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MOLDAM additive manufacturing robotic cell for extruding thermoplastic pellets

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Resumen

Durante los últimos años la fabricación aditiva se está posicionando como una tecnología atractiva por su sencillez y accesibilidad en el mercado, posibilitando la extrusión de diferentes materiales. Sin embargo, las dimensiones del área de trabajo y las limitadas capacidades de extrusoras comerciales de pequeñas dimensiones están derivando en la investigación y puesta en marcha de máquinas más grandes con una mayor tasa de deposición de material. Este artículo describe una nueva celda robótica automatizada para la extrusión de materiales termoplásticos en formato de granza o pellet siendo posible la extrusión de material a alta tasas de deposición. En este sentido, el artículo define la arquitectura de la celda robótica, el interfaz de usuario y los resultados preliminares. Además, se ha desarrollado el gemelo digital para la monitorización del proceso de una manera virtual. Finalmente, el artículo describe un nuevo software registrado en el que se puede analizar las variables del proceso o el comportamiento del material impreso.

Palabras clave: Gemelo Digital, HMI, Robot, Celda Robótica, Automatización, Fabricación Aditiva, Impresión 3D, Controlador Lógico Programable.

MOLDAM Additive Manufacturing Robotic Cell for extruding thermoplastic pellets

Abstract

During the last years, the additive manufacturing is becoming an attractive technology due to simplicity and market accessibility enabling the extrusion of different materials. However, the workspace requirements and the limitation of the small commercial extruders, are leading to research and develop big machines with higher material feed rate. This article describes a new robotic cell for extruding thermoplastic material in pellet format, being able to deposit high material feed rate. In this sense, this article defines the architecture of the cell, the user interfaces for controlling and monitoring the robotic cells and the preliminary results. Furthermore, a digital twin (DT) has been developed to monitor the process virtually. Finally, the paper describes a new registered software in which the data process or the behaviour of the printed material after testing can be shown.

Keywords: Digital Twin, HMI, Robot, Robotics Cell, Automation, Additive Manufacturing, 3D printing, Programmable Logic Controller.

1. Introduction

During last two decades a growing interest in 3D printing technologies has generated a great quantity of researches under seven technologies established in ASTM 52900:2021. This standard defines the different additive manufacturing processes, the design rules and the recommendations for printing processes. In this sense, some researchers have been reviewed the technologies focused on the advantages and disadvantages (Blyweert et al., 2018). This 3D printing process basically creates parts layer by layer (Lee et al., 2017) from a CAD model transformed in .stl format file using available

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CAM programs (Patel and Taufik, 2022; Penumakala et al., 2020; Roschli et al., 2019).

This type of technology, in addition to save material, allow the manufacturing of complex geometries due to the high flexibility of the process, being able to print parts on-demand, reducing the timeline with lower costs (Frazier, 2014; Lee et al., 2017; Tofail et al., 2018).

With this kind of systems several researchers are working in the additive manufacturing process of thermoplastic material for creating new parts saving material. In fact, the investigation in printing mould preforms has increased with the aim to reduce the generation of wasted material in sectors such us aeronautics (Tofail et al., 2018), wind (Post et al., 2017) or furniture industry (Akbari et al., 2022).

Due to the economic advantages and simplicity of the process, generally the thermoplastic materials have been printed using extrusion techniques by means of melting filaments using Fused Modelling Deposition (FDM) techniques (Barış Vatandaş et al., 2023; Valino et al., 2019). During last years, several researchers have been investigating to increase the deposition rate using bigger extruders with higher feed deposition rate assembled in gantry systems (Roschli et al., 2019; Chesser et al., 2019) or robots (Akbari et al., 2022).

This article describes a new robotic cell for additive manufacturing of thermoplastic material in pellet format, being able to deposit high rate of material, about tens of kg/h. Therefore, this article defines the architecture of the cell, showing the main components, the user interfaces for controlling and monitoring the robotic cells and the preliminary results. Additionally, the developed digital twin (DT) improves the intuition of the process, representing the current printing process virtually. Furthermore, the paper describes a new registered software in which the data process or the behaviour of the printed material after testing can be shown off-line.

