4D Printing: Personalization on 3D Objects

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Introduction

The digital printing market has expanded greatly over the past twenty years with increasing use of personalization. This has typically been using variable data on flat printed pieces, such as letters and marketing collateral. With the continued developments and improvements in the application of variable data and personalization there has been an complementary increase in awareness of the value derived from the this and the interest to print directly variable data on the surface of multi-dimensional objects, such as cups and balls shown in Figure 1. The Omnifire 250 was developed specifically for these types of applications and was a 2016 recipient of the Printing Industry of America's InterTech Technology Award.

Figure 1. *Typical examples of printing on dimensional surfaces*

Heidelberg USA, Inc.

Background to printing on dimensional objects

There are a number of different ways in which images can be produced on three dimensional objects; all of these had specific advantages and disadvantages to the user. If we consider the different options they would be:

1. Print the image flat using a traditional print technology and then transfer the image in a second step. This initial printing is done for many static objects using techniques such as screen printing, Figure 2, and can also be achieved by digital toner based or inkjet based technologies to allow for variable date. An example of the screen printing would be in the printing of transfers that are used in china crockery, such as plates and cups. The use of transfers within the process will increase costs for materials, logistics, and labor. It also will increase the waste as there will be additional set up and quality control steps, this can be an issue when the cost of the item to be imaged is high.

Figure 2. *Typical screen printing transfers*

2. Print the image flat and then form the object in applications such as in thermoforming, Figure 3. This will involve a high set up costs and can have much longer lead times to prepare for imaged objects to be produced. This will work for a limited amount of objects and materials that are capable to be thermoformed. In addition, special care needs to be taken in compensating for the distortion of the images and also in maintaining color fidelity throughout.

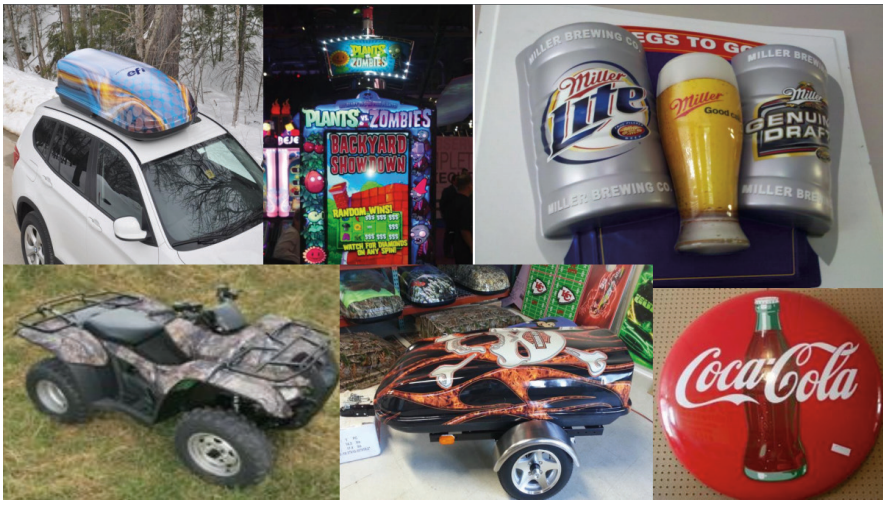

Figure 3. *Typical thermoforming examples (EFI, TAGA 2015)*

3. Static images can be printed directly on dimensional objects using pad printing, Figure 4. It is not possible to print using variable data. There will be relatively high set up costs with the engraving of the cliché plate and limited material applications that this can be applied to. Multiple prints are also required to print the full circumference of an object, such as a ball or a cup. This has been used in a diverse set of applications such as printing of keyboards and gas tanks for motorcycles.

Figure 4. *Typical pad printing examples (inkcups.com)*

4. Static or variable images can be printed with dedicated industrial systems that need a linear plane through the object, such as a can mounted on a mandrill with very high set up and machine costs. These tend to be systems that are integrated directly into a manufacturing line and are only capable of printing on a single object.

The objective of the work with the Omnifire 250 was to develop a machine that would overcome many of the limitations described above and be able to print on a wide range of three dimensional objects with variable data (creating $d printing), be cost effective and versatile in its different applications.

There were a number of key challenges to overcome in the development of the Omnifire 250, some of the main ones are listed below and discussed in the following section:

- Software & engineering development to rotate and print on 3D objects with robotics
- The development of programs for the control and sequences for mapping a 2D image on a 3D object
- Registration of CMYK on a 3D product
- Quick change over from object to object
- Identification and incorporation of the appropriate workflow software
- Development of the appropriate inks, pre-treatment process & drying processes
- Plasma development to treat the surface of the material for ink adhesion

Technology Significance and Innovation

The Omnifire 250 democratizes the personalization and decoration of a wide variety of three-dimensional objects in an easy simple manner using UV inkjet printing combined with advanced robotics. It is a truly innovative solution for printing on pre-formed objects and is the first of its kind in the personalization of products of variable object size and shape. It is highly flexible with a very fast and easy change between objects, while most other solutions in this space are custom designed for industrial printing of a single shape and sized object.

The Omnifire 250 is capable of printing on spherical, cylindrical, and conical objects up to 11.8 inches (300 mm) in size, Figure 5. It provides the immediacy to the personalization of products having multi-dimensional shape and a wide surface material range using a mass production machine. It utilizes UV ink that is pin cured after each color is printed, resulting in a wide range of materials that can be printed utilizing a plasma pretreatment when needed. Variants in ink formulation along with pretreatment with primer are possible along with post printing coating that provides for an even wider variety of materials that can be printed on.

