Design of Triaxial Production Device

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Like most new technologies, 3D printing has long been a domain of narrowly specialized fields. However, the potential of this technology is enormous and thus it has been gradually finding its application in ever-newer sectors. This paper focuses on the structure and overall implementation of a triaxle manufacturing device inspired by an existing 3D printer design based on the modular RepRap concept. The result is a functional triaxle manufacturing device capable of performing 3D printing and laser cutting or laser engraving.

Keywords: Manufacturing equipment, Laser engraving, FFF technology, ZMORPH 2.0 SX

1 Introduction

Rapid prototyping is a series of manufacturing methods for producing prototypes in the shortest possible lead times, based on a computer-aided (CAD) design of a feature model. The first attempts at 3D printing are attributed to Dr. Hideo Kodam of Japan for his rapid prototyping technique in May 1980. He was the first to describe the principle of incremental deposition of layers one on top of the other, usable in production. Three years later, Charles Hull made the first device using this technology. In 2004, Dr. Adrian Bowyer began working on the open-source RepRap (Replicating Rapid Prototyper) project, with the interest of creating a 3D printer that would be able to print at least the majority of the components the printer itself consists of. As a result, a 3D printer called Darwin, based on the idea of a modular design concept RepRap, was constructed in January 2008, first released to the public as a patented retail version called BfB RapMan. Thanks to the initial idea of creating a self-reproducing machine, a growing community of enthusiasts has obtained a powerful tool for creating new designs and concepts. [1]

RepRap devices are mostly based on Fused Deposition Modeling (FDM), a modeling method using the concept of fusion, extruding material in the form of either a thin, semi-molten fiber, paste, solution or reaction material to create a cross section of a designed component. This additive technology includes Fused Filament Fabrication (FFF), described in more detail below. [3] Furthermore, the technologies such as Fused Deposition of Ceramics (FDC), Low-temperature Deposition Manufacturing (LDM), Precise Extrusion Manufacturing (PEM), Rapid Prototyping Robotic Dispensing (RPBOD), Bioplotter techniques and other belong here, too.

2 Classification of manufacturing devices by the number of working axes

The individual axes for each individual type of machine are determined on the basis of a normal coordinate system, also called a Cartesian coordinate system that is associated with the given machine. Marking of coordinate axes and movements of individual CNC machine nodes is due to the unification and introduction of a particular system and order into construction of these machines.

This Cartesian coordinate system is a tri-axis one, composed of rectangular coordinates marked X, Y, Z, and is oriented so that its axes are parallel to the guiding surfaces of the machine. The coordinates of the moving tool are determined by the previously defined set, relative to the workpiece, where the positive direction of the motion causes the workpiece to be larger in size. This is true for both, the tool motion relative to the workpiece and for the workpiece motion relative to the static tool. The rotational movements of individual axes of the coordinate system are marked in capital letters (A, B, C) as can be seen in the following figure.
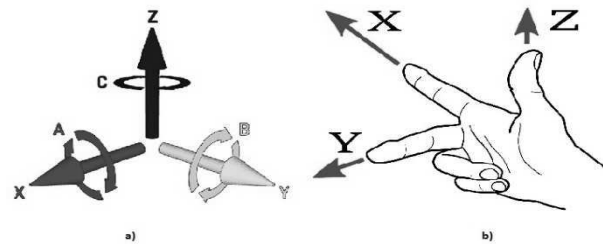

Fig. 1 *Cartesian coordinate system (a.), Right-hand rule (b.) [6]*

Tool movements are marked by letters without the apostrophe, and the movements of the workpieces are marked by letters with the apostrophe (e.g. X'). The positive direction of direct and rotary motion of the coordinate system axes is determined by the rule of the right hand, when the right-hand thumb points to the positive direction of the motion in the triaxle system, and its fingers point to the positive direction of rotation around the axis. In order to determine the exact position of the tool and the workpiece in the machine in the given coordinate system, points are defined in the workspace of the machine (the reference point of the machine, the zero point of the tool and the workpiece), through which it is then possible to determine and check the position of the tool. [5]

In evaluation of the sophistication of the manufacturing machine design, one of the indicators is the number of axes of its coordinate system that may be simultaneously engaged in the process of machining. Based on this number of axes, the machine can be classified according to the so-called 1D to 5D machining, where the number in front of "D" indeed denotes the number of axes.

