Novel Robotic 3D Printing Technology for the Manufacture of Large Parts

Uwe Klaeger[1] and Andriy Telesh[1]

[1] Fraunhofer Institute for Factory Operation and Automation IFF, Magdeburg, Germany
uwe.klaeger@iff.fraunhofer.de; andriy.telesh@iff.fraunhofer.de

Abstract. Additive manufacturing technologies are being used more widely to manufacture complex part geometries. Given the existing space limitations and the substantial time required to build up parts (small layer thicknesses), most 3D printing technologies do not operate cost effectively. When they are combined with industrial robotics, however, they become particularly interesting for the manufacture of large parts. This paper reports on the development of the design of a novel high-production system that can build parts weighing as much as 50 kg and measuring more than 1000 mm.

The innovative solution is based on the build platform's six-axis controller to deposit large quantities of material (5-10 dm^3/h) with layer thicknesses of 5-10 mm rapidly. The use of three extruders makes it possible to process different thermoplastics such as ABS, PC, PLA or PP in granule form. Both hard-soft materials and different colors can be combined. The VINCENT simulation tool developed by the Fraunhofer IFF is being used to develop the control system for complex manufacturing operations. This this new integrative approach to motion planning and event simulation makes it possible to test geometry and function even before the system starts being built.

Keywords: 3D printing, large parts, multi-material, simulation

1 Introduction

The manufacture of large parts in particular is connected with high production costs in many sectors [1]. Numerous manufacturing processes require models, molds, jigs and gauges that have to be built in elaborate and frequently manual steps. While 3D printing is a promising alternative to manually building such items, it is stymied at present by build space limitations and long manufacturing times resulting from the low build rates of currently available technologies. Our new innovative approach is intended to overcome these shortcomings by combining the advantages of 3D printing with universal industrial robotics in one high-production and cost effective system.

2 State-of-the-Art

2.1 3D Printing Technologies for Large Sizes

Large-scale 3D printers are based on thermoplastics (granules, filaments). Some projects on overcoming build space limitations have been completed in recent years. Stratasys, the pioneer of Fused Layer Modeling [2], introduced its first large-scale system, the Fortus 900mc, with a build space in the range of 900 mm [3]. Its low build rates with just four adjustable layer thicknesses in the range of 0.5 to 0.18 mm limit its productivity greatly, though. The Voxeljet VX4000 with a build space of 4000 x 2000 x 1000 mm^3 can process approximately fifty liters per hour at layer thicknesses of 0.2 to 0.4 mm [4]. The drawback of this technology is the very low strength of parts (material: infiltrated quartz sand), which severely limits their uses.

2.2 Industrial Robotics for 3D Printing

The use of industrial robots in additive manufacturing has only started attracting attention in recent years. Cranfield University developed Wire+Arc Additive Manufacturing to manufacture large airframe structural components [5]. Robots build up layers with thicknesses of up to 4 mm in a dimensional range of 2000 mm x 1000 mm. Although this facilitates faster part building, the stresses induced when heat is applied cause parts to warp. Stratasys introduced its “Infinite-Build 3D Demonstrator” together with Boeing, Ford and Siemens at the formnext in Frankfurt [6]. No concrete industrial applications have been reported yet. The University of Nantes built an emergency shelter measuring 3m x 3m x 3m in thirty minutes. The part quality obtained is too low for industrial applications, though [7].

German company Gefertec’s 3D metal printing uses CNC robots to arc weld parts [8]. Parts with dimensions of 1000 mm x 1000 mm x 1000 mm can be manufactured at build rates of 0.5-1 dm^3/h (aluminum) and are finished by milling.

3 Large-Scale Printer System Design

3.1 System Components

The system developed and its individual subsystems are described in detail below. The prototype demonstrator system includes the following main components:

- an articulated robot that builds and handles parts (1),
- a base frame (gantry) that holds the extruder units (2),
- three extruder units with needle nozzles (3),
- a scanner that measures temperatures (part surface, melt temperature) and captures geometry data (4),
- a robot that machines and positions inserts (5), and
- VINCENT tool for simulations concomitant to development (6)