Figure 5. *Examples of printing on dimensional surfaces*

The Omnifire 250, Figure 6, transforms the personalization that can be achieved with products using non-contact printing technology. Its industrial design means that it can be operated in either a retail environment or an industrial environment, with the machines uptime being very high along with minimal intervention and maintenance by an operator. The Omnifire 250 can be set up in a transportable arrangement, for example in a truck that it could be driven to sporting or music events and used as a mobile printing center. No flushing of the heads is required; only head capping before shutting the machine down and doing a quick preparation of the print heads and print test before going into production. The object is printed with each color and between each printing step the ink is pin cured with LED UV, Figure 7. After the final color is printed a full UV cure is applied, allowing the product to be handled and used immediately.

Figure 6. *The Omnifire 250*

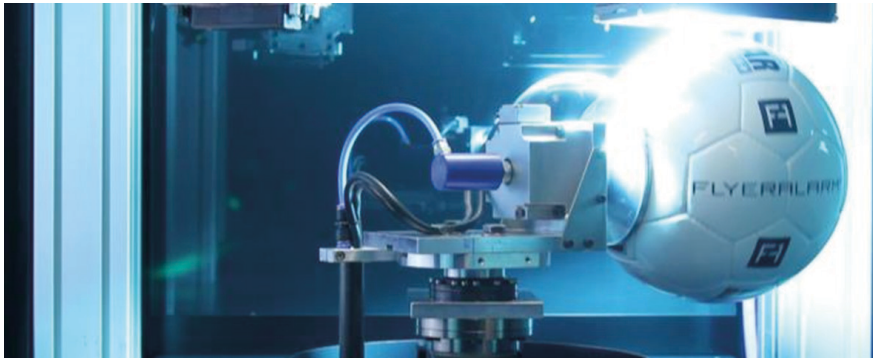

***Figure** 7. Pin curing of object*

Direct digital printing on objects enables users to delay product decoration to the very last point in the production chain using a high degree of automation and flexibility. Real time customization concepts for events or at point of sale can be easily implemented. The Omnifire 250 provides true flexibility for personalization and decoration of multi-dimensional objects and democratizes this printing to companies of all sizes and the potential applications are limited by the imagination of the user.

In developing the Omnifire 250 technical innovations were required to overcome the challenges of printing variable data on variable (and possibly inconsistent) multi-dimensional objects, with the added objective of fast and cost effective change between objects.

In development of the Omnifire 250 precise robotic motion control was developed for the axial and rotational location accuracy of the start and stopping position of the printing, Figure 8. This is critical in ensuring the register accuracy between the colors as the object being printed is moved between the different print heads and pin curing station. In addition, it also designed an innovative control functionality of the robotic motion between the start and ending points of the print so as to ensure smoothness and uniformity. This was further enhanced when the objects were not of a constant radius and the rotational speed needed to be altered during printing process. This smoothness of motion is essential for high quality printing on an object. In the Omnifire 250 both the axial motion and the rotational motion of the object are fully controlled and optimized using the advanced software capabilities. This means the highest print quality is achieved regardless of image size or shape, be it a golf ball, soccer ball, ruby ball, bottle, tube, drink cup, phone case, packaging, Frisbee, helmet, vase, automotive interiors or even glasses frames!

Figure 8. *Printing of three dimensional surface*

The inkjet heads have the ability to print up to 70mm wide for 360 degrees around the objects to be printed. If wider image is required, then stitching of the image for multiple passes adjacent to each other is carried out. This required the development of additional control algorithms so that the quality of the image was not degraded as part of the stitching process.

Prior to printing, the object's shape and size are verified for dimensional tolerance by the machine to ensure safe operation of the machine, reliability, and print quality. Following the scan, the deviation from the defined shape is calculated and the advanced robotics then adjust the relative position of the object, on the fly, as it moves under each of the print heads ensuring maximum print quality and maintaining the integrity of the heads from contact with the object.

For flexibility and cost effectiveness, the Omnifire 250 utilizes quick-change object holders, Figure 9, that minimize makeready time with changeover between like objects being seconds. The holders are also designed to be as universal as possible, such as a baseball and a soccer ball could be held by the same holder. The typical time to move between disparate objects, such as a ball to a drinking glass is under 20 seconds.

Figure 9. *Object holders*

Conclusion

The technologies developed for the Omnifire 250 are unique and provide the user with a wide variety of opportunities to personalize a extensive variety of three dimensional objects, adding to them personalization as the fourth dimension. This is achieved by inkjet printing directly on the surface of the object with UV inks. The objects to be printed are mounted in a holder and rotated using advanced robotics under the print heads. Each color is printed in turn and specific software was developed to ensure accurate registration between colors. Pre-treatment of the surface may be carried out prior to printing to improve ink adherence to the object. Being aware of the varying size of the objects and each of these are scanned prior to printing to ensure the optimal distance from the inkjet nozzles and also to eliminate the object crashing into the inkjet heads.

Digital printing using the Omnifire 250 enables product decoration and personalization to be delayed to the last point in the production or sales cycle, providing significant added value to the product. It democratizes the printing to companies of all sizes and the potential applications are boundless, limited by the imagination of the user.