Digital Decoration of Consumer and Industrial Goods

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Abstract

Inkjet printing has a huge potential in direct decoration of three dimensional consumer and industrial goods due to its non-impact character. As a digital method, inkjet provides several benefits compared to analog printing: Personalized and customized products, on demand production and production optimization due to integration into production line, to mention some. On the other hand, there are also several challenges to overcome, e.g. how to integrate inkjet print heads to transfer system properly, how to handle and monitor complex shaped products and how to ensure substrate-ink compatibility and controlled interactions between them. In addition, applicability and reliability of inkjet technology itself in various challenging conditions needs careful consideration and examination. In this paper we consider different benefits and challenges related to direct decoration using inkjet technology. Based on empirical studies, we present some results which demonstrate applicability of inkjet technology in direct digital decoration.

Introduction

Decoration and design have great impact on brand of products. Decoration is a way to product to stand out of other products. There is clear trend towards to more personalized and customized products especially in consumer product area.

Printing on 3D surfaces is not a new idea, and there are several possibilities how to do that. Pad printing provides high quality and wide choice of inks for different purposes. However, as an analog method it has its limitations, e.g. lack of effective personalization. Digital methods like laser engraving, on the other hand, are typically limited to one color. Dye sublimation printing is rather new method for full color decoration and provides good fastness properties for several materials. It has some limitations for materials and especially when opaque colors are needed[1]. Water transfer printing (dip printing) works well in certain applications but has some limitations when accurate images are needed. In addition to these above mentioned methods, there are several indirect methods for 3D decoration, where image is first transferred to some intermediate, and from there to the final 3D surface. Surprisingly high amount of decoration is still done at handwork, e.g. by painting or by adding stickers.

Inkjet printing has been used to print on 3D objects in coding and marking applications for many years. However, there the quality requirements are usually rather low and printing is done mainly by using one color. As a common issue for direct digital decoration, throwing distance in coding is usually rather high, up to 40 mm. Recently, we have seen first launches of using Drop on Demand (DoD) inkjet for 3D product decoration. However, public information about this topic has been very limited[2].

In this paper we focus on high quality, full color direct digital decoration done by using DoD inkjet printing. At its best, it can provide several benefits for producers of industrial or consumer goods:

- internet based product personalization and customization
- more efficient production by integrating decoration more closely to production e.g. online decoration
- cost savings by higher automation degree
- reduction on ware-house costs by changing to on-demand production
- added value by utilizing the strength of digital printing e.g. in tracking
- simple user interface due to well developed interfaces in standard printing applications

Although the benefits of direct decoration are evident, there are several challenges to overcome before this technology will be widely accepted. In following, some of them are considered from various perspectives.

Challenges of direct digital decoration

Throwing distance and drop trajectory

Drop on demand print heads are typically optimized to print on one to two millimeters throwing distance. Depending on shape and curvature of the products, it is quite likely that this optimal distance will not be reached and at least in some points, distance will be clearly higher (and in some points maybe shorter). This raise up several potential problems and open questions: What is an acceptable operating distance from product surface to nozzle plate and are there means to increase this distance? If the throwing distance varies from spot to spot, how would this influence in print quality?

Another issue is the position of print head and its effect on drop trajectory and printing reliability. In some applications, print head position might differ from normal top down position. If print head is tilted, how that would effect on trajectory and formation of the drop and is the print head functioning in general. In addition, one should be aware of air flow in printing area, which can hinder positioning of drops when throwing distance is increased.

Image modification

In addition to standard prepress operations, extra modifications of images are needed, when two dimensional image is printed on three dimensional surface. As an example, we can consider printing rectangular shapes on spherical surface. Without any corrections, the shapes will not appear rectangular on angled surfaces[3]. On almost flat surfaces this is not a problem, but the stronger the curvature of the object, the more important modification is. There are some algorithms for correction available; however, they should be integrated for other interface program to improve usability.

Material Interactions

Decorations are needed for wide variety of materials from different plastics to metals, ceramics and fiber based substrates. Due to development of inkjet inks, there are commercially available several inks compatible with many materials. To ensure good adhesion and adequate ink spreading, material compatibility should be tested in every case.

