The development of 3D food printer for printing fibrous meat materials

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Abstract. In this study, 3-D food printer was developed by integrating 3D printing technology with fibrous meat materials. With the help of computer-aided design and computer animation modeling software, users can model a desired pattern or shape, and then divide the model into layer-based sections. As the 3D food printer reads the design profile, food materials are extruded gradually through the nozzle to form the desired shape layer by layer. With the design of multiple nozzles, a wide variety of meat materials can be printed on the same product without the mixing of flavors. The technology can also extract the nutrients from the meat material to the food surface, allowing the freshness and sweetness of food to be tasted immediately upon eating it. This will also help the elderly’s eating experience since they often have bad teeth and poor taste sensing problems. Here, meat protein energy-type printing is used to solve the problem of currently available powder slurry calorie-type starch printing. The results show the novel technology development which uses pressurized tank with soft piping for material transport will improve the solid-liquid separation problem of fibrous meat material. In addition, the technology also allows amino acids from meat proteins as well as ketone body molecular substances from fatty acids to be substantially released, making ketogenic diet to be easier to accomplish. Moreover, time and volume controlled material feeding is made available by peristaltic pump to produce different food patterns and shapes with food materials of different viscosities, allowing food to be more eye-catching.

1. Introduction

The development of 3D printing has grown significantly. The technology has been applied in various fields such as medicine, aviation, automobile and architecture modeling. There is no doubt that 3D printing will bring revolutionary change to every industry and this trend has reached the field of food safety. Currently, the 3D printing foods available on the market are based on starch-type, sugar-type, butter-type and gel-type powders that are processed into single, slurry-form printing material. The material is printed by using pressurized syringe with needle-type valve to control the material flow rate or piston type material container to squeeze out the power slurry material to form desired shape. So far, there is no 3D printer using fibrous meat or related studies. The reason is that it is difficult to extrude meat material by a 3D printer due to the fibrous tissue and the viscosity of the meat material. This study made improvements to the syringe-piston material container applied by most food material processors. The 3D meat printer developed in this study is equipped with peristaltic pump and...
pressurized tank to help the transport of food material. Compared to other food modeling machines available in the market, the 3D meat printer designed in this study will overcome the limitations of rough extrusion and container capacity, and thus, significantly enhance production efficiency and volume.

The 3D food printer is developed based on the concept of smart home appliance. In this study, the 3D food printer uses fibrous mud-like protein and fat from meat. This allows a wide variety of products to be manufactured, and the printed products are not only for display. The technology developed will improve household’s willingness to use 3D printer and minimize its limitations, allowing the printer to be mass produced in the factory.

According to the Food & Health study conducted by IFIC Foundation in 2015, 69% of the adults feel excited about 3D printing technology that can produce any types of food. The Y generation (born in 1991~2000) is more passionate about this technology (79% of the population) because this generation is more willing to use software and machine for cooking.

In the past, 3D printing also known as Additive Manufacturing or Rapid Prototyping, which adopts the stacking method to add targeted materials layer by layer in forming the desired pattern rather than using the traditional production method via mold. With the help of software, the 3D CAD drawing will be converted into several cross-sectional thin slices. The benefit of this technique is that there is no processing shape limitation, any complex shape can be formed, and no supporting fixation is needed during the printing process. In 2011, 3D printing technology has been applied to the field of food processing. Researchers in the UK have developed the first 3D chocolate printer, which became the prototype of 3D food printer. Later, a Spanish company developed a 3D food printer named Foodini, which began the era of 3D food printer. The rapid development of 3D food printing technology has revolutionized the food and catering industries.

2. Literature and review
The basic concept of 3D printing, in fact, is similar to regular printer. In regular printing, the printer only need to print one layer of ink on a flat 2D (XY axis) printing paper, however, the image is only limited to two dimensional display. On the other hand, in 3D printing, one extra dimension (Z axis) printing (multiple layer stack printing) is utilized with special printing ink (food material) to add the printing material layer by layer in forming the desired shape [1]. With regards to the shape forming technique, 3D printing overcomes the limitation of traditional shape formation method. By integrating the fast & automatic shape forming system with computer simulated model, a wide variety of complex shape products can be manufactured with the needs of traditional molds and processing machines, which greatly shortens the manufacturing cycle of the product and significantly reduces the manufacturing cost.

2.1. Additive manufacturing technology classification
Additive manufacturing has evolved from the Rapid Prototyping (RP) in the early period to the Rapid Manufacturing (RM). The name was finalized as Additive Manufacturing (AM) by American Society for Testing and Materials (ASTM) in 2009 and related standards were stipulated [2]. ASTM has divided additive manufacturing into 7 categories, including:

I. VP (Vat Photopolymerization) uses a vat of liquid photopolymer resin, out of which the model is constructed layer by layer. An ultraviolet (UV) light is used to cure or harden the resin where required, whilst a platform moves the object being made downwards after each new layer is cured [3].