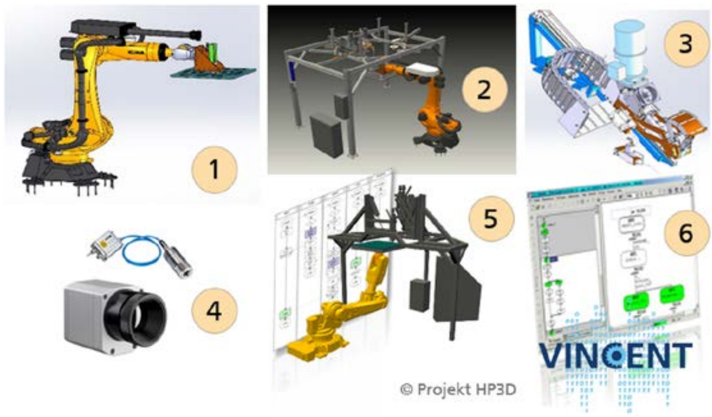

Fig. 1. Main components of the complete system

Fig. 1 presents the complete system and its main components. The three extruders in the upper section of the gantry are arranged at a 30 ° angle as a revolving magazine. Every extruder can be moved linearly to the work plane by a pneumatic cylinder. This establishes a safe separation distance to the gantry while simultaneously increasing the robot's operating range. Parts are built up layer-by-layer on a work platform, which is mounted directly on the articulated robot. The build platform's six-axis movement ensures that the point of material deposition is always perpendicular to the extruder nozzle. This greatly reduces anisotropy of part properties. The system design foresees using a second robot to position other (even metallic) components (inserts) in parts so that other functional elements can be integrated automatically [9].

3.2 Extruder Development and Dispensing System Testing

An extrusion system that directly processes standard plastic granules was developed for the HP3D process (see Fig. 2). Substituting the filament material presently used in FDM systems resulted in a substantial cost-benefit of as much as a factor of five. That boosts the cost effectiveness of manufacturing, something that ought to open up other uses for this new technology.

The extruder unit was designed for a maximum part build rate of 5 kg/h. Tests have been performed with the materials ABS, SAN, PMMA, PP, PC, PC / ABS, PLA, and PVA to date. The extruder nozzle's diameter can be varied in a range of 1 to 5 mm at present. A modified needle nozzle was installed in the extruder to ensure a continuous and consistent flow of material.

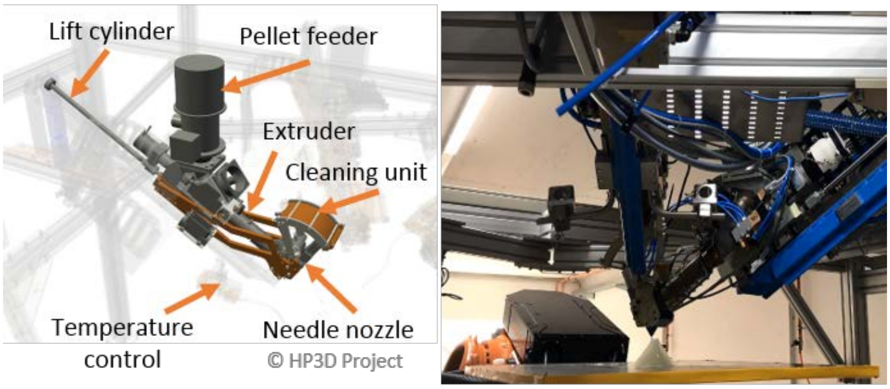

Fig. 2. Schematic of the extruder unit and a part being built on the demonstrator

This prevents material from escaping uncontrollably during the build process. The heated build platform is clamped on the six-axis articulated robot, which interacts with the extruders through the control program. At first, the simultaneous opening and closing of the nozzle system caused material defects, especially at the beginnings and ends of seams, when parts were built. This problem was solved by introducing a dwell time (delay). A material-dependent time constant, which correlates extruded volume, temperature and extruder speed, was calculated depending on the material model. This eliminates voids in the needle nozzle caused by the inertia of the melt process.

4 Controller Development Using the VINCENT Simulation Tool

The development of the controller for the complete system was a major priority. The controller includes the components of component control, motion planning, machine monitoring and machine controls. Key activities are coupling the simulation with the machine controller (PLC, robot control by a real-time interface) and developing safety specifications that prevent collisions in workspaces (safe machine operation).

Moreover, workpieces and materials are being incorporated in all of the operations and the real-time capability is being demonstrated for the created models under real conditions. The development of the control system for complex manufacturing operations is being supported by the VINCENT simulation tool developed by the Fraunhofer IFF [10]. The simulation results are entering directly into the engineering of the complete system (see Fig. 3).

The software module can be used to design both PLC controlled and robot movements (e.g. variable target position) parametrically. This makes it possible during planning for processes later implemented on the PLC and robot programs to read and write the same parameters. When functions are transferred to the controller (control code generation) the program ensures that these variables are consistently crosschecked between the PLC and the robot by a fieldbus.