The classification includes the following:

- **single axis machining (1D)** engages one basic motion, along one axis. An example of this 1D machining can be e.g. a single-purpose drilling machine,
- **double axis machining (2D)** uses simultaneous dual axis control. An example of this type of machining can be a conventional milling machine (X, Y axes) or a lathe (X, Z axes) where, for example, when the milling machine assumes the cutting depth (Z axis) and as a result of machining (along the X, Y axes) performs more than just the motion along 2 axes, i.e. we deal with a pseudo 2.5D machining
- **triaxle machining (3D)**, three axes, X, Y and Z, are driven simultaneously, an example of which is a three-axis CNC milling machine,
- **five-axis machining (5D),** 5 axes are driven simultaneously in course of machining. This type of machining mainly includes machining centers.

The three-axis CNC control elements of a manufacturing device are capable of performing simultaneous dual and triaxle machining. This is possible in biaxial combinations by moving the work table or cross slide along XY, XZ or YZ planes at a preset path and distance from the spindle or the thread of the machine. Three-axis combinations can machine surfaces of more complex forms. With the simultaneous movement of the X, Y and Z axes, the precisely controlled path can be combined by linear and circular interpolation to create the desired shape of the workpiece surface that previously required to pass through multiple operations. [6]

3 Design types of 3D printers

Design of 3D printing devices can widely vary, also thanks to the RepRap concept. At present, four basic types of design are used, which are often modified or combined with industrial robots, mobile devices or conveyors.

- Scara type printer - this printer design is rather rare, in spite of the design simplicity. Their disadvantage is the need to compensate for the height of the nozzle which varies according to the distance in which the arms are located. The principle of these printers lies in the motion of the robotic arms with the print nozzle located at their ends. [2]
- Polar printer type – this design is yet in the experimental stage. In essence, it is the simplest possible design of a 3D printer that unlike other types uses only 2 motors for movement along the X and Y axes. However, the complication is the need to rotate and move the base plate that provides for the motion in the Z axis. [7]
- XYZ printers - Printers using the Cartesian coordinate system, of a rectangular frame, in which the nozzle moves along the X, Y, and Z axes. This printer type is one of the most common. The principle of their activity lies in moving the print head along three axes perpendicular to each other. The nozzle moves in any direction along one of these axes within the defined space. [7]
- Delta printer type - this type of design is inspired by industrial robots. Its design, unlike the classic XYZ printer, is a bit more complicated, the motion in individual axes is estimated by trigonometry. In spite of more complicated mathematics involved in moving the printer head, Delta printers are faster, more accurately, and more versatile than the XYZ printers, as they can print rather tall objects. [7]
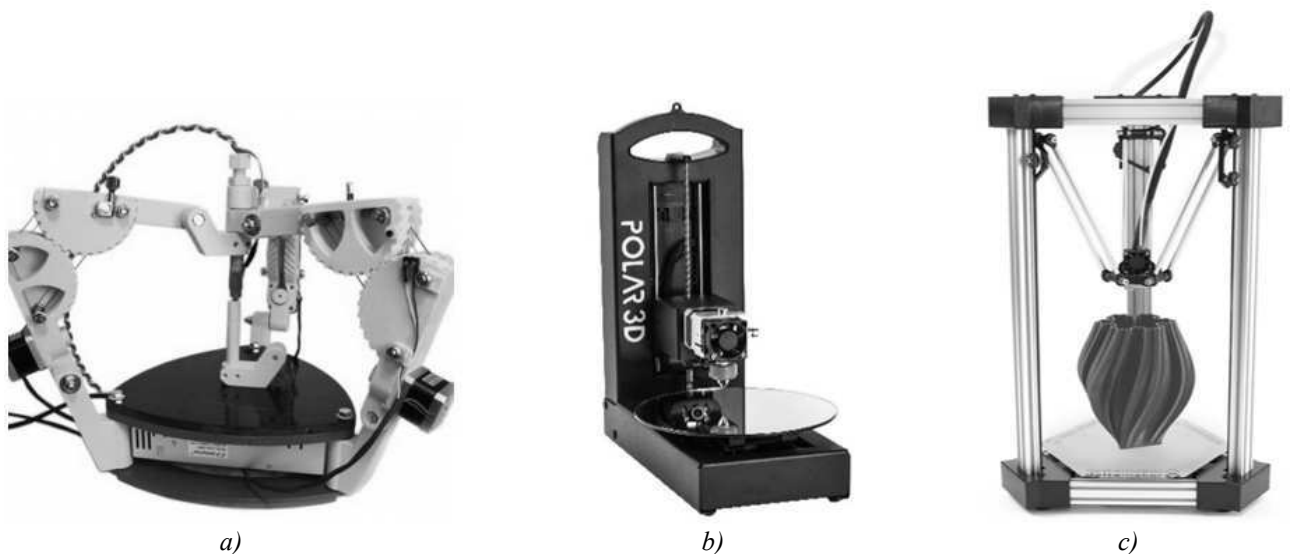

