a useful option of implementation in higher vocational education.

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