Design and Implementation of 3D Printing Using a Universal Printing System on the Robot Arm UR5

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***Abstract* – The combination of two rapidly evolving technologies such as additive manufacturing technology and robotics opens up a wide potential for solving new production tasks. In advance, several challenges need to be addressed in order to intensify the possibilities for developing the combination of these technologies. The aim of the article is to point out the possibility of designing a simple universal printing system for the collaborative robot UR5 with an orientation on the need to implement 3D printing. The solution proposed in this way makes it possible to simplify the design of the movements to reduce any further structural modifications and also to reduce the potential mechanical deficiencies of the structure of the printing device.**

***Keywords* – 3D printing, UR5 collaborative robot, robot programing, universal printing system**

1. Introduction

The production of moving parts, composite structures made of various composite materials and large format printing are areas of technology that are actively pursued by a number of researchers around the world. Most currently used 3D printing devices are based on the portal movement of the printing system.

However, a significant disadvantage of portal-designed 3D printer constructions is the limiting spatial movement of the print head in the Cartesian coordinates x, y and z directions. To overcome these limitations, the design of a universal printing system connected to a robotic arm was considered. One of the basic pillars for modernization, restructuring and more complex automation in the production system is robotics. The main changes that modernization has brought to robotics technology are the improvement of technical parameters of equipment and high reliability in the production process. [1], [2] Robots can also be used for unconventional production technologies, where the robot works with water jet, laser or 3D print head to provide a description of movement in complicated spatial curves. [3] Thanks to these innovations it is possible to reduce innovation and production time to the required minimum. In the production area during machining, robots are used to change the workpiece, measure the accuracy of production, change tools, etc. In the non-production area, they are rather used for maintenance or service. In order to increase the flexibility and productivity of production it is necessary to include not only automation, but especially cybernetics and IT. [4], [5] These production implementations would not have been achieved without industrial revolutions and their development. The ever-increasing demands on the quality and greater production of products also result in the constant development of robotics and automation. It is no longer enough just to adjust the increasingly complex technological process. It is necessary to improve and modernize the end effectors of robots, robot construction or automation as a whole. [6]

Additive manufacturing allows the production of complex shapes with a high degree of freedom compared to conventional manufacturing techniques, such as injection moulding, thermoforming or compression technology. [7], [8] With these

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conventional manufacturing techniques, designers need to consider several steps. Addressing these disadvantages opens up new possibilities for 3D printing. The 3D printing technique produces components directly generated from a computer designed in a CAD system which significantly reduces production time. The entire design process, from conceptual ideas to product production, is usually managed by a single designer. It is robotic 3D printing using FDM technology that eliminates the main drawback of traditional 3D printing and thus the dimensional limitation is given by the design of portal printers. [9] Therefore, its use is focused mainly on industries such as interior design and construction. One of the pioneers in the use of robotics and 3D printing is engineer Ascan Aldag, who is a participant in the engineering art of connecting these technologies. Instead of using models only to print small concepts, he uses robotic printing to make interior products with complex geometry. Platt Boyd came up with the idea of a process for making the walls of buildings with 3D printing, called Cellular Fabrication. They feature Branch's patented 3D printing technology which uses KUKA's large robotic arm to print objects in the open, rather than in confined areas, as seen in other traditional 3D portal printers. CyBe Construction offers 3D concrete printing services to clients in all aspects of the construction industry worldwide. CyBe hardware, software and learning materials simplify the usually complex construction process and make 3D concrete printing accessible to everyone. Thanks to short cycle times, fast changes and accuracy, mobile 3D printers are the perfect answer to the challenges in construction [10].

The aim of the article is to point out the possibility of designing a universal printing system for the collaborative robot UR5. The article deals with the design and implementation of 3D printing using a 3D printing pen 3D Simo Multipro in conjunction with the arm of a collaborative robot UR5 providing the main movement of the print head needed for 3D printing. The design was implemented in order to ensure 3D printing with FDM technology using the necessary equipment and software. A more detailed description of the obtained results is described in the content of the article. At the same time, the procedure of creating and modifying the control program for a collaborative robot generated in the simulation software RoboDK and a demonstration of the subsequent implementation of product production in the laboratory are presented.