II. MJ (Material Jetting) uses wax and photopolymer resin as the main material. Sometimes metals are also used. The hardened wax model can be directly removed to proceed with shape formation. The well-known technology that uses this technique is objet.

III. BJ (Binder Jetting), the computer-controlled nozzle moves according to the cross-sectional information of the designed object and deposits alternating layers of the powder-based building material and the binding material. The binder acts as an adhesive between powder layers. After each layer, the object being printed is lowered to proceed with the next layer [4].
The current commercialized technology is 3D Printing and Gluing (3DPG) such as Chef Jet and Chef Jet Pro.

IV. ME (Material Extrusion) first uses heat source such as electricity to melt filament material then a 3D control system is adopted to move the melted filament material and deposit it layer by layer to form the desired 3D object. The printing material used (usually low melting point plastic such as ABS) first is made into filament and delivered into the nozzle via filament delivery system. The filament is then melted by heat inside the nozzle, and extruded along the desired cross-sectional profile and track controlled by a computer. The extruded material quickly hardens and bind with the nearby material. The process continues to form the desired shape layer by layer. The surface may be rough as the product finishes, therefore, post-polishing process is needed [5].

V. Currently, the commercialized technology is Fused Deposition Modeling (FDM) and Fused Filament Fabrication (FFM). Most of the food printers on the market use these two technologies; however, the products produced are not as good (in terms of printing accuracy) as those manufactured by 3DPG in which requirements for this technology is low and it is applicable to a wide variety of food materials [6].

VI. PBF (Powder Bed Fusion), a computer-controlled high energy laser beam then scans across the powder layer selectively according to the CAD information of each cross section of the desired model to fuse the powder. The scanned powder due to melting will bind together while the un-scanned powder will still be loosen and remains in position. The process repeats until the entire model is created [7].

VII. SL (Sheet Lamination) uses laser or knife to cut thin papers, plastics, metals or ceramics and then adopts thermal pressing or other technique to bind each layers together, obtaining the 3D object. During the process, laser or knife is controlled by computer to cut down a thin layer of the desired model. The unwanted area is cut into many small squares so that they can be removed later easily. The cut down layer material is bonded in place, over the previous layer, using heat pressing or other methods [8].

VIII. Directed Energy Deposition or Laser Metal Deposition (LMD) uses high power laser energy to melt the material on the processing surface. Metal powder is then injected into the melted material to complete the deposition process. The process is conducted with the help of positioning platform or robotic arm, which moves according to the desired 2D cross-sectional profile to build the 3D object [9].

2.2. Food 3D printing technology
The working principle of 3D food printer is similar to that of printing technology. However, the printing material used consists of one type or many types of liquid or mud-like foods that can be extruded rather than plastic or other industrial materials. The printer is composed of control computer, food material extruder, and transport device, etc. The food model and recipe is stored in the computer in advance. Food materials and other ingredients are placed first in the storage container. Once the user selected a preferred model and pressed the start button, the nozzle on the printer head will begin to move and extrude the food materials layer by layer to form the desired pattern, realizing 3D food printing.

2.2.1. Fused deposition modeling. The printing material is heated up to a certain temperature to form semi-melted material. The material is extruded on the flat supporting table where it quickly hardens. The process is repeated until the desired 3D object is formed [10].

2.2.2. Powder bed binder jetting. A thin layer of powder is spread first on the platform, and then glue is ejected by nozzle on the printer to bind the powder together. The process is repeated to spread another layer of powder on top of this bonded layer and glue is ejected again to bind them together. Finally, the un-bonded powder at each side is recovered for reutilization [10].
2.2.3. **Selective laser sintering.** This method uses computer to control the location of laser irradiation. Once the powder is irradiated by the laser beam, it will sinter to form aggregates. The process is repeated to add another layer of powder on top of this sintered layer followed by the sintering process until the final product is formed [11].

2.3. **Summary of literature review**

After reviewing the above literatures, it is found that currently available 3D food printers mainly use granular powder as the extruding material. However, 3D food printer that uses fibrous material as the extruding material will be more practical and useful, which will be the emphasis of this study. Moreover, most of the food printers on the market use piston-type mechanism or syringe container with flow rate controlling needle-head valve to extrude powder based food materials. One of the disadvantages of such design is the small storage container, which limits the possibility for mass printing and makes material replenishing more difficult. Another disadvantage is the difficulty in controlling the flow rate of solid-liquid separated fibrous meat material using the needle-head valve. As for the storage tank used in this study, it is large and independent, allowing more food material to be stored and making the change of food material to be more convenient. Such design is appropriate for household usage or factory mass production.