Apart from this brief introduction, the article has been structured in five additional sections. Section two describes the additive Manufacturing cell based on a robot. Section 3 describes all developed user interfaces. Section 4 shows the preliminary results of the operation of the MOLDAM additive Manufacturing cell, meanwhile section 5 summarizes conclusions and future work.

2. Additive manufacturing cell based on a robot

An additive manufacturing cell is a complete and integrated system designed for the automated production of three-dimensional objects using additive manufacturing techniques. Additive manufacturing cells offer enhanced efficiency, accuracy and scalability, enabling the creation of complex and customized objects with various materials and geometries, making them invaluable in industries such as aerospace, automotive, healthcare, etc.

In Figure 1 the communication diagram of the cell is illustrated, where all the main components are defined.

The developed additive manufacturing at its core is the Fanuc M900iB/700 robot. This robot oversees executing the trajectories, so that the KFM 20XD extruder follows the path defined by the CAM software. This high-performance extruder is responsible for depositing the additive material with accuracy and consistency. It can print a wide range of materials, making it suitable for diverse manufacturing applications. This extruder is composed of three independent heated zones to generate the optimal gradient for each material inside the barrel. Each of these independent zones is able to increase its temperatures up to 450ºC. This is due to the fact that the thermoplastic material in pellet format must be molten with the aim to print the material in a surface while the motor of the extruder turns the screw. Pushed by the extruder screw, it is critical that the material flows along the barrel in a suitable way using the optimum temperature according to the specifications of the material. This optimal temperatures in the barrels are obtained experimentally. Therefore, the temperature of the molten material must be extruded at a temperature high enough to allow it to flow. Depending on the material, the printing process must be carried out in a heated surface to improve the adhesion of the material, mainly, in the first layers. Thus, the cell has incorporated a heated bed of 1000x1000mm, providing that the surface where the material is deposited can be heated by some resistors up to 150ºC.

To ensure a smooth material supply, the cell incorporates the ICEVA Colorload V-AL Venturi Loader Controller. This loader controller enables efficient and reliable material loading by creating vacuum to transport the additive material from a supply source to the extruder automatically.

Maintaining the optimal working properties of the additive material is crucial to ensure an optimal response of the material. Thus, the QIP GmbH BD44 Basic Dryer is critical. This dryer effectively removes moisture from the material, ensuring it is kept in optimal conditions for printing. By eliminating moisture-related issues, it helps to prevent defects ensuring consistent output quality.

Additionally, the SMC HRS012-A Cooling Unit is integrated into the cell to manage the temperature of the extruder. It provides cooling flow to the intake area of the extruder. In this way the material does not melt in the admission, avoiding possible obstructions at that point.

To govern and control the entire additive manufacturing cell, Siemens S7-1500 controller serves as the central control system. This powerful programmable logic controller (PLC) enables seamless communication and coordination between all the components through suitable functions developed in TIA Portal. It ensures synchronized operation, monitors process parameters, and facilitates real-time adjustments for enhanced efficiency and quality control.

Finally, in order to provide the operator an easy and intuitive system for interacting with the system, a human machine interface (HMI) has been designed as it is explained in the following section.