2. Robot Selection and Printing System Design to Provide 3D Printing

The Universal UR5 collaborative robot was chosen to implement the 3D printing design. The robot is suitable for work in laboratory conditions, as it is a light and flexible robot. The UR5 robotic arm makes it possible to handle 6 axes with a load of up to 5 kg at a tool speed of approx. 1 m/s, with a working range of 850 mm with a repeatable positioning accuracy of +/-0.1 mm specified by the manufacturer. It is suitable for cooperative processes such as e.g., manipulating, storage, machining, assembly and others. [11] The UR5 robot is easy to program, cooperate and offers quick action settings. Thanks to the integrated safety functions and restrictions, it stops when in contact with humans, thus guaranteeing the safety of human-robot work. The manufacturer states the participation of 15 safety functions to ensure the operation of the equipment specified in EN ISO 13849: 2008 PL d EN ISO 10218-1: 2011.

The 3D Simo Multipro printing pen was used as the printing device. It is a 3D pen weighing 70 g which can work with materials ABS, PLA, PETG, HIPS, WOOD and nylon in the form of a fibre with a diameter of 1.75 mm. The diameter of the replaceable pen nozzle is 0.5 mm with a maximum adjustable temperature of 250°C intended for 3D printing. When using extensions heads, it can reach an adjustable temperature of up to 450°C. The pen makes it easy to create 3D models with high precision by extruding fast-setting heated material which creates a solid and stable structure of the manufactured product. The pen can be used to create products directly on the pad or the ability to create 3D objects in free space. At the same time, it is used to repair 3D models and devices made of plastic materials, even with more complicated 2D and 3D geometries. The control itself is realized by means of buttons and OLED display on the body of the pen or by means of an available mobile application interface connected by Bluetooth technology. Other possibilities of use and application of the pen are soldering, firing, drilling, screwing or cutting plastic with a resistance wire.

Figure 1. shows a design for attaching the pen to the robot support flange. To hold the 3D printing pen, a holding jig was designed and manufactured in accordance with the dimensions of the support flange of the robot arm. To ensure accuracy, the 3D printing pen was digitized into the computer environment by scanning technology. Subsequently, the model of the fixture in the CAD software was modified and printed by a 3D printer for its final completion.

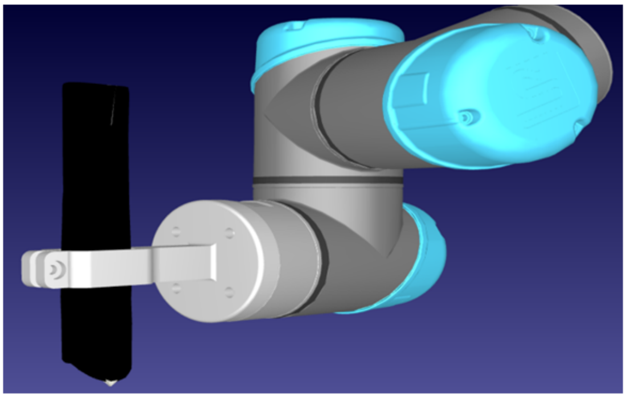

Figure 1. Design of the pen attachment to the robot support flange

3. Software Selection for Creating a Robot Control Program

RoboDK software was used for virtual workplace design, simulation and control program creation which enables creation of control program for UR5 robot [12]. The individual steps of the program design procedure up to the actual implementation of the loading into the robot control unit can be schematically shown in Figure 2. The great advantage of RoboDK software is offline programming and motion simulation of a wide range of industrial as well as collaborative robots. Creating a virtual environment for process simulation is very intuitive and fast in this software. At the same time, it supports the creation of programs for a large number of other types of robots without the need to constantly learn to program in a new programming language and software environment supplied by the manufacturer of the specifically used robot.

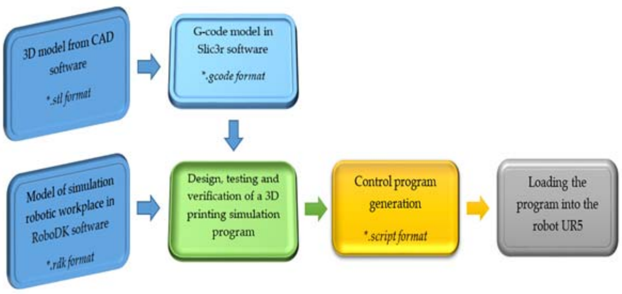

Figure 2. Flow chart from design to implementation of 3D printing application

The software enables the design of programs for the use of the robot arm as a manipulator for pick and place applications, laser cutting of material, 5-axis CNC milling machine, as well as a tool for solving the design of robot movement for 3D printing. [13] It also offers the possibility of simulation and conversion of NC program into G-code, APT or DXF files with the possibility of loading the generated program directly into the robot control unit with automatic optimization of the movement of the robot arm axes. [14] At the same time, it ensures trouble-free operation of the robot without the occurrence of unwanted collisions by verification of simulation. [15] in Figure 3. shows an example of the designed workplace and simulation of the movement of a robot providing 3D printing in the RoboDK software environment.

