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SIMULATION PROJECT DESIGN OF THE ROBOTIC 3D PRINTING PROCESS

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Abstract: *3D printing technology offers not only the possibility of rapid production of models, samples or prototypes of components at any stage of development, but mainly the possibility of producing a whole range of modifications and structural arrangements of the proposed product, without the use of specialized production equipment of the final product, molds and tools. The article deals with the simulation design of a workplace in the Robot Studio software environment for 3D printing with a robotic arm using the designed print head, the creation of a robot control program for additive manufacturing and the actual production of the selected object in laboratory conditions. The sequence of steps in the initial stages of the design of the virtual workplace model, the 3D printing model and the complete processing of the simulation design project for the generation of control programs for the implementation of the production process are described in more detail.*

Key words: *3D printing, ABB RobotStudio, ABB IRB 140, Simulation of robot 3D printing, Design, FDM technology.*

1. INTRODUCTION

We are currently experiencing a significant rise in 3D technologies globally. Fused Deposition Modeling (FDM) is an additive manufacturing process that belongs to the group of material fusion. In FDM, an object is assembled by selectively depositing melted material layer by layer in a predetermined way [1]. The materials used are thermoplastic polymers in the form of fibres. Compared to other 3D printing technologies, FDM is the most widely used, especially between designers and engineers when creating models and prototypes in the pre-production stages [2, 3]. FDM is a part of the group of 3D printing technologies that originated as a tool of Rapid Prototyping (RP) technique. Commercialised in the late 1980s, RP methods allow the rapid production of a model, sample or prototype based on a 3D model created in a CAD system or from 3D scanned data obtained by spatial digitization (Fig. 1). Compared to conventional manufacturing methods, the production of a prototype using RP methods takes significantly less time [4, 5].

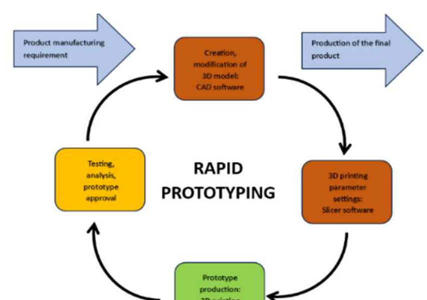

Fig. 1. The process of designing and manufacturing components using Rapid Prototyping technology.

In order to take full advantage of Rapid Prototyping, it is important to properly integrate the entire product development workflow and incorporate RP technology into the development cycle. The advantage of this method is not only the possibility of rapid production of models, samples or prototype at any stage of development, but especially the possibility of producing a range of modifications and design configurations of the designed product, without the use of end product production equipment, moulds and tooling. [6]

The creation of moving parts, composite structures made from different composite materials and large scale printing remains extremely challenging and is being actively researched [7]. Existing 3D printing systems are based on a gantry movement system; the movement of the printer head. As a result, the gantry dimensions of the design limit the movement of the extruder head in the x, y and z directions [8, 9]. To overcome these limitations, the development of robotic systems has been initiated to simplify processes, reduce additional designs and reduce potential mechanical flaws in the design [10, 11]. Considering the technology of the individual additive processes, their complexity and the necessity to use stationary 3D printer designs, it follows that for the combination of 3D printing technology with robotics, the best solution for the creation of large-scale components is in the form of material extrusion - FDM technology [12, 13].

The paper focuses on the design of a printing system using an E3D Hemera print head controlled by an Arduino Uno microcomputer controller. The print system is mounted on an ABB IRB140 robot arm providing the main motion of the print head for the additive manufacturing process.

2. DESIGN OF 3D PRINTING SYSTEM

The Hemera extruder from E3D was used for the design of the printing system. The basic parameters that the extruder has are:

- Motor: 2-phase stepper motor with adjustable filament feeder tension
- Maximum 3D printing temperature: 285°C
- Extruder weight: 388 g
- Nominal motor steps: 409 steps/mm at 1/16 motor step setting
- Filament diameter: 1.75 mm

In terms of shape requirements, it was necessary to design a jig (Fig. 2) to connect the contact surfaces of the robot arm flange and the extruder in the shape of a cross. The designed cross shape sufficiently tolerates the mechanical loads the fixture is subjected to due to the overload effects caused by the high accelerations during the movement of the robot with the extruder. The offset contributes significantly to the rapid changes in extruder angular momentum and to the stresses on the holder during accelerations resulting from achieving the high required precision of the robot movements.