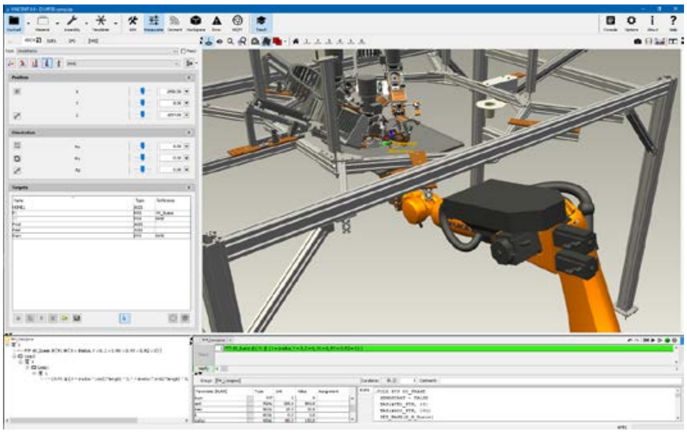

Fig. 3. Results of VINCENT simulations as the basis for system engineering

The machine's function has to be verified on the virtual model largely offline in order to transfer virtual operations planning to the real PLC or the robot is. Then, the PLC and robot programs can be exported directly from VINCENT. Linking the virtual system model and real controller online makes it possible to identify potential collisions between different system components and a complex part before a task is executed. Both brief movements and complete manufacturing programs lasting several hours can be tested in advance. One of the tool's significant strengths is its rapid collision detection based on 3D CAD data and kinematic structure. This can be used to identify danger zones and automatically generate and verify motion rules for collision testing in real time. Now upgraded with these program components, VINCENT can generate every system component's safety zones automatically at the push of a button. Integrated rules prevent collisions between the individual components as well as with the operator. The use of established standard formats to exchange data ensures operations are defined simply and continuously in the machine. The demonstrator's engineering (gantry design, extruder unit configuration) and the extruder's interaction with the robot and build platform were optimized in several iterative cycles. At the same time, the controller components (PLC) were put through other simulations (motion optimization, part building, path planning) concomitant to design

5 Conclusion

The new technological approach reduces manufacturing times of large-size/large-volume parts significantly. It can save 10-40% of costs over the conventional approach.

The use of robots makes it possible to produce parts with practically unlimited dimensions. Part volumes of 1-10 m^3 are possible depending on the robot's size. The build platform's six degrees of freedom make it possible to manufacture parts with highly complex geometries such as freeforms, support structures and undercuts. The use of three extruder units shortens non-productive time refilling material, on the one hand, and expands the range of materials to hard-soft components and different colors, on the other. The system was successfully tested under industrial conditions. This is grounds for optimism about widely marketing it. Other tests will involve optimizing the controller design. The materials' thermostability during part building especially has to be improved. This will be done by employing different additives.

Another task will be to optimize the build space's movements as a function of the extruder units' locations. The technical specifications of the electrical components (drives, sensors, control loops, etc.) for the control module have to be improved, as do the safety specifications for the complete system, factoring in every assembly. The most important future research activities will include:

- testing different material compositions with the goal of increasing part strength as layers are built up,
- refining the VINCENT control module to optimize motion paths of robots, extruders and insert handling,
- optimizing the extruder units' mixing and dispensing system to process materials of varying viscosity, and
- improving temperature control during part building.

6 Acknowledgement

This joint project was funded by the German Federal Ministry of Education and Research (BMBF) in its "Innovations for Tomorrow's Production, Services and Work" (funding code 02P14A027).

References

1. Hohmann, L.: Metav: Durchgängige Prozessketten in der Fertigung-Vision and Wirklichkeit. MM Maschinenmarkt. Vogel Business Media GmbH &Co. KG 2016.
2. Patent No. US5121329 A. Stratasys. 1992
3. 900mc: http://www.stratasys.com/de/3d-drucker/ production- series/fortus-900mc
4. Steck, R.: Voxeljet V4000: Größter Sandform-Drucker der Welt. www.engineeringspot.de/ 2016/07/ voxeljet-vx4000-groesster-sandform-3d-drucker-der-welt
5. Innovative Process Model of Ti-6Al-4V Additive Layer Manufacturing Using Cold Metal Transfer (CMT). International Solid Freeform Fabrication Symposium. Austin (USA) 2015.
6. Knabel, J.: 3druck.com/drucker-and-produkte/stratasys-zeigt-neue-fdm-fertigungsanlage-mit-8-axen-1448149
7. www.iutnantes.univ-nantes.fr/accueil/une-imprimante-3d-pour-construire-un-habitat-d-urgence-en-20-minutes-1283343.kjsp.
8. Röhrich, T.: Potentials and applications of additive manufacturing with arc and wire (3DMP®) in tool-making industry. Fachtagung Werkstoffe and Additive Fertigung, Potsdam,25./26.04.2018
9. Klaeger, U., Steuer, J.: High Performance 3D-3D-Druck mittels Robotertechnik. Vortrag auf dem 5. Mitteldeutschen Forum »3D-Druck in Anwendung«. Jena, 5. September 2018.
10. Juhasz, T: Digital Twin - Business Value and Technical Implementation Confirm Industry. Workshop and Information Day. Thomond Park Stadium, Limerick, December 6, 2018.