3. **3D Food Printer Developing Experiments**

This section introduces the design framework of the food printer developed in this study, which includes process design, printer design concept, mechanical design (XYZ) of each component, and operation design (pressure tank and pump), etc.

3.1 **System operation process flow diagram**

In order to use the 3D food printer developed in this study, the 3D drawing file must be converted first to STL format. The converted file is then input into the printer and the desired food materials are placed inside the storage tank. After waiting for a while, the system can begin to operate. Figure 1 shows the system operation process flow diagram.

![Figure 1. System operation process flow diagram](image)

3.2 **Novel extrusion technology of food printer**

The extrusion method used by the food printer developed in this study is different from the traditional methods adopted by other food printers on the market. The traditional extrusion methods include pressurized syringe with needle-type valve to control the material flow rate or piston type material container to squeeze out the powder based food material. The system in this study uses pressure generated by a pump to squeeze out the meat material out from the storage tank. By integrating peristaltic pump with multiple-nozzle device, the flow rate of meat material extruded can be easily controlled to form the desired pattern. Figure 2 shows the extrusion of technology of food printer.
3.3 Mechanical design

The purpose of the food printer designed in this study is to extrude food material in forming the desired pattern or shape. The area for the pattern formation is approximately 15cm x 30cm. However, since the mud-like food material is hard to stack up, the maximum height for the pattern formation is around 5cm.

In this study, four stepper motors were used to provide movement in the XYZ axis. The movement of Y axis is independent and carried out mainly by ball screw with the support of slide rail, which is responsible for moving the platform forward and backward. The movement of X and Z axis is interrelated and carried out mainly by ball screw with the support of optical axis. X axis is responsible for left and right movement while Z axis is responsible for up and down movement. This can prevent interfering product on the platform during operation, leading to distortion of the final product. Figure 3 shows the mechanical design of the food printer.

3.4 Material development

Besides creating a novel food processing method for elderly who has poor taste sensing and bad teeth, another important objective of this study is to offer a new and effective solution for dieting and cancer patients who require Ketogenic Diet to obtain Ketone body food elements.

The 3D food printing device developed in this study can provide significant amount of hypoxanthine (948 ppm of ketone group), 1170mg/100g of taurine and 35.41g/100g of unsaturated fatty acid, making ketogenic diet easier to carry out. In addition, it also lowers the diet of sugar and carbohydrates [12]. Evidences are shown in table 1, 2 and 3:

| Table 1. Ketone group analysis results of original meat material and product. |
|-------------------|-------------------|-------------------|
| Test method: After the samples were extracted and purified by solid phase extraction cartridge, the samples were analyzed by high performance liquid chromatography (HPLC-DAD) |
| Test result: | Test limit (ppm) | Tested result of original meat material (ppm) | Tested result of product (ppm) |
| Guanline | 50 | 58 | 133 |
| Hypoxanthine | 50 | 636 | 948 |
| Adenine | 50 | 50 | 98 |
| Xanthine | 50 | 54 | 61 |
| Sum | -- | 798 | 1240 |
Table 2. Results of taurine analysis.

| Test item                              | Tested result (mg/100 g) | Test method                                         |
|----------------------------------------|--------------------------|-----------------------------------------------------|
| Taurine                                | 1170                     | Spectrophotometric method                           |
| Isoleucine                             | 57.67                    | Determined by ethyl chloroformate derivatization and GC-MS determination |
| Leucine                                | 137.04                   |                                                     |
| Branched Chain Amino Acid (BCAA)       | 303.20                   | Determined by ethyl chloroformate derivatization and GC-MS determination |
| Valine                                 | 108.49                   |                                                     |

Table 3. Results of fatty acid analysis.

| Test item                              | Test method                                                                 | Test result | Test limit | unit     |
|----------------------------------------|-----------------------------------------------------------------------------|-------------|------------|----------|
| Saturated fat                          | The samples were extracted with oil, saponified and methylated, and the gas chromatograph (GC) was used. (Method of Test for Fatty Acids in Food) | 47.9        | 0.1        | g/100g   |
| Trans fats                             | N/A                                                                         | N/A         | 0.3        | g/100g   |
| Monounsaturated fatty acid             |                                                                             | 35.41       | 0.05       | g/100g   |
| Polyunsaturated fatty acid             |                                                                             | 1.26        | 0.05       | g/100g   |

Before preparing the slurry meat material, its characteristics must first be studied. By selecting an appropriate slurry ratio, the actual printing material is prepared and used to test the extrusion system. Different from single powder material where the viscosity can be uniformly adjusted by controlling the amount solvent, fibrous meat material tends to have solid (meat)-liquid (juice) separation, making material extrusion to be more difficult. The researchers first add water into the material. However, after stirring, the granule size was too big. Then, fine gelatin powder with water was tested. It was found that 5:2 ratio of water to gelatin powder (100 g of water with 20 g of gelatin powder) is the most appropriate ratio for preparing the material. Figure 4, 5, 6, and table 4 show the result of material extrusion with different nozzle diameter. If the viscosity of the extruding material is too low, it may be difficult to form the desired shape. On the other hand, if the viscosity is too high, the extrusion of material may be difficult. Additional ingredients such as pork bone essence, pork liver essence and chicken essence can also be added to another pressure tanks.