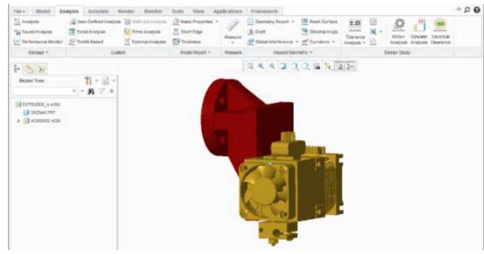

Fig. 2. Design of the fixture for attaching the print head to the robot flange.

An Arduino Uno programmable control unit with a DRV 8825 stepper controller was chosen to process the analog signal generated by the robot program to adjust the nozzle heating, control the fans and material feeder. The analog signal represents the feed rate value of the extruded filament. The Arduino Uno controller reads this signal at the input port, then converts it to the desired value in the program and generates a STEP frequency output pulse for the stepper controller. The pulse frequency is the transmitted value of the filament feed rate. To control the DRV 8825 stepper motor driver, it was necessary to set up and connect the inputs and outputs as shown in Fig. 3.

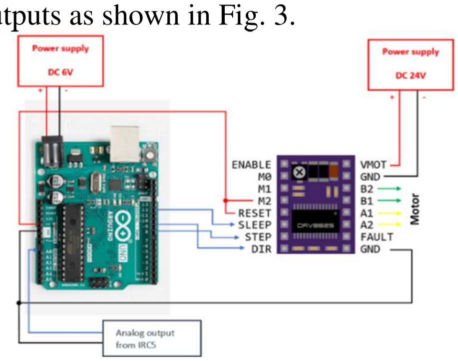

Fig. 3. Connecting the Arduino Uno control board and the DRV 8825 controller.

- DIR - signal generated by Arduino Uno, determines the direction of the stepper motor
- STEP - signal generated by Arduino Uno, frequency step pulse
- SLEEP - signal generated by Arduino Uno, protection of the current load of the DRV 8825 driver
- RESET - the signal is permanently connected to +5V, the function is reversed
- M2 - signal is permanently connected to +5V, determines the value of the step resolution 1/16 step

- A1, A2, B1, B2 - outputs to stepper motor coils
- A0 - analog input signal from the robot controller IRC5

3. DESIGN OF SIMULATION MODEL IN ROBOT STUDIO 3D PRINTING POWER PAC

The simulation and program generation of the 3D printing robot was created in the Robot Studio software with support for the 3D printing module. In generating the simulation, the design of the 3D printing system structure was completed and mounted on the robot arm. The simulation project includes an ABB IRB 140 robot, a workbench, a Hemera extruder with holder and the actual object selected for 3D printing.

The first step was to add the robot and the virtual robot controller to a new Robot Studio project, which can be done using the program's online library. A model in *.stl format was used to import the extruder model with the holder. with a modified coordinate system that was created in PTC Creo Parametric. The coordinates of the coordination system of the new TCP tool were set according to the measured coordinates of the point that was created in the nozzle tip of the extruder model. The addition of other components (workbench and print object) was implemented based on the object reference settings found in the robotic work environment shown in Fig. 4.

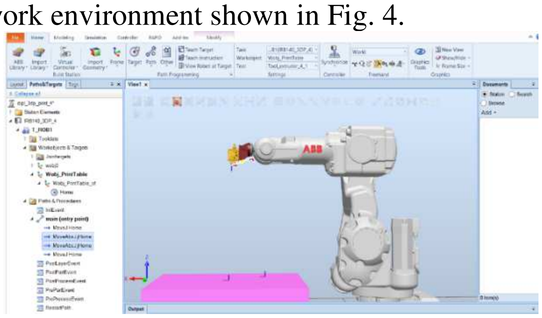

Fig. 4. Created robot 3D printing workplace.

This position in the project represents the place intended for testing the quality of the extruded filament and setting the correct temperature of the extruder nozzle heater outside the 3D printing work area.

The PrintL instruction is part of the 3DP application of the new IRB140_3DP_4 virtual unit, but in order to use it in the Robot Studio 3DP project, you need to add the PrintL instruction to the Instruction Template. All settings made in the Project Station such as the creation of the TCP Tool_extruder_4_1, the 3D printing reference position - Wobj_PrintTable and the Home position of the robot are synchronized with the Rapid modules of the virtual unit.

After checking all the settings, you can proceed to the creation of the 3D printing project itself using the installed 3DP RobotWare Add-In package, located in the Add-In - 3D Printing PowerPac project tab. We are guided through the 3D printing setup by the icons in the 3DP project, shown in Fig.5: Open G-code, Save/Load Settings, Path Tune, Targets Orientation, Process, External Axis, Check Reach and Export Program. In the window on the right, under the 3DP title.