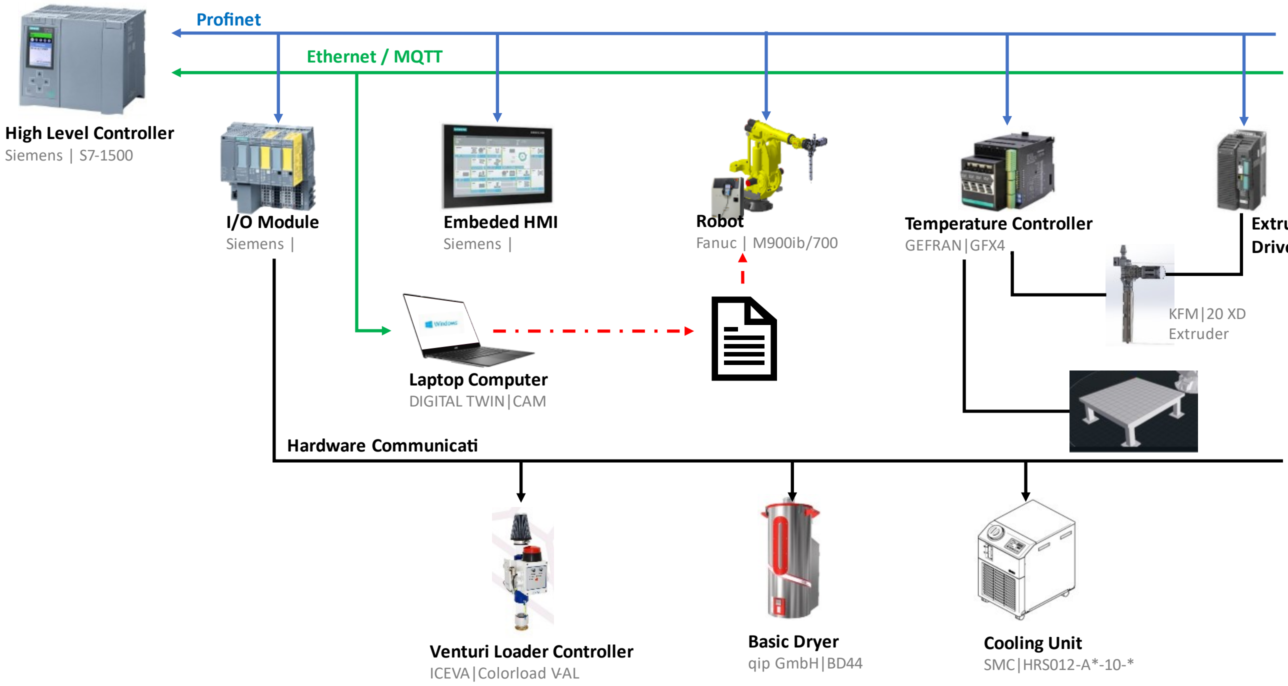

Figure 1 Communication diagram of the cell showing the main components of the MOLDAM Additive Manufacturing System.

3. Human machine interface

An intuitive human-machine interface (HMI) is crucially important in an additive manufacturing cell, just as essential as the physical components themselves. The HMI serves as the primary point of interaction between the human operator and the manufacturing cell, providing a user-friendly interface to monitor and control the system. An intuitive HMI design plays a significant role in enhancing user experience, reducing training requirements, and improving overall productivity. It allows operators to easily navigate through the system, access relevant information, and make real-time adjustments. Clear visualizations, intuitive controls, and well-organized menus enable operators to monitor process parameters, troubleshoot issues, and optimize production settings efficiently. By ensuring a seamless and intuitive interaction, an HMI empowers operators to effectively leverage the capabilities of the additive manufacturing cell, contributing to increased efficiency, reduced errors, and improved overall output quality.

In this sense the developed cell is composed of three main applications regarding the human machine interface: a user interface to control the additive manufacturing process, a Digital Twin to show the current state of the cell, enabling the acquisition, monitoring and recording of the data along the complete process. In order to visualize the acquired data of the process, another software is required, being named MOLDAM knowledge software. In the following subsection each of them is described.

4.1. User interface

The user interface is the main interface to control the cell. It has been developed in Siemens WinCC and all the parameters considered in the additive manufacturing process can be configured from there.

In order to start the printing process, the operator must define which kind of material is going to be used. For that end, a predefined recipe is loaded. In this recipe the reference temperatures of each area of the extruder and the temperature of the heated bed are defined. Thus, once the recipe is loaded, this data is read by the controller, and it starts to heat each area to the expected temperature.

Once the temperatures of all the areas are inside the defined intervals, as long as all the elements are in the optimal state, the robot has permission to start the printing process. All these variables can be found and followed from this interface.

