Inkjet Printings on FFF printed curved surfaces

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Abstract

We used robot guided inkjet printing to print graphical patterns on the surface of 3D freeform objects printed by Fused Filament Fabrication (FFF) Fused Filament Fabrication (FFF, also known and trademarked as "Fused deposition modeling", FDM [0]). Material tests as well as process development for robot guided inkjet printing on curved surfaces was carried out and evaluated. System concepts and intermediate results are presented.

1 Introduction

Surface finishing of 3D printed objects is an important topic and many different methods and approaches have been taken using e.g. lasers [0][2], hot air [3], chemical [4][5][6] or mechanical means [7]. We want to use the method of inkjet printing to additively deposit functional materials to the surface of 3D printed objects. The use of inkjet printing is also motivated by the fact that both 3D printing and inkjet printing are digital methods and it is therefore easy to inkjet print a different pattern for each 3D printed object. In a first step we are investigating graphical patterns but at a later stage printing organic electronic devices is also envisioned.

2 Inkjet printing on 3D printed surfaces

In the framework of the addmanu project [8][13] PROFACTOR [9] is developing the basics for a multi-material hybrid manufacturing technology based on InkJet printing. The main challenge is InkJet printing on 3D curved surfaces of parts which are pre-manufactured using additive manufacturing technologies. The goals are divided into 4 different parts:

- Development of UV (ultra violet) curable inks for multi-material hybrid manufacturing technologies, which is done by project partner TIGER Coatings [8] and is not covered in this paper.
- Research on printing processes using InkJet printing on FFF pre-manufactured free-form parts.
- System and process development of free-form printing using a robot based InkJet printing system.
- Development of a non-destructive quality control system using machine vision, which is a topic for an additional publication.

To design a pilot system several challenges have to be met. Especially the robot based InkJet application of the print material to the right spot is based on existing and extensive Know-How of PROFACTOR. This includes 3D machine vision [10] extended robotics [11][12] that allows object position invariant print head positioning above the 3D-printed surface. Figure 1 shows a robot moving a surface inspection system across the 3D surface of a carbon fibre part for automotive applications.

Figure 1: Photograph of a robot during surface inspection

3 First Results

The first results include inkjet printing tests on flat 3D printed substrates, setting up of the robot assisted inkjet printhead and printing test with the robot on flat and curved objects.

3.1 Inkjet Printing on flat FFF printed substrates

First InkJet printing trials were done on 3D printed surfaces (FFF) using a Heavy Duty Ink from TIGER Coatings. Used substrates were FFF printed parts without any pre-treatment. The material was white PLA (Polylactides from Orbi-Tech) [20], which was printed with a HAGE 3Dp-A2 printer in the labs of

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PROFACTOR. The layer thickness was, in most cases, 0.4mm printed at 210°C. The geometry of the test samples was a simply cuboid (75x25x10mm³, 30% infill). In the first trials the results are three important findings:

- Adhesion on PLA substrate is very good, even without pre-treatment of the substrate good results were reached.
- The printed image was strongly influenced by the capillary effects. These capillaries occur during the FFF process and can be seen in Figure 3.
- Curing with UV-LEDS (Ultraviolet Light-emitting diode) (395nm) worked very well in a few seconds (also in air).

Figure 2 and Figure 3 show the first test samples. Missing horizontal lines are caused by suboptimal parameters on the used Dimatix printer and are not a result of the 3D printed substrate. By choosing a greater distance between the drops the capillary effect could be reduced. For example it is better to print 2 times with 50µm drop distance instead of using 1 layer with 25µm drop distance, since the chance of hitting the bottom of the trench between 2 adjacent FFF layers, where capillary effects appear, is reduced. A smaller layer thickness (0.2mm instead 0.4mm) raised the possibility that drops are getting inside the small channels and also reduced inkjet image quality in this respect.

Figure 2: Photograph of a printed test sample, length ~55mm

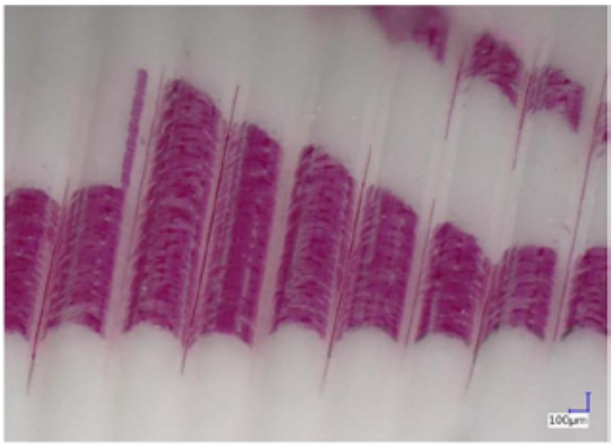

Figure 3: Optical micrograph of InkJet printed UV-curable ink on a 3D-printed surface.

