FAST INK-JET BASED PROCESS

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ABSTRACT

With a new ink-jet based SFF processes, the building rate can be improved dramatically compared to single laser based processes. One reason for that is the multi-jet-technology well known in ink-jet-printing. Process velocity can be additionally increased by dividing material application and geometry information transfer. Theoretically, the cross section of an object can be described only by its outline. This paper describes a new ink-jet based process reducing printing times by using a combination of creating thin shells and a rapid application of building material.

INTRODUCTION

Three Dimensional Printing technique becomes more and more important: because it is accurate, cost effective and can be fast. At the moment we can find three different ink-jet based processes at the market.

- MIT's powder-based "Three Dimensional Printing" with different applications
- Multi-Jet-Modeling by 3D Systems
- Model-Maker by Sanders

The common problems of all these processes are:

- the jetted material must have special properties (low viscosity, enough surface tension)
- typically the droplet volume amounts about 113 fl. This means for 1 liter dosed material about 8840 billion droplets are needed!
- the support structure should be easily removable

For each problem we find different solutions used by these processes. Sanders and 3D Systems use wax in a melted state as dosing material, MIT uses liquid binder. Due to that, stiffness and rigidity of the models are limited. Likewise the volume problematic is solved differently. As the name expresses, the MJM uses numerous parallel addressable nozzles to increase speed. A 3DP model consists out of powder material at the main part, thus a comparable small part of binder has to be jetted.

The idea behind the development is to achieve a fast process with good model properties by combining the positive characteristics of the described processes.

3D PRINTING METHOD

To set up this new process, two steps are necessary: the amount of the jetted material must be reduced to a minimum, and the dosed material mustn't be a part of the desired object.

This will be achieved by segregation of the process in information transfer and material deposition. The minimum information to create the cross section of an object is the boundary line. This outline will be printed by means of a droplet generator. Thus a thin shell of the model will be formed. For example, the shell material could be a release wax with a high melting point. In the next step the layer is filled with building material by a rapid application. This material could be also wax with a lower melting point or a fast curing resin etc.

Figure 1 shows the new printing method for making a three-dimensional body:

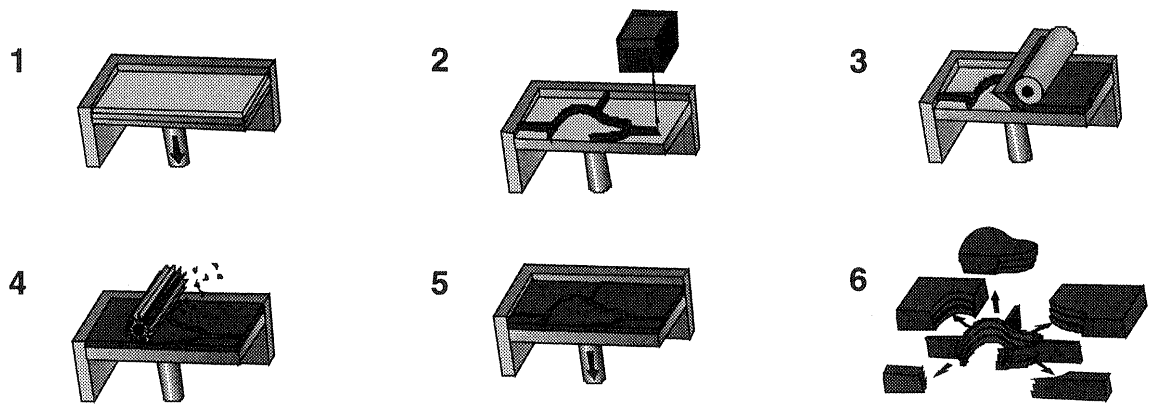

Figure 1: 3D Printing Process

The repeated steps are:

1) Lowering the platform according to the layer thickness.