a)   *b)*   *c)*

Fig. 2 *3D printers of scara (a.), polar (b.), XYZ (c.), delta (d.) type Spatial printing with robots [9]*

Technology capable of creating architectural designs using 3D printing and a mix of concrete has been known for several years now. Relatively large dimensions of the devices used for these purposes are known, too. The "Minibuilder" robot is one of the answers to the question of the dimensions and limitations of these devices. Robots work in two phases, the first builds the foundation with a robot capable of following the outline indicated on the base slab. After the so-called foundation is created, a grip robot is placed thereon, as can be seen in Fig. 3b, which actuates itself to "climb" the structure it is itself creating. Using this technology, it is possible to create stand-alone, efficient and high-quality mobile device that is not limited by a dedicated workspace and that will be capable of performing 3D printing as well as using other manufacturing technologies.

3&Dbot
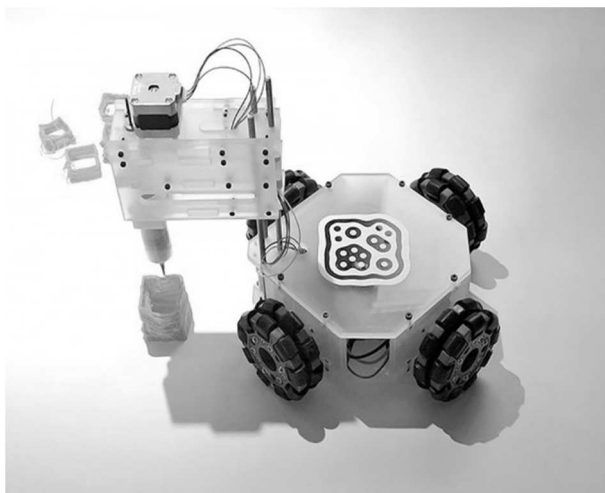
a)

b)

Fig. 3 *3&Dbot (a), robot minibuilder (b)*

Current devices operating on the FDM principle or similar technology are limited by the values of the X, Y, and Z axes along which they can move within their workspace. The 3 & dbot device is currently being built in a way as not to be restricted by these parameters. This is a 3D mobile printer that is capable of producing several times larger products than its size. The device works on the basis of a video traction system that ensures its precision and positioning at the point of its operation, ensuring the accuracy of the 3D model in the process of creation. The robot communicates with a computer using a built-in wireless device, making it capable of impressive accuracy. Thanks to the wheel design, a smooth change in the direction of the robot's rotation is possible without rotating its structure, and thus the extruder. The movement of the device in terms of motion along the X and Y axes is not constrained by anything but the flatness of the surface on which it is moving. The motion along the vertical Z axis is possible even without a complicated attached extruder structure, the robot simply "manufactures" a temporary structure on which it places itself and which moves the robot in the vertical direction by the value required. [9]

4 Triaxle Device Design

Factors influencing the design of a manufacturing device, such as a 3D printer, are one of the most important factors in terms of print quality and reliability. All other parts of the 3D printer may be in absolute order, but if the printer frame is poorly built, the print results will be poor, too. The printer frame's task is not only to hold all the printer's elements together, but also to be stable and properly attached. It must withstand the momentum and inertia forces caused by the mass shifting along the printer axis, as well as to maintain the axis, along which the mass is currently transported, in a straight line over its entire length, and to maintain the calibration of the printer under constant motion, vibration and stress. 3D printers based on a Cartesian coordinate system are by far the most used on the consumer or professional market, mainly because of the simplicity of mathematics involved in regulating their motions. Other design types, such as Delta printers, require trigonometry even for as easy a motion as is the motion along a single axis. The Cartesian coordinate system uses a ground-based way of defining a point in a three-dimensional space. This point is easily defined by its X and Y coordinates in the 2D plane. Its third coordinate Z adds third dimension to this point, namely the height of its position in the 3D space. [8]