From the same interface, the operator can enable the printing process by pushing the start button. Once the printing process is running, the main variables of the process are shown and the amount of material or the temperature of each heated areas can be modified from the user interface, as it can be seen in Figure 2.

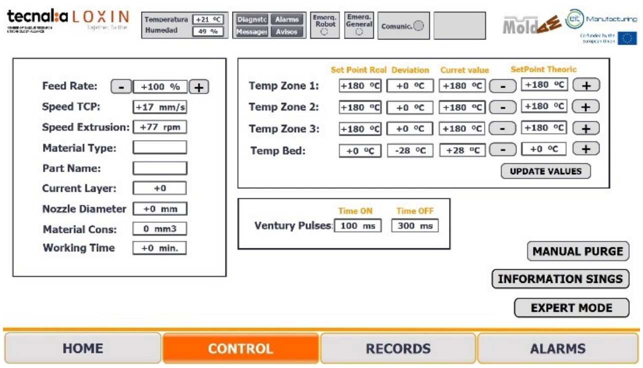

Figure 2 Screenshot of the user interface.

In this sense, the operator can modify on-flight the percentage of the feed rate of the material extrusion and the temperatures of each area of the extruder barrel and the heated bed.

Moreover, the interface has also an expert mode page form where same advanced parameters can be modified. Finally, if any parameters reach a value out of the boundaries, an alarm will be displayed in the alarm page.

However, before starting the process, a "part program" must be loaded in the FANUC controller. This "part program" is generated in a CAM software, called AdaOne, in which the engineer defines the parameters of the perimeters, TCP speed, infill of the part and so on.

Taking into account the previous description, the basic workflow for printing a part is summarised in Figure *2*.

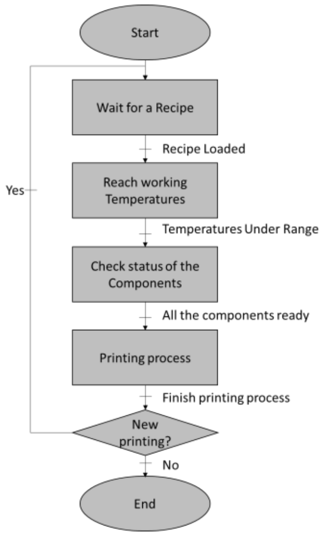

Figure 3 Workflow of the process for printing a part.

4.2. Digital twin

In addition to the HMI, the main process data is also included in the digital Twin of the Additive Manufacturing Cell. The application connects the PLC via MQTT communication protocol, having online data of the process every 20ms. The received data is used to make a 3D representation of the cell at the same time as the main information is displayed. A screenshot of the Digital Twin can be shown in Figure 4.

Figure 4 Screenshot of the Digital Twin generated for monitoring the behaviour of the Additive Manufacturing process

The Digital Twin application can be employed remotely to monitor the execution of the process in the absence of the physical existence. In addition, crucial information is gathered and saved in a database for future analysis and processing to improve the decision-making process.

4.3. MOLDAM knowledge software

This software consists in a Database and Knowledge Repository including the parameters of the MOLDAM process to be used in each new case, for each combination of input variables. The software is not only fed by those offline data but also by the online values of those variables acquired in real time from the different sensors of the cell. The database has been generated and updated along the project. MOLDAM Knowledge Software consists of a set of functionalities to gather and visualizes all information generated in a process for printing parts using mainly, but not exclusively, thermoplastics material.

The application, which has been developed in python, is packaged using Docker containers and it consists in three main options: Data Process, Simulation and Material Characterization.

Data Process Option visualizes (off-line) the values acquired by an external device, PLC, which controls a robotic cell. This Robotic cell consists in some devices (extruder, extruder accessories, temperature controller and auxiliary devices) able to provide values to check the behavior of the process (setpoints and present values), generated layer by layer along the time. A screenshot of this option can be seen below. The software allows to visualize the temperature in three zones of the extruder or the speed of the robot, among others. The operator can select the Setpoints, the measurement or present values, or the Error between them. In Figure 5 a screenshot of the data process option can be shown. In this figure the measured data of the temperature of the nozzle, between 234ºC-236ºC, in layer 23 is displayed.

