# Extrusion-Based Multiple Material Mixer Design in Food Printing

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***Abstract*— Food products can be designed and fabricated to meet individual needs through controlling the amount of printing material and nutrition content. Applying multiple-material is quite common in food design. Food printing technology with both single and multiple extrusion-based printhead are utilized to deliver such customized food products. The objectives of this study are to analyze the printing platforms and materials, and printhead design, such as single printhead for multiple material extrusion, and multi-material mixing printhead for dynamic mixing. The extrusion and mixing mechanisms, and design consideration are reported. Both single extrusion printhead and dual extrusion-based mixing printhead designs are discussed. An improvement design version is proposed.**

***Index Terms*—food printer, mixing printhead, food material, mixing chamber, extrusion mechanism**

## I. Introduction

Customized food pieces such as frosted patterns on biscuits and chocolates, letters carved into cookies, and logos painted onto food are currently designed and made by specially trained artisans and need longer time for design and fabrication, which results in a relatively higher cost than that of food products from mass production. This blocks their way to be widely adopted by the public. Traditional food preparation processes even with advanced processing technologies cannot produce such food pieces effectively [1].

Three-dimensional (3D) Food Printing, also known as Food Layered Manufacture [2], can be one of the potential ways to bridge this gap. It is a digitally controlled, robotic construction process which can build up complex 3D food products layer by layer [3]. It has started a revolution in cooking by precisely mixing, depositing, and cooking layers of ingredients, so that users can easily and rapidly experiment with different material combinations.

A range of 3D printing methods have been utilized for food printing, such as selective laser sintering/hot air sintering, hot-melt extrusion/room temperature extrusion, binder jetting, and inkjet printing [4]. Among them, the extrusion-based 3D food printing is the most widely adopted method. The printed food pieces with customized shapes can be used to teach shape, taste, color and design in early child education [5].

The extrusion-based printing process creates objects in a layer-by-layer manner. Fabricated layers do not need to be completely solidified, but require sufficient rigidity and strength to support its own weight and the weight of subsequent layers without a significant deformation or shape change. Thus, the quality of fabricated food items depends on the fabrication process rather than operator skills.

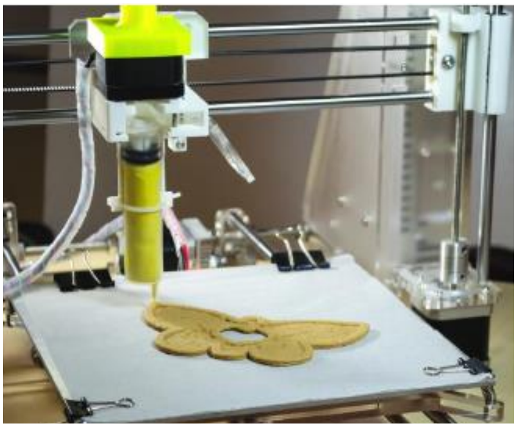

Figure 1. Extrusion-Based food printing

### A. Printing Platform and Printing Materials

As shown in Fig. 1, an extrusion-based food printing platform basically consists of an X-Y-Z three axis stage (i.e., a Cartesian coordinate system), dispensing units (printheads), and a user interface. With a computer controlled material feeding system, such platforms can manipulate food fabrication process in real time. Both commercial and self-developed platforms have been utilized for food printing projects in the literature.

The commonly available multi-axis platforms is Cartesian configuration. As shown in Fig. 1, the Cartesian configuration has X, Y, and Z axes for left to right, front to back and up and down motion, respectively. It may have a square stage moving along Z-axis and a printhead sitting on X-Y axis or a printhead moving along X-Z axis and a square stage sitting on Y-axis.

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The role of this stage in 3D Printing is to enable the movement and positioning of printhead in three dimensional space with reliable accuracy and repeatability. Many first generation food printers use this Cartesian configuration, since a machine with this configuration is simpler to design, easier to maintain and calibrate. Examples of Cartesian configuration include Choc Creator, Foodini, and Robot pizza printer. Most importantly, comprehensive software and hardware resources are available to support the design and development work under this configuration, such as slicing software, printing path planning and dual printhead design.

### *B. Printing Multiple Material Using Single Printhead*

Applying multiple-material is quite common in customized food design, and the diversity of printing materials empowers consumers to take control of food design. Some of these materials are from traditional food recipes, additives and others are non-traditional edible materials or primarily non-food such as ingredients extracted from algae, beet or even insects. Multi-material may also generate multi-scale ingredients after processing, and require corresponding fabrication techniques.

Both single and multiple extrusion-based printhead have been developed in food printing process.

Food printer projects such as ChocALM, Insects Au Gratin, are developed using single printhead extrusion for a mixture of multiple material. Some researchers even compared different printheads to choose a suitable one so as to optimize printing performance [6]. However, a food printer with single printhead is not capable to control material distribution or composition within each layer or in a whole structure.

To achieve controlled material deposition and distribution, multiple extrusion-based printheads are allocated to print supporting or fabrication materials. The data from each layer are directed to a platform controller, which activates the associated motors to move the corresponding dispensing head and control its feeding rate and deposition area.

### *C. Printing Multiple Material Using Multi-printhead*

Printing multiple-material from multiple-printhead is a highly attractive feature which allows switching among material sources for fabricating complex food constructs. It can be applied to testing various nutrition/ingredient combinations in a food product development process or tailor nutrition for individual preference.

Researchers have tried multiple-printhead using Fab@Home 3D printer, and tested frosting, chocolate, processed cheese, muffin mix, hydrocolloid mixtures, caramel and cookie dough [7]. Three-printhead printing was tested to fabircated biscuits using separated deposition heads for three types of material mixture with flour, butter, sugar and egg white [8].