Based on the assessment of different types of 3D printer designs and the possibility of their combining with various structurally more complicated devices, we choose a modified delta printer for our design. More specifically, it is a modification of the effector of an existing Kossel mini printer design. The design of the delta type is chosen because of its speed and complexity, the structures enable faster and more precise positioning, especially in the Z axis. The design and modification of the effector structure consists in its modification so that the printer can be used in other technological operations, e.g. in milling and laser cutting as is the case with a similar multifunction device of ZMORPH 2.0 SX type.

Fig. 4 *Delta type design*

Zmorph 2. 0 SX

The device is currently one of the most innovative in the field of FDM technology. Its design is tailored to the use of as many as several print heads that allow for not only the classic FDM printing with a single or double print head of 1.75mm diameter, but a headset installation that enables a complete change to the technology for which the design of similar devices was being developed originally. The design of individual heads similar in shape, as we can see (Fig. 3), allows them to be easily exchanged, for example, to turn the device into a milling machine (Fig.3a). That is, the device can work on the completely opposite principle than the original FDM extruder. Alternatively, the use of a laser head (Fig. 3b) equipped with a 2W laser diode, allows for cutting or engraving materials such as paper, cardboard, plywood and other. [8]

Fig. 5 *ZMORPH device with exchangeable heads, laser (a), milling spindle (b) [6]*

The main results are:

1. The result of the work is a functional design of delta version. The advantage of this design is the large working space in the Z axis as well as the empty conical space between the load bearing arms of the working head.
2. A structure capable of operating as a multipurpose manufacturing device. It allows for storing even larger work tools and auxiliary spindles. The structure contains enough space for attachment and storage of the individual exchange tools and the container, e.g. for resins and other suitable liquids.
3. Integration of the 3D printer, laser engraver, milling machines for printed circuit boards and resin dispenser in one unit. The individual anchor points are designed to achieve the optimal distance of the work module from the zero coordinate of the Z-axis of the workbench. The distance of the print nozzle, the length of the milling cutter and the laser module are taken into account. Fine adjustments are possible with a mechanical touch probe.
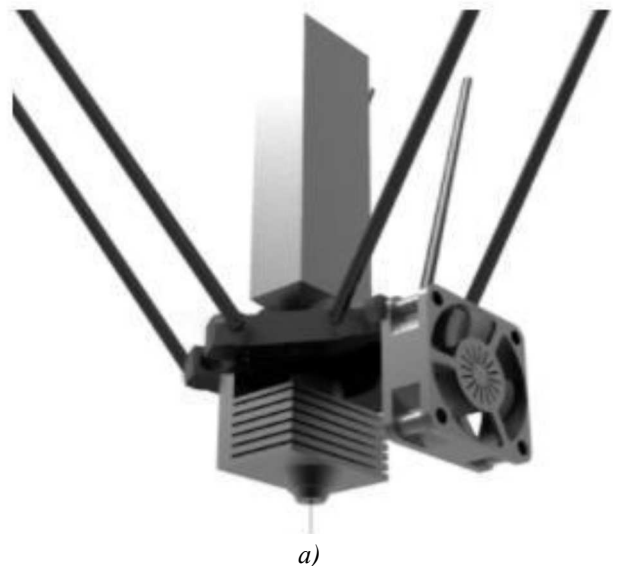

a)

b)

Fig. 5 *Replaceable print heads and their applications to delta, laser (a.), milling spindles (b.) [8]*

5 Conclusion

The design of the final structure of the production device was inspired by the existing RepRap designs, the Kossel mini 3D printer design, which is a modified version of the delta design. The model focuses on structural modification that will translate into creation of room for location and handling of devices such as laser and milling head. Inspiration for its creation was an existing device of the ZMORPH 2.0 SX type, of a similar multifunctional design type. This model was created in the form of a complex CAD model with corresponding dimensions and individual structural elements corresponding to the required real model of a part of the manufacturing device. This paper describes the resulting functional model that is capable of performing the 3D printing process and the cutting process or, alternately, laser engraving and simple milling to form printed circuit boards.

Acknowledgement

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