3.2 Robot controlled InkJet printing head with process control for free form printing

The work was divided into software and hardware related research. Hardware: A printing head -Ricoh Gen 4 [18], ink transport system, meniscus control system, drivers for the printing head with master control unit und slave control unit were installed at the. The software system will contain subsystems for low level printing head control as well as a high level path planning software with a print pattern deduction. The reasons for choosing the Ricoh Gen 4 printhead were the following:

- Compact dimension: In general, compact dimensions are an advantage for the integration on the robot. Additional it's a benefit for printing on curved surfaces if the printing area is not too wide. A smaller printing enables a better printed image over the total printed area, because the variation of the distance from printing head to the surface can be better controlled.
- Integrated heating: inks, which do not have a suitable viscosity at room temperature can also be used.
- Tilting: The printing head could be also used in a tilted position for printing. This is an essential feature for printing on curved surfaces.
- Compatibility with project partner TIGER´s [8] heavy duty ink: TIGER inks were already tested with this printing head.

Requirements to the tool holder are:

- tooling change system for an easy demounting of the printing head from the robot arm
- mechanical fixtures for
  - print head (Ricoh Gen IV MH2420)
  - driver board (Ardeje)
  - ink-storage (2 inks for 2 nozzle rows)
- The controller for the printing head must be situated close to the robot caused by limited length of wires

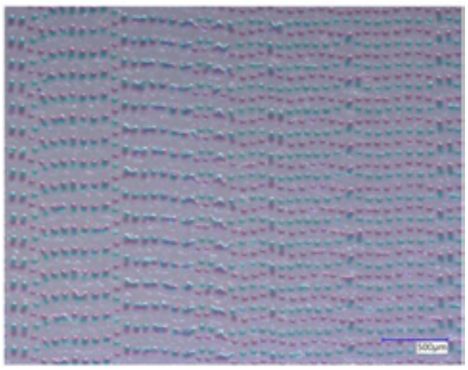

Figure 4 Individual droplets of TIGER Heavy Duty Ink on PVC printed with the UR10 robot

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A PC creates a robot program simultaneously with a command list for the printhead controller. This controller starts the actual printing process. Triggering of the printhead cannot be performed by the robot controller and path points, because signals with the necessary frequencies cannot be directly generated. Therefore discrete synchronization points trigger frequency update of a signal generator scaled to the actual feed motion velocity at the synchronization point.

Figure 5 shows the suggested workflow for printing (disregarding the path planning for the robot).

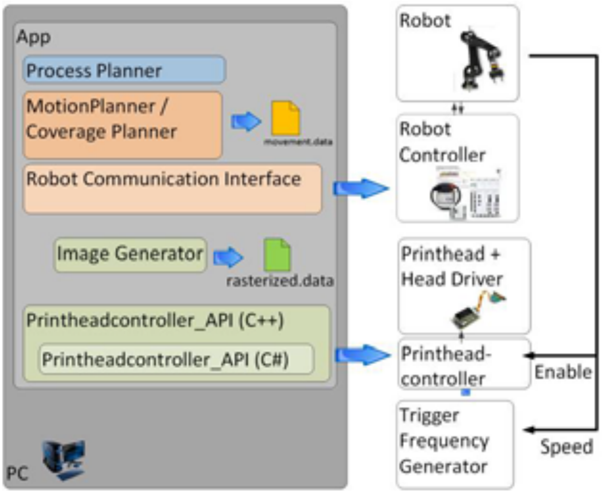

Figure 5: System overview of robot based printing system

Using the software module „Image generator“ a printing picture is created and prepared for the printhead controller by a special „raster image processing“ software module. In this step, vector graphics are translated into raster-graphics, resolutions are converted, colour channels separated and colour management processes executed. Precompiled information is sent to the controller. The controller needs afterwards only a start signal (enable) and the “feed” signal (synchronized with the robot movement)

3.3 Printing test with the robotic system

In addition to printing tests on 3D printed surfaces with the Dimatix Printer the Ricoh Gen4 printhead was used on different robotic systems to perform printing tests. Two types of tests were performed: Printing on polymeric foils to better understand the movement of the robot and printing on a 3D object, in our case a shoe.