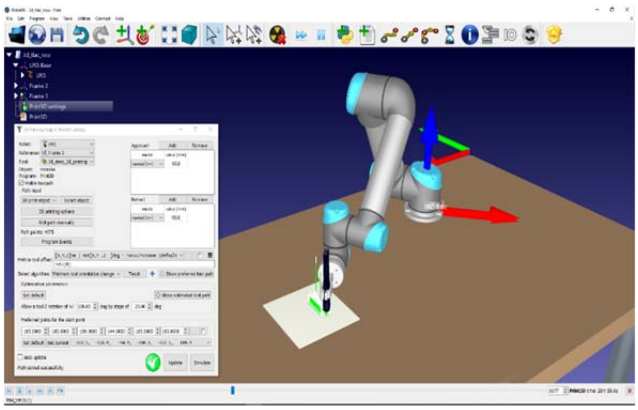

Figure 3. Simulation of the proposed robot movement program in the RoboDK software environment

3.1. *Software Selection for G-code Generation*

To design the program using RoboDK software, it was first necessary to select the appropriate software for creating the G-code of the printed model which will be loaded into the software environment. G-code is a text entry in a format readable for a specific type of commercially available commercial 3D printer or CNC machine on the market. It stores information about the coordinates of the printhead nozzle trajectory, the amount and type of material needed to produce the products, speed, temperature, time, feeds, the support material used and many other important parameters for the production. By entering the required values, the program is ready to be loaded into the printing device with the achieved accuracy and quality of production. The selected software Slic3r, which we can see in Figure 4., enables the creation of the G-code necessary both for the control of the 3D print head (material dosing) and for the creation of the robot movement program itself (path, feed and movement speed). Slic3r is currently one of the most popular freeware tools for generating G-code 3D models in *.stl format. Using the available tools, it is possible to perform a number of basic tasks needed to prepare data for 3D printing. Furthermore, it is possible to manipulate the object in the software environment, change its location on the desktop or change the scale and size of the printed object. The main benefits of the software include:

- three-dimensional preview of the printed model,
- automatic editing of model files,
- possibility of different print settings for several models in one printing operation,
- optimization of the generated code,
- open-source license with availability for Windows and Linux platforms.

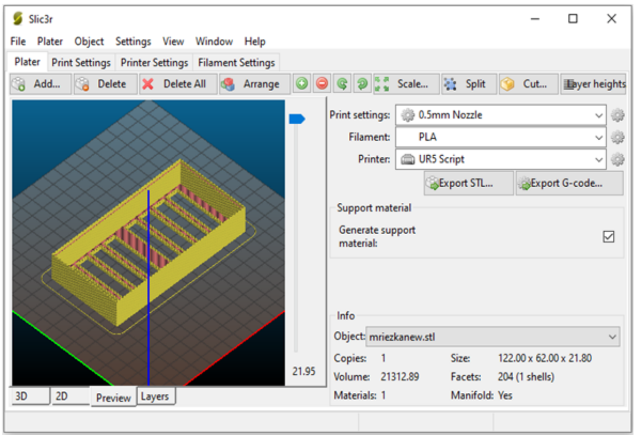

Figure 4. Simulation of the proposed robot movement program in the RoboDK software environment

4. Realization of 3D printing by Robot UR5

The robot movement program was loaded into the environment of the robot control unit for printing by means of the generated text entry of the program *.script file from the RoboDK software environment. Figure 5. shows a script code read in the teach pendant of the robot UR5, which provides real-time information for controlling the robot. This record is read from the USB key and partially modified for the needs of robot motion control. By obtaining the correct notation, it is possible to verify and implement the movement of the robotic arm. [16]