In addition to normal requirements, which occurs also in planar printing, in non-planar printing one should take care also that position of the printed object after printing does not cause any extra spreading of ink. That would most likely to occur if wetting of surface is weak. In the case of UV-curable inks, it is possible to use intermediate driers (pinning) to avoid these problems.

Reliability

Reliability is key issue in industrial systems. Especially, if print head is moved and not used in its typical position, it requires extra care. The main focus should be in ink delivery system, which should be able to operate also on these demanding situations.

Path planning

Depending on configuration, there might be needs to design printing paths i.e. in which order and using which paths the product is decorated. If printing is done using a robot and print head attached on robot's tool, the analogs to path design can be taken from other robot applications.

Basic configurations

There are several different approaches i.e. configurations how decoration of 3D products can be done by inkjet, all approaches having their benefits and drawbacks. In following, three different configurations are presented. We believe that these basic configurations cover most of the needs.

First configuration is based on stationary single pass heads, and the products are transferred in a linear fashion below the heads using proper transfer system, e.g. belt transfer or similar. This approach remains pretty much on standard roll-to-roll printing and is therefore quite straight forward configuration. While the heads are positioned in their typical position, the reliability issues are similar like in normal single pass printing. This configuration is suitable for flat-like products with rather low surface curvature, and only one side of the products could be printed in one pass. Typically, products dimensions also in other directions are small. One of the key design issues is to plan a good, flexible solution to attach the products in transfer system and keep them positioned right during the printing.

Modified version of the first configuration is configuration, where the transfer system is a robot or similar, which enables movements in several dimensions. It enables non-linear movements (e.g. rotation) and therefore to use this same configuration for much more complex products. At same time it makes the system itself much more complex.

In third configuration the print head is moved in 3D space by robot. Actually, in the case of robot there are 6 dimensions, since also angle of print head towards to product can be changed, not only its position in 3D space. In principle, with this sort of configuration it is possible to decorate very complex shapes. However, this sort of system is rather complex itself and there are several challenges related e.g. reliability of print head used in various positions.

Experimental

To better understand the potential of inkjet in digital decoration, we carried out an experimental study focusing in some very principle research questions.

Research environment

Tests were carried out using print heads of two major print head manufactures, Fujifilm Dimatix (SL128, SE128 and SX128) and Xaar (1001). These print heads gives wide variety in native resolution, (nominal) drop size and velocity. As print head drive electronics, Apollo and XUSB were used, respectively. Inks used in study are commercially available UV-curable inks, compatible to be used with print heads in case. In case we were using paper, it was such which we knew would give good quality with inks in case.

For imaging the drops and drop trajectory we used ImageXpert JetXpert. Drop volumes and velocities were calculated based on images. Printed images were scanned using standard Epson scanner.

The basic tests were carried out using our normal printing systems, XY table and roll-to-roll inkjet presses, where the print heads were positioned in normal manner.

To be able to study digital decoration in more complex situations, we build up a research and demonstration environment for 3D product printing (figure 1). Environment is modular and flexible, making possible to study different kind of products and serving different needs. It is based on integration of six-axis robot and inkjet printing system. Robot is ABB IRB 120, having pose accuracy of 0.02 mm and linear path accuracy of 0.21-0.38 mm. Print head used in system is Xaar 1001 and XUSB. Robot tool has space to move one or two print heads in one run. Alternatively, one pinning lamp can be attached to the tool. The control system of robot gives signal about the speed of robot's tool center point to print head electronics to synchronize the printing speed with robot movements. Trigger signal is given to control starting point of printing.