To understand better the movement of the robot and the influence of any vibrations that might occur, we printed a pattern consisting of individual drops on polymeric foils. These substrates were chosen so that it would be possible to still see the individual droplets. Figure 4 shows a micrograph of individual droplets of TIGER Heavy Duty ink on PVC. It can be seen, that the droplets of the individual colours do not form a straight line. This is due to imperfections of the robot movement. Additionally it can be seen that the lines are not the same for the different colors. The reason for this is that drops at the same x-position on the substrate (if x is the direction of movement of the printhead (left-right in the figure above) are not jetted at the same time due to the distance between the nozzle rows. The periodicity of approx. 530µm can be seen in the image, which corresponds well to the distance between the two nozzle rows (row 1 for cyan, row 2 for magenta). The Ricoh Gen 4 printhead has 2 nozzle rows, which can be individually supplied with ink, therefore it is possible to use two different inks (colors) to be able to distinguish between the individual nozzle rows. The nozzle rows are arranged in such a way that the nozzles of row 2 are located just in between the nozzles of row 1. The spacing between nozzle rows is 529µm, within one row they are 1/150"(0.1693 mm) apart. This effect has to be considered for multicolour printing.

The setup to print on 3D objects is shown in Figure 6. The Ricoh Gen 4 printhead was mounted on a Universal Robots UR10 robot. The inkjet electronics was acquired from Ardeje [22]. Other robots used for testing were Stäubli [19]and Kuka systems.

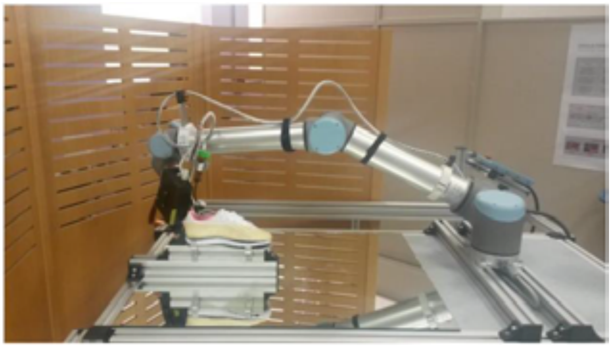

Figure 7 close-up of the inkjet setup with the shoe

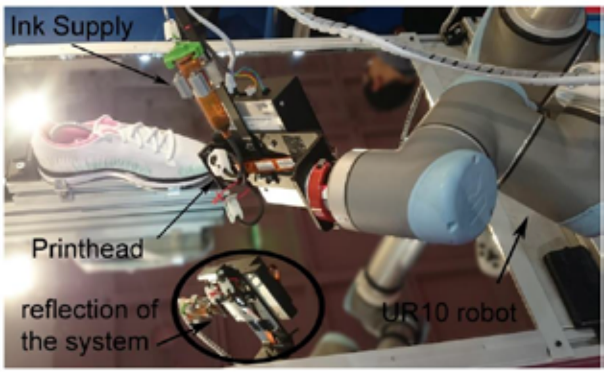

Figure 6: Printing setup of inkjet printing on a shoe with the UR10 robot

Overall printing head dimension are 63x16.2 mm with 32.4 mm print width [https://industry.ricoh.com/en/industrialinkjet/mh/2420/]

Figure 8 Green grass-like pattern inkjet printed on shoes.

It could be observed that inkjet printing with this configuration is possible although the printhead's orientation was changed constantly during the movement of the robot and the deviation from the 90° sideways position was significant. Nevertheless encouraging results could be obtained.

4 Conclusions and Further Work

4.1 Conclusions

Multilayer printing on FFF manufactured parts needs a lot of process and also material development to be successfully implemented and brought to industry. First steps of a proof of concept shows promising results, but each component of the system has to be optimized individually and from a whole system perspective.

4.2 Further work and next planned steps

Based on the studies and on the results of the first printing tests the next steps will be:

- Ongoing printing tests and generation of parameters for further ink development and for advanced robot set up
- trials for quality control with existing equipment of PROFACTOR and implementing the best fitting technology into the printing system
- Surveying test samples from other project partner to find a set of parameters for quality control

All steps will be done in a strong interaction with industry to have a feedback and a "closed loop" development which meets the industrial requirements.

Acknowledgements

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