1. Open G-code offers options for importing G-code into a project (Fig. 5). It contains basic information such as the name of the embedded file, the number of points and layers. The 3DP window offers the possibility to view the imported file in the Preview section, either as a Point Cloud or as a printed filament Process Visualization.

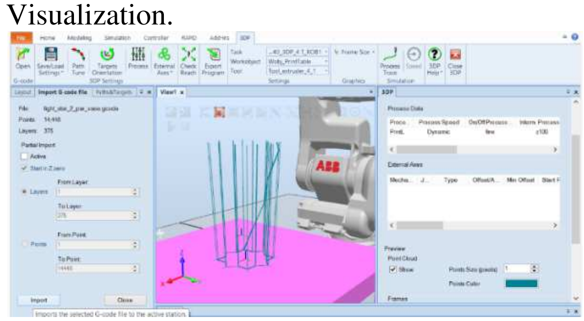

Fig. 5. Importing G-code into a project.

2. Path Tune allows you to optimize the 3D printing process by removing points based on their minimum distance, maximum radius, On/Off process, or endpoint distance, as shown in Fig. 6.
3. Targets Orientation is used to set the position of the tool at each point of the 3D printing process, in this case it is necessary to rotate the tool by 180° in the Y axis according to the TCP coordination tool. The display of the coordination systems is set in the 3DP window, Preview - Show Frames options.

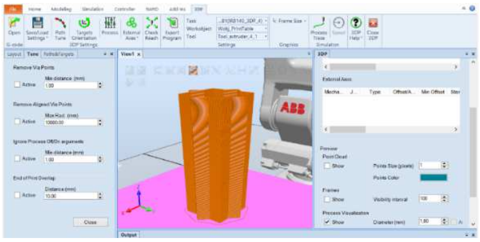

Fig. 6. Path Tune - 3D printing process optimization.

4. Process defines the 3D printing parameters. In the project, PrintL is selected as the motion instruction installed. The process mode is set to Accuracy_Mode for increased accuracy, the process speed is defined as dynamic based on the G-code, and the Fine parameter is selected for the accuracy of the Zone movements.
5. Check Reach verifies the reachability of all robot motion points during 3D printing. The points of this project are only successfully reachable if the robot configuration is set to Cfg3(-1,-1,0,1). The Reachability Succeeded dialog box informs about the success of the verification.
6. Export The program offers to view the basic settings of the 3D printing project, create Rapid Modules and load them into the virtual unit. After the export is started, a new folder is created with the name of the printed object "light_star_2" and placed in the Robot Studio program files. The simulation of the 3D printing process is started with the Play button and the visualization options are set using the Process Trace icon, where the parameters for displaying the different layers of the printed filament are adjusted, shown in Fig. 7.

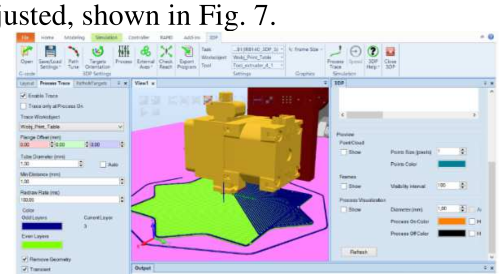

Fig. 7. Simulation of the 3D printing process.

The generated robot control program consists of the main program "T_ROB1_3DP", which contains the robot configuration, 3D printing and retrieves the robot position data from fifteen modules. The structure of the program is composed of two main subroutines and 15 modules with data to execute the motion instructions.

4. IMPLEMENTATION, CONTROL AND TESTING OF THE DESIGNED PRINTING SYSTEM

Achieving the desired quality of 3D printing by testing in laboratory conditions (Fig. 8) requires frequent change of printing parameters, especially the amount of printed filament. These adjustments can be made in the simulation programs Robot Studio or Slic3r in the form of changing the speed of the robot movements or changing the speed of the extruder. The modifications are time consuming and contribute to unwanted errors as they are done by repeatedly generating G-codes and robot programs.

Fig. 8. 3D printing laboratory workplace.

In order to make the testing more efficient, the Arduino Uno control unit with the DRV 8825 stepper controller was modified with a potentiometer to control the amount of filament printed directly during the 3D printing process. The flow of setting the desired amount of filament is shown in Fig. 9a.

During the pilot tests of 3D printing, several shortcomings arose affecting the course of production of the selected object. By correcting the settings of the observed material dosage gaps, the correct amount of filament applied was determined to achieve the desired quality of the 3D printing process of the test object.