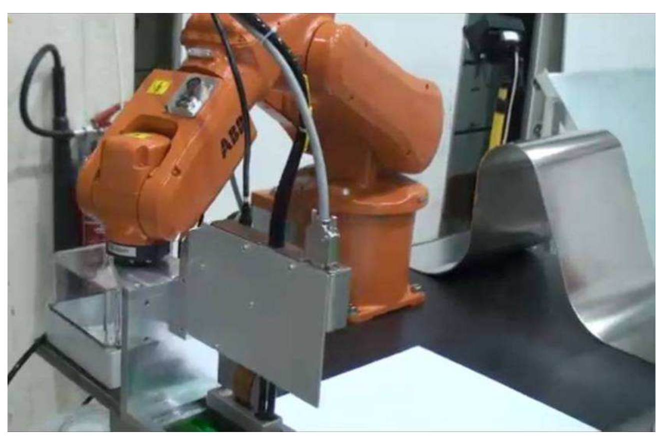

Figure 1. *Research and demonstration environment for 3D decoration.*

Experiments

First we wanted to test potential throwing distance of print heads in standard use and position. This was simply done by caring the printing in normal manner but increasing the distance between substrate surface and nozzle plate step by step. Printing speed was varied between 100 and 400 mm/s. Printed image was then scanned and analyzed. Drop volumes and velocities were analyzed by attaching print head to JetXpert imaging system. As a starting point, print head parameters were optimized for short distance printing, i.e. drop formation was good in short throwing distance. We used Xaar 1001 print head in binary mode, therefore making possible to study how drop size influence on throwing distance. In next phase, we also changed print head parameters, i.e. voltage of Fujifilm Dimatix print heads. In this case, print heads were also studied with JetXpert system to analyze the effect print head voltage. This was done only with Fujifilm Dimatix print heads.

Other goal was to study how print head position affects on functioning of print head and print. First, we attached print heads in imaging system and then tilted print heads in various angles (so that other edge of nozzle matrix was therefore closer to horizontal line than other). In this test, we mainly followed trajectories of the drops. In addition, we used our developed research environment to print with print head in various angles.

Finally, we did some tests to print on curved model surfaces to understand which factors are dominating in actual printing situation.

Results and discussion

Print head throwing distance

In figure 2 we present the images printed with variable throwing distance.

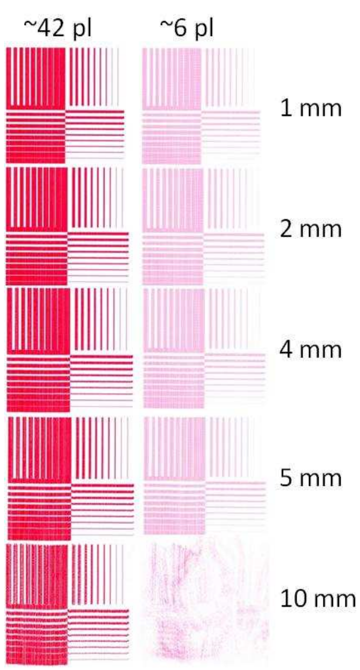

Figure 2. *Image is printed with varying throwing distance and drop size. Print head Xaar 1001. Print direction top to down.*

Measured properties of the drops optimized for short distance are shown in table 1. One can notice that measured values are clearly lower than nominal values, but this clearly depends on ink properties and print head settings.

Table 1. Measured values of drop properties

Print head type	Drop volume, pl	Drop velocity, m/s
SX128	20	2.2
SE128	31	3.6
SL128	47	2.8
Xaar 1001	35	4.0

In figure, the throwing distance increases from top to down and two columns presents prints printed with different nominal drop size. As we can notice from the image, drop size has clear effect on print quality when throwing distance is increased. With 5 mm throwing distance, image printed with smaller drop starts to clearly deteriorate, while the image printed with bigger drops is still rather good even when throwing distance has been 10 mm.

We can also notice that print direction has some effect on print quality. Lines in print direction (i.e. lines printed with same nozzles) look better than lines perpendicular to print direction, when throwing distance has been increased. This can be also quantitatively measured: raggedness of line increases clearly in print cross direction as a function of throwing distance, while in machine direction it is more or less constant. This indicates that deterioration of image is more due to differences in drop speed or initial firing point than problems with drop trajectory. First signs of increased raggedness in cross direction are sawn already when the throwing distance has been increased from its original. Therefore, it would be misleading to give any accurate number for suitable throwing distance, since it always depends on quality requirement in case.

Rather similar results were obtained with Fujifilm Dimatix print heads. Increasing the throwing distance started to deteriorate image faster if print head used smaller drops.