2) Applying a release wax in its liquid state onto selected areas of a building platform by a multi-jet printhead, using a pattern according to the cross-section of a thin-walled shell around the three-dimensional body, and a grid pattern (not shown in Figure 1) across the remaining area of the building platform.

3) After finishing of the pattern of the current layer, the areas enclosed by the release wax are filled with the building wax.

4) Smoothing and planing of the layer in order to expose the upper surface of the release wax.

5) Ready for the next layer. Repetition of the steps 1) to 4) with patterns according to the current cross-section of the three-dimensional body, thereby making the body itself.

6) Removing the structures not belonging to the body by dissolving the release wax.

FEATURES

The advantages of the described process in comparison with the state of the art consists of the combination of a selective material deposition, mostly in lines and a non selective, rapid application of building material for filling up the layer. Due to the application of the release agent in small regions during the first step the whole process will be accelerated significantly.

Moreover, the differentiation between building and support material can be neglected because both structures will be formed by the same material during the rapid application of the building material. The differentiation is made due to the location of the material, either it is located inside the region enclosed by the border corresponding to the section plane of the object and therefore building material, or outside the border and therefore support material. The applied release agent is the preposition for this decision.

The building of a cavity is possible by filling the release wax layerwise in regions which belong to the cavity volume. By solving the release wax after the process, extracting the object and emptying the cavity through a provided hole the designated object will be demoulded.

Due to the use of a ink-jet like drop-on-demand dosing device for the application of the release agent, cost-effective and accurate systems can be designed which will reduce the overall system price.

Additionally the choice of building materials is much wider than with the processes described above, because material properties like viscosity and surface tension in the liquid state are affecting the application much less. Due to that, objects with much better properties like rigidity, stiffness, hardness and surface quality can be made.

Because of the wide choice of materials, it is possible to find material combinations which will produce less emissions during the building process and which are not affective to skin. Due to that, the most important requirement for an office compatible device is fulfilled.

After the process the complete building volume is taken from the device as a solid cube. Therefore no special handling devices are necessary. There are no loose particles or unhardened resin which can pollute the environment or affect the user.

With a suitable composition of a release wax the removal of the non-object-parts can be done without any tools. Solving of the release agent is possible by a solvent, preferably water or by means of heat.

Due to the complete hardening of the wax there is no hazardous waste.

Any object geometry can be produced in short time and without use of other means, provided that object defining three-dimensional computer data exist, for example CAD-data. Other data sources can be used as well, for example output of three-dimensional scanners.

DROP-ON-DEMAND DOSING DEVICE

A printhead has been developed to apply the release wax in its melted state onto selected areas. The dosing device (see Figure 2) is a multi-jet drop-on-demand printhead that can be heated up to 130 °C. Due to the rheologic characteristics of the release wax a piezoelectric multilayer bending actuator is used. Existing acoustically systems can't generate the necessary impulse and bubble jet systems have negative effect on release wax because of the heat transfer into the release wax.