Figure 4. Diameter 2 mm
Figure 5. Diameter 4 mm
Table 4. Test parameters.

| Slurry Solvent Ratio | Pressure Kg/cm² | 5mm | 4mm | 2mm |
|----------------------|-----------------|-----|-----|-----|
| 5:0                  | 2.7             | N.G | N.G | N.G |
| 5:1                  | 2.7             | Not Smooth | N.G | N.G |
| 5:2                  | 2.7             | Smooth | Smooth | Smooth |

Figure 6. Diameter 5 mm

Meat materials (chicken, pork, and fish) can be cooked first to obtain the meat juice. The remaining meat can then be converted to slurry form by adding gelatin powder and meat juice with uniform stirring. The processed material is suitable for elderly who has bad teeth and poor taste sensing. In addition, after processing, the nutrients from the meat material are extracted to the food surface, allowing the freshness and sweetness of food to be tasted immediately upon eating it, greatly enhancing the eating experience. Therefore, the process developed in this study not only improves the sensing of taste but also makes chewing much easier.

3.5 Extrusion mode

One of the 3D food printers currently on the market uses chocolate as the printing material and extrude melted chocolate to form desired shape upon cooling. Another type of food printer uses granular and powder-based slurry as the printing material with piston or syringe-type container and needle-head valve to extrude the material. However, the blocking or overflow of printing material are commonly seen.

In this study, the extrusion method uses fibrous protein meat as the printing material which is completely different from that used by the commercial 3D food printers. In our system, pressurized air is used to push out the printing material. With the help of peristaltic pump, extrusion of material inside the soft silicon tube can be accurately controlled as shown in figure 7. The extrusion nozzle is made of teflon tube. All the above components are combined to come up with the novel 3D food printer.

Figure 7. Operation of peristaltic pump

3.6 Extrusion product

Different types of meat materials were placed separately in two different pressurized tanks. After tightening the pressurized tanks and switching on the pressure pump, food material will move slowly from soft silicon tube towards the nozzle. Once the air inside the front end of the nozzle is released, meat material will be extruded out from the soft silicon tube to form the desired pattern as shown in figure 8.

The system developed in this study uses two pressurized tanks and two extrusion nozzles. The first set of nozzle and pressurized tank can extrude fibrous meat material to form block shape with porous texture. The second set of nozzle and pressurized tank can inject liquid pork essence, chicken essence, etc. into the porous material to form juicy and moisturized food material, improving its appearance and test as shown in figure 9.
4. Results and discussion

4.1. Use of pressure tank to solve the limitation of syringe and piston type storage
Most of the food printers on the market use syringe and piston type material storage with needle-head valve to control the amount of food material extruded. These systems often encounter the problem of solid-liquid separation of the food material, leading to poor control of the extrusion volume, or small storage volume which requires frequent feeding of the printing material or is difficult to clean. In addition, overflow of printing material is often seen in system with needle-head valve. By using pressure tank developed in this study, the above mentioned limitations can be overcome.

4.2 Peristaltic pump control
The peristaltic pump and soft tube for material transport can be cleaned by simply using water while keeping peristaltic pump running. Most of the food printers on the market have the problems mentioned in Section 4.1. For instance, when the system is paused or prior to the start of the system, overflow of printing material may occur. In this study, peristaltic pump is used which can control the extrusion of printing material more accurately, making the printing process stable and smooth.

4.3 Three axes ball screw mechanism:
Most of the food printers on the market use belt to move XYZ axis, which may lead to unstable printing. As for the food printer developed in this study, ball screw was used for the movement of axis, which has the advantages of small vibration, accurate printing area, precise printing height and robust.

5. Conclusion
This study aims to develop a 3D food printer which has a printing dimension of 15cmx30cmx5cm. The food printer developed uses peristaltic pump to provide power for material extrusion, with the support of the driving board, the three axes can be driven separately. Comparing to the food printers currently on the market that only can use powder or granular food material to make slurry printing material, the novel food printer developed in this study can use fibrous meat as the printing material. The novel food printer improved the limitation of storage capacity, material property, and material type. It significantly enhance the operation efficiency and productivity. With the new food printer, a wide variety of food can be printed with improved chewing experience. The system uses ball screw as the main driving mechanism which has the advantages of large printing area, accurate printing height and fast printing speed.

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