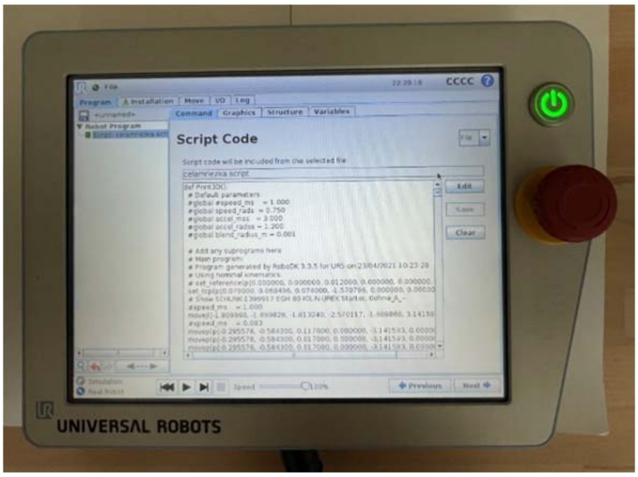

Figure 5. Script code in the teach pendant environment of the UR5 robot

In Figure 6. there is an illustration of the implementation of 3D printing by means of a printing pen mounted on the flange of the UR5 robot arm. In the design of the program for the robot and the G-code of 3D printing, the settings of the nozzle diameter of 0.5 mm and the applied layer of material 0.4 mm were considered. The printing temperature was at 180°C without the participation of a heated pad. The material used for the printing was PLA in the continuous application of a layer of material by a pen nozzle on a pad. As auxiliary material for surface treatment of the pad were used tape and dispersion glue.

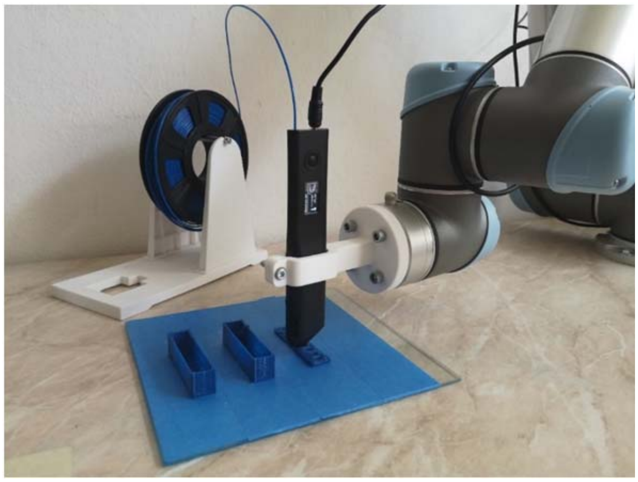

Figure 6. Realization of 3D printing by robot UR5

The implemented design was focused on the creation of a universal printing system for a robotic arm in order to develop the formation and creation of oversized components for prototype production. Part of the implementation of 3D printing was the design of a clamping member for tool heads in the form of a 3D printing pen with attachment to a robotic arm. The main task was the design and production of a functional unit of the printing system consisting of a replaceable printing nozzle and a process medium feeder in the form of a fibre with a diameter of 1.75 mm. Another task was the creation and optimization of post-processors for the proposed production solution. The advantage of this design is the work with a diverse range of printing fibres and flexible materials, thanks to the possibility of setting the working melting temperature of the fed material. The disadvantage of such a combination of devices is that the printing system is able to work only with plastic fibre with a diameter of 1.75 mm and the ability to print only by continuous application of material for 3D printing. By using the compact design of a 3D printing pen, it is possible to turn almost any robotic arm into a 3D printing system, mainly due to its low weight and small dimensions.

5. Conclusion

Although 3D printing in connection with robots is progressing more slowly than we are willing to admit, in the future we can expect their normal deployment in everyday life. Along with the further improvement of robots and technologies, it will be common for humans to use these technologies. Compared to conventional technologies which take material in the production of the model, additive technologies create the shape of the model by gradual addition of material that is in the form of fibre, photopolymer, powder, melt, etc. With regard to the technologies of individual additive processes, their complexity and the need to use stationary constructions of a 3D printer, it follows that the best solution for combining 3D printing with robotics is the application of individual layers using material extrusion – the FDM technology. By combining two advanced technologies into one unit, an interesting idea can arise how to create a device for printing larger and more complex products. Thanks to the availability of the UR5 robot and the available working conditions, it was decided to implement the 3D printing design through the designed universal printing system and the robot arm. The implementation of 3D printing consisted in the design of the selected 3D printing pen as the main part of the designed printing system and knowledge of the work of programming the collaborative robot UR5 with a description of the individual steps and settings. Due to the small dimensions and low weight of the used printing pen and the designed jig for its attachment, the manipulation by means of the robotic arm was problem-free with the required maximum load capacity on the flange of the robot arm and thus the accuracy of its positioning was not reduced. 3D printing was tested and successfully implemented in laboratory conditions with the achievement and verification of the required goals. All necessary movements of the printing system during production were performed by means of a robotic arm. A great advantage of such a design is the possibility of printing more complex shaped surfaces of products, as the robot arm can work in 6 axes of rotary motion compared to a conventional 3D FDM printer. Another advantage is the possibility of printing larger parts, which is limited by the maximum length of the arm and the size of the work pad.

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