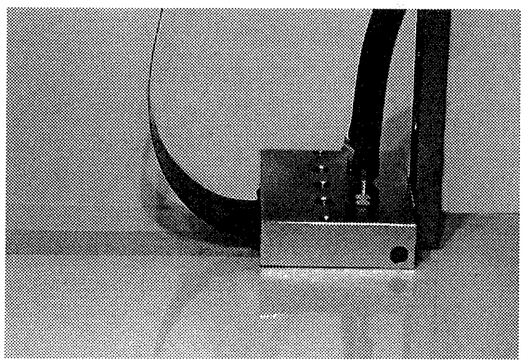

Figure 2: Piezo Printhead

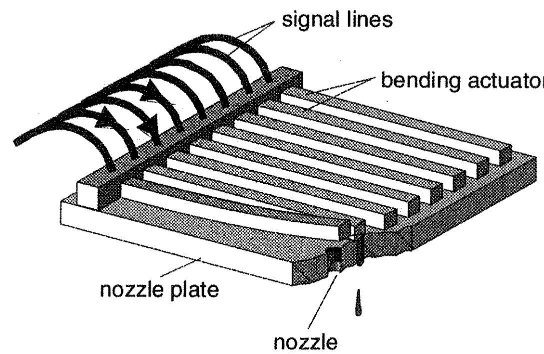

Figure 3: Nozzle plate with actuators

The nozzle plate (see Figure 3) indicates a row of very small, precise nozzles. An actuator is assigned to every nozzle. This assembly is covered by the chassis which has the function of a fluid chamber to provide the actuators with fluid. Each of the actuators can be run independently from the remaining actuators. The bending actuators are fixed at one end. The nozzles are placed below the free ends of the actuators.

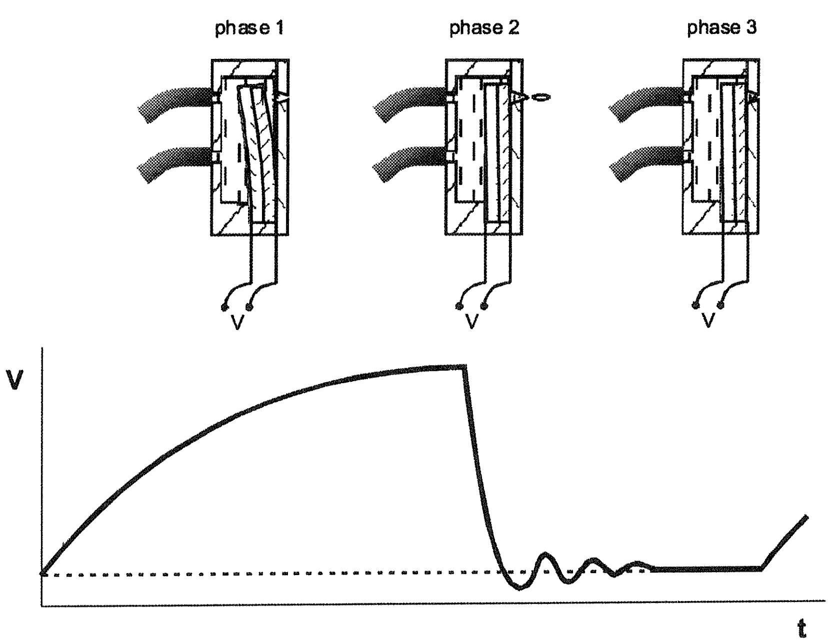

Figure 4: Functionality of the Piezo Printhead

The piezoactuator is a bending actuator. The functionality of the printhead is shown in Figure 4. After applying a voltage the bending actuator deviates at its free end away from the nozzle plate, so the fluid can flow in the gap between the bending actuator and the nozzle plate. After discharging, the bending actuator relaxes suddenly towards the nozzle plate and forces the liquid through the nozzle. The resulting droplet is moving perpendicularly away from the nozzle plate. Piezo bending actuators combine a high deflection with a high velocity of the actuator. Thus a high fluid-mechanical impulse is transfered to the fluid. Due to that it is possible to dose a wide range of release waxes.

Figure 5 shows the features of a single printhead:

number of nozzles	32	
viscosity	0,7 - 20	mPa s
temperature range	20 – 130 (68 – 266)	°C (°F)
nozzle pitch	50	dpi
continuous frequency	5	kHz
nozzle diameter	50	µm
supply voltage	35 - 55	V

Figure 5: Features of the printhead

SOFTWARE

For the shell production a special layer-based algorithm is needed. The following lines show a method to calculate the dividing shell given the outline of the objects as CLI-data.

From slice-data to the object-shell

If the workspace is assumed as a room with voxels representing the drops of the release material, the cross sections of the dividing shell would be monochrome bitmaps. The presented algorithm operates directly on these bitmaps being printed by the wax-jet later on.

Let w be the necessary width of the dividing shell in the xy-plane. Then the easiest way to produce the shell is to draw a w pixels thick line (i.e. with a standard Bresenham-algorithm) around the border of the object-area. This line is called an offset-line.