Adjusting the print head voltage changed clearly the properties of drops. Drop volumes and velocities with three different voltage settings are presented in table 2.

Table 2. Measured drop volumes and velocities as a function of print head (SX128) voltage.

Voltage, V	Drop volume, pl	Drop velocity, m/s
60	19	3.2
80	23	6.2
100	26	8.9

Increasing the print head voltage clearly increases the drop velocity. Increase from 60 V to 100 V nearly triples the drop velocity. Voltage has some effect also on drop volume, but clearly smaller.

The print head voltage also clearly affected on potential throwing distance. While the image started to get worse right after 5 mm when voltage was adjusted to 60 V, almost the same quality was achieved still in 15 mm, when 100 V voltage was used in same print head.

However, closer examination of flying drops shows also one drawback which can occurs when voltage adjustments are done. In figure 3 we show images taken from drops printed with respective settings.

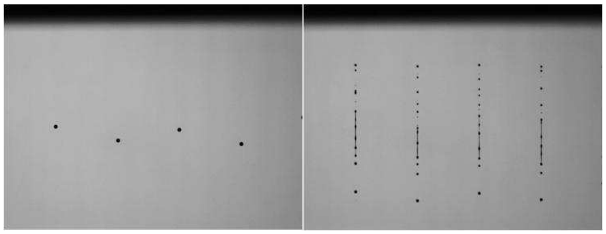

Figure 3. Images taken from flying drops, print head SE128. At left, printhead voltage is set to 60 V, and at right, to 100 V.

As shown in figure, drop formation has clearly suffered when print head voltage has been increased. We can assume, that it might increase e.g. satellite drops.

Print head operation in tilted angle

We also wanted to test print head operation in tilted position, i.e. not in upright position. Attached in JetXpert imaging system, we tilted the print head to 25°, 60° and 90° angle from its normal position.

All tested print heads functioned also in tilted position. However, in 90° angle some special arrangements were needed to make ink support system to function well.

Figure 4 shows flying drops in when print head is tilted in to 60° angle.

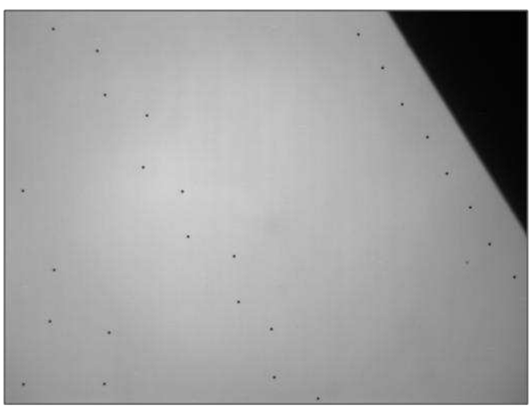

Figure 4. Flying drops printed with tilted print head. In right upper corner is print head nozzle plate.

In adjacent to nozzle plate, flying drops form a rather nice straight line. However, when the throwing distance increases, we can see that there is variance in the position of flying drops, most presumable due to differences in drop velocities. As mentioned earlier, this is then seen in print quality as a raggedness of cross direction lines. It should be mentioned, that this phenomenon was seen in every case regardless of the print head angle.

We also printed on substrate using print head (Xaar 1001) in tilted angle. Print head functioned well in various positions and movements did not affect to function of print head.

Printing on curved surfaces

Printing was done on paper, which was attached on metal plate, bent on curved shaped and having a radius of 52 mm. Modifications for the image were not done. When printing path was selected so that print head followed the curved shape of the metal plate, it was carried out without a problem. However, when the direction was chosen to be in line with a comb of the plate, several problems occurred. Image was deteriorated at the edges for several reasons. It was stretched from its original form, and due to long throwing distance, image was also slightly haze in the edges. This short test clearly demonstrates that several issues can simply be handled by choosing the printing path correctly.

Conclusions

There is a high potential to utilize inkjet printing to decorate 3D objects. To really mobilize this potential, inkjet manufactures should take this topic on agenda and focus to develop hardware and software, which would be specially developed for 3D decoration purposes.

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Author Biography

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