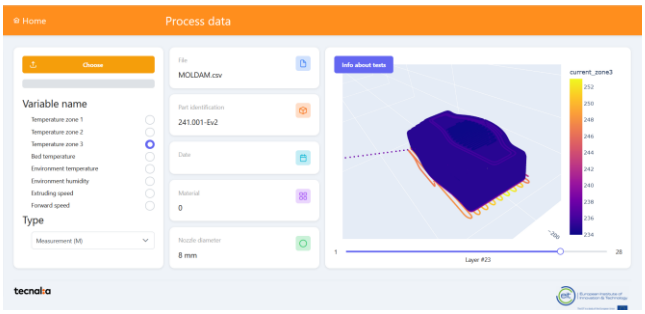

Figure 5 Screenshot of the Data process option of the MOLDAM Knowledge Software.

In this case the data of the tests are included in an Excel file following a specific Template. Any file with the same structure could be uploaded to be readable by this option.

The *Simulation Option* presents the numerical results concerning the thermo-elastic behaviours of the moulds under specific operating conditions. About the mechanical results, net displacements are plotted for each mould. X, Y and Z components of displacements are also available. Regarding the thermal results, transient temperature contours when specific thermal cycles are carried out are plotted. In this case, the data of the simulations are generated through Simcenter 3D. Depending on the result type, files extensions can be ".csv" (mechanical results) or ".fld" (thermal results).

Finally, the *Material Characterization Option* gathers all information about the material that can be used in the extruder. Under this option, the user can analyse the mean and individual results of the performed test of the machined tests probes. The test probes have been obtained from a printed part. The user can check the results of the mechanical test (tensile, flexural, compression and shear test), the CTE values, Specific heat capacity and thermal conductivity. The values depend on the temperature in which the tests have been done.

In this case the data of the tests are included in an Excel file following a specific Template. Any file with the same structure could be uploaded to be readable by this option.

4. Results

After checking the individual operation of each component of the robotic cell some evaluation parts for testing the material behaviour were printed. Moreover, the validation of the operation of the MOLDAM additive manufacturing cell was completed printing a real part. For this purpose, a designed CAD model for a mould preforms was manufactured in a heated bed as seen on the left in Figure 6. The printing process was successfully finished, completing the manufacturing of the part as shown on the right in Figure 6.

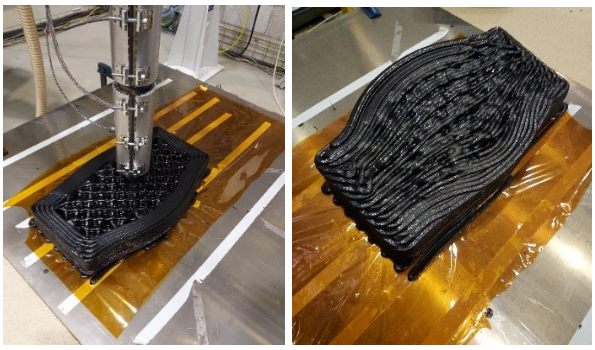

Figure 6 MOLDAM Additive Manufacturing printing a designed part (left). Completed printed part (right).

5. Conclusions and further work

This article describes a new additive manufacturing cell based on a FANUC Robot using an extruder for melting thermoplastic material in pellet format. Along the paper the architecture of the cell is described. Also, the basic workflow of the operation for printing a part is illustrated. Moreover, the paper describes the developed software for controlling, and monitoring the process. In this sense, the human machine interface, the digital twin and the MOLDAM knowledge software are described.

With this new robotic cell specific researches related to the additive manufacturing of thermoplastic material in pellet formats for creating mould preforms under end user specification will be developed. In fact, the investigation in printing mould preforms is increased with the aim to reduce the generation of wasted material in several sectors, such us aeronautic, wind sector or furniture sectors.

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