However, some circumstances require that we consider the sections lying above and below the layer currently processed. In order to describe these facts we need some definitions:

- L_z is the layer currently processed.
- $r\in$ □ recoating interval (recoating takes place every r layers).
- $s\in$ □ is the thickness of a layer.
- *inner*(z) the union of all regions covered by the part within layer L_z.
- *outer*(z) is the complement of *inner*(z).

The requirements for considering layers in the neighborhood are

a) We only want to recoat the layers $L_{i \cdot r}$ with $i \in$ □. Therefore we have to take into account the layers L_{z+1} up to $L_{n(r)}$ in order to support overhangs directed to the outside, where $n(r) = \min\{x \geq z \mid x = i \cdot r,\ i \in$ □$\}$.

b) The boarding of the current layer requires to look at the layers $\{L_{z-s}, \ldots, L_{z-1}\} \cup \{L_{z+1}, \ldots, L_{z+s}\}$.

c) All regions covered by the part must not contain release material, so if $inner(z) \cap outer(z+1) \neq \emptyset$ (the part tapers) $\Rightarrow$ we have to recoat after layer L_z.

Additional application of release material to facilitate a thermic separation

To uncover the prototype after the building process, we need extra dividing walls. For example we could cut the workspace into cubes with our dividing material. The cubes could have different sizes - outside the prototype big cubes would shorten the building time, in hollow spaces the cubes have to be small enough in order to get them out through the holes of the object.

The Algorithm

The above considerations lead to the following algorithm for the shell around a prototype using it's CLI-Data:

$$
\begin{aligned}
shell(z) = \; & (outer(z) \cap (cubeshell(z) \cup offsetshell(z))) \;\cup \\
& (outer(z) \cap (inner(z-s) \cup offsetshell(z-s))) \;\cup \\
& \qquad \ldots \qquad \cup \\
& (outer(z) \cap (inner(z-1) \cup offsetshell(z-1))) \;\cup \\
& (outer(z) \cap (inner(z+1) \cup offsetshell(z+1))) \;\cup \\
& \qquad \ldots \qquad \cup \\
& (outer(z) \cap (inner(max(n(r), z+s)) \cup offsetshell(max(n(r), z+s)))) \\
= \; & outer(z) \cap [\; inner(z-s) \cup \ldots \cup inner(max(n(r), z+s)) \;\cup \\
& \qquad offsetshell(z-s) \cup \ldots \cup offsetshell(max(n(r), z+s)) \;\cup \\
& \qquad cubeshell(z) \;]
\end{aligned}
$$

Figure 6 illustrates the formula above for r = 3 and s = 2. It is a vertical section through a part showing the points of dividing material.

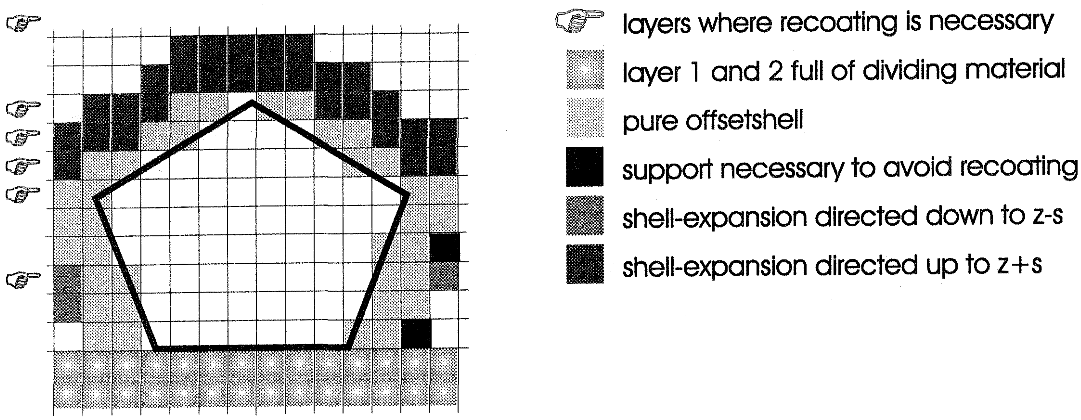

Figure 6: Vertical section through a part

In the illustration you can see that in some cases the shell is 3 pixels high. To avoid this, we change our formula to:

$$\begin{aligned} shell(z) \quad = \quad outer(z) \cap [\; & inner(z\text{-}s) \cup \ldots \cup inner(max(n(r), z+s)) \cup \\ & offsetshell(z\text{-}s+1) \cup \ldots \cup offsetshell(max(n(r), z+s\text{-}1)) \cup \\ & cubeshell(z) \;] \end{aligned}$$

Then we consider that the layer L_{z-1} is already top-covered partly by the offsetshell of layer L_z and layer L_{z+1} is already bottom-covered in an analogous way.

The union- and intersection-operators can be implemented by *or*- and *and*-operations on the bitmap. Better performance can be reached by intersecting the CLI-polygons directly without drawing them into a bitmap. However this requires more complicated algorithms to calculate the offset-polygons and their intersections or unions.

STATE OF THE DEVELOPMENT

Presently, we have already demonstrated the functionality of the basic processes such as printing of the release wax and applying thin layers of building wax.

A prototype of the pinthead has already been realised. A first printing samlpe of the release wax is shown in Figure 7. This sample has a size of about 0.6 x 1.65. The printed areas have not been filled in order to see the datails of the structure.

Some waxes have beesn tested in regard to find a building wax with the desired properties. Now a suitable combination of release and building wax is disposable and some application tests can be executed.

Furthermore a software with GUI has been programmed.

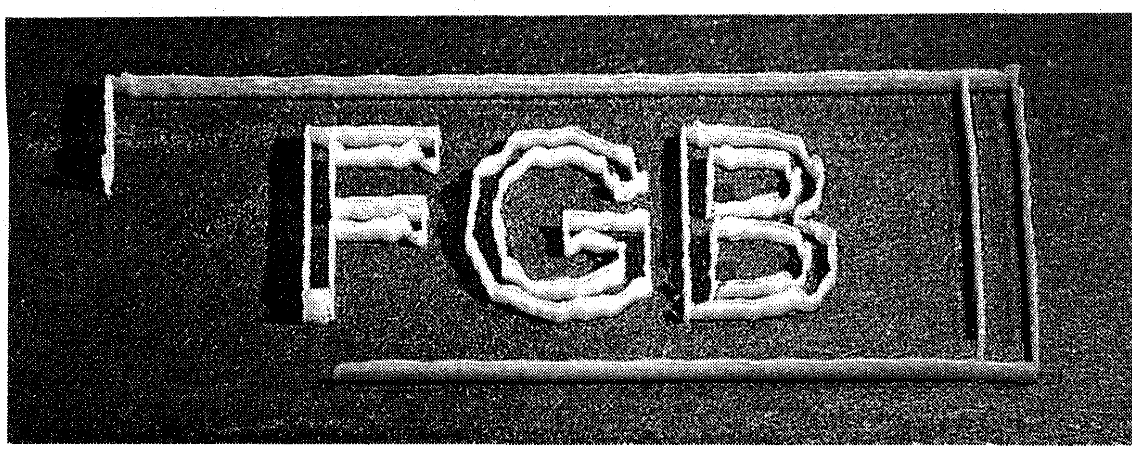

Figure 7: Printed release wax structure

CONCLUSION

A fast 3DP process has been developed. In this process, only the thin shell of the modell has to be printed by a multi-jet printhead. The building material is applied by a rapid process. The next steps are the realiziation of a prototype of the 3D printer and the optimization of process parameters. Future enhancements to these systems will lead to improvements of the rapid prototyping system in accuracy, surface finish and in application development.

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