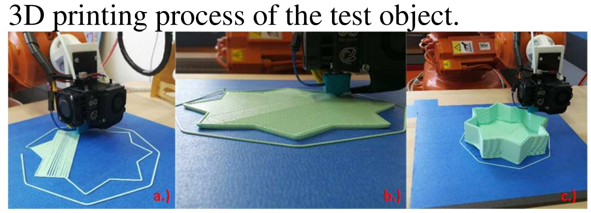

Fig. 9. 3D printing testing.

During the deposition of the third layer of the printed object, a slight deformation was observed at the outer edges, which is shown in Fig. 9b. This deformation is caused by the anisotropic properties of the printed model, caused by the melt layering technology and extrusion. Uneven cooling of the layers of the printed filament also contributes significantly to the deformation, with the temperature of the layers at the protruding edges of the model being lower than the temperature in the middle of the printed model. Elimination of these deformations can be achieved by adding pad heating or by separating the print area from the surrounding environment, e.g., by forming separating barriers. However, the application of barriers to the entire 3D printing assembly by the robot is counterproductive, as it negates the main advantage of 3D printing by robot, consisting in the spatial unboundedness of the printed object with respect to the radius of action of the robot used. The resulting printed model, shown in Fig. 9c, is negatively affected by an error in the Slic3r postprocessor, caused by the incorrect generation of the printed filament path, which misses the inner contour of the model wall and consequently leads to an imperfect joining of the following layer.

5. CONCLUSION

FDM technology has undergone a major evolution since its inception, moving it from a Rapid Prototyping technique, as a tool for designers and developers, to the production of final products. Compared to other 3D printing technologies, it has the lowest dimensional accuracy and resolution, making it unsuitable for parts with complex details. FDM models have visible material transitions in the layers, so additional processing is required for a smooth surface. They are also space constrained by printer design and process time. The technology of melting and layering the material significantly reduces the necessary physical parameters of the resulting model, which becomes anisotropic. FDM is the most cost-effective 3D printing technology in conjunction with robotics, used especially in interior design, in the production of products with complex geometry, where its shortcomings - visible layering of objects are even desirable, or in civil engineering in the production of supporting wall structures and 3D printing of buildings using concrete mixtures.

As a highly advanced simulation tool from ABB, Robot Studio requires precisely defined user procedures that result in perfect simulation projects of selected robot applications in a highly complex project structure and generated programs. The elaboration of the thesis concludes that it is a suitable tool for testing the design of the 3D printing process. The software offers the possibility to efficiently automate the modifications of the generated robot programs by editing the Postprocessor. The design significantly reduces the time consuming and user error rate of process modifications due to the size of the generated programs and the frequency of such modifications.

The paper dealt with 3D printing through the proposed device of a 3D printing head mounted on the arm of an ABB IRB140 robot in a laboratory setting. The implemented tests confirm the usability of the designed printing system. The achievement of the desired quality of printed objects is documented by the appropriate choice of the compact E3D Hemera print head and the correctness of the settings of all controls. During the testing of the 3D printing process, the enhancement of the Arduino Uno controller with the DRV 8825 stepper controller by adding a potentiometer, which can control the amount of printed filament directly during the 3D printing process, was significantly appreciated.

The future perspective of FDM technology development is oriented towards research and application of new materials. By using composite materials with continuous filament, the resulting 3D printing objects obtain tensile and compressive strengths approaching those of aluminum products, which opens up new possibilities for the use of FDM technology in the manufacturing process of final products, perhaps by linking it with robotics.

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CREAREA PROIECTULUI DE SIMULARE A PROCESULUI DE IMPRIMARE 3D ROBOTIZATĂ

Rezumat: Tehnologia de imprimare 3D oferă nu numai posibilitatea producerii rapide de modele, mostre sau prototipuri de componente în orice stadiu de dezvoltare, ci mai ales posibilitatea de a produce o întreagă gamă de modificări și aranjamente structurale ale produsului propus, fără a utiliza echipamente specializate de producție a produsului final, matrițe și scule. Articolul se referă la proiectarea prin simulare a unui loc de muncă în mediul software Robot Studio pentru imprimarea 3D cu un braț robotizat folosind capul de imprimare proiectat, crearea unui program de control al robotului pentru fabricarea aditivă și producția efectivă a obiectului selectat în condiții de laborator. Secvența etapelor inițiale de proiectare a modelului virtual al locului de muncă, a modelului de imprimare 3D și procesarea completă a proiectului de proiectare prin simulare pentru generarea programelor de control pentru implementarea procesului de producție sunt descrise mai detaliat.

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