### *D. Printing Multiple Material Using Mixing Printhead*

Even with multiple printheads, it is not possible to develop a platform compatible with all food material printing. Therefore, an alternative solution is to mix a small group of food ingredients in a controllable way to achieve a relatively large food materials matrix.

To achieve dynamic material mixing, an extrusion-based mixing printhead should be designed, where the feed rate of each printhead can be individually controlled for mixing. Thus, food printers may achieve multi-material object fabrication with dynamic mixing ratio and material concentration.

In this study, we would introduce available food materials, single extrusion printhead design, and dynamic extrusion-based material mixing design. That would be a preliminary experimental investigation for the future food ingredient customization. The rest of the paper is organized as follows: Section II discusses the diverse printing materials. Section III introduces single printhead design for multiple material printing. Section IV investigates the mixing mechanism and design consideration from an engineering perspective. Section V discusses the mixing printhead design and its improved version. Finally, a conclusion is presented in Section VI.

## II. Available Printing Materials

Raw materials and unprocessed ingredients usually have longer shelf life than the final food products. If food products can be quickly printed on the spot based on users' requirements, people can have fresh meals all the time. Substantial efforts have been made to pre-process materials suitable for 3D printing. Generally, the available printing materials can be classified into three categories based on their printability [4].

### *A. Natively Printable Materials*

Natively printable materials like hydrogel, cake frosting, cheese, hummus, and chocolate can be extruded smoothly from a syringe [9]. The mixture of sugars, starch, and mashed potato are used to fabricate sugar teeth in Z Corporation powder/binder 3D printer [10]. However, none of them is the main course of meals. Some traditional foods are tested for printability study. Judging by the printing viscosity, product consistency, and solidifying properties, the most successful material is pasta dough. Food products made by natively printable materials can be fully customized for taste, nutritional value, and texture. Some of the natively printable materials are stable enough to hold the shape after deposition and do not require further post processing. Other composite formulations such as batters and protein pastes may require post-processing to improve taste and nutrition absorption.

### *B. Non-printable Traditional Food Material*

Food like rice, meat, fruit, and vegetables, largely consumed by people daily, are not printable by nature. These solid foods or semi-solid liquids have already been manipulated to become printable by gastronomic tricks, however it is difficult to test and modify the whole list of traditional food materials. One solution is to use a small group of ingredients to create a platform with extensive degrees of freedom on texture and flavor. By fine tuning hydrocolloids' concentrations, a very wide range of textures (i.e. mouthfeels) can be achieved such as cooked spaghetti, cake icing, tomato, etc. The flavors can be altered by adjusting the amount of flavor additives being added [11].

### *C. Alternative Ingredients*

Introducing alternative ingredients in food products can be one of the solutions to deal with the global crisis of food shortage. In the ‘Insects Au Gratin’ project, Susanna Soares and Kenneth mixed insect powders with extrudable icing and soft cheese to shape food structures and make tasty pieces with 3D printing [12]. Compared with traditional meat products, the protein concentration in insect powder, an alternative source for protein intake, is slightly higher. Besides, residues from the current agricultural and food processing can be transformed to biologically active metabolites, enzymes, and food flavor compounds, as sustainable printing material sources.

## III. Single Printhead Design for Multiple Material Printing

The hardware design of single printhead printing system includes the development of the printing platform and the development of the print head. An open source 3D printing stage with Cartesian configuration is selected for design modification and improvement.

Since this cookie printer is targeted for home users, both the efficiency and economy of the hardware design need to be considered. Fig. 2 shows the printhead design overview of cookie printer in this project.

The extrusion process for semi-solid food materials in this 3D Cookie Printer requires a suitable pumping system. The concept of pushing syringe pump is applied for cookie dough materials extrusion. It is based on the linear actuator design with a lead screw to transmit rotational motion into linear movement. The same type of stepper motor for printing stage is used for this actuation.

A through-shaft linear motion stepper motor is selected and attached to the pusher of the syringe to force the materials out of the syringe. When the rotation of the shaft is constrained externally, actuating the motor will enable the translational motion of the shaft.

The material capsule is inserted from the front of the structure and pushed until the capsule tube is concentric with the motor shaft. And the flange of the tube needs to be twisted slightly to get fixed in the vertical direction. The bottom of this structure has an aligner to let the material capsule rest along the vertical position. With a cable tie at the end, the capsule can be locked after installation of materials. After the shaft is attached to the piston of the capsule, the print head is then ready for printing. Fig. 2(a) shows the CAD model of the printhead design, Fig. 2(b) describes the installation process, and Fig. 2(c) shows the physical prototype of this design. As Fig. 2(c), the yellow structure was printed in unibody design. The side hole is designed for the interchange of syringe tube with different sizes. Fig. 3 shows some fabricated cookie samples using a mixture of unsalted butter powdered sugar, egg white, food dye and all-purpose flour.


(a)CAD model (b) Installation (c) Physical Prototype

Figure 2. Single printhead design and installation

Figure 3. Fabricated cookie samples

## IV. Design Consideration for Mixing Printhead

### *A. Mixing Technique*

In this study, we would focus on flour-based semi-solid viscoelastic materials. Two types of mixing techniques are explored to achieve dynamic material composition. They are, namely, the static and agitated mixing techniques.

*1) Static mixing*

The static mixing fully relies on the driving force for material feeding and the friction force between materials and the mixer’s built-in structure (mixing helical element). It is very similar to the static mixer concept for A-B epoxy adhesive resin mixing and dispensing.

In static mixing, there is no moving component inside the structure. The mixing takes place solely due to the driving force from the materials pumping system, and there may be a large pressure drop when materials go through the inbuilt structure [13]. Applying such a concept in food mixing process, we need to overcome a few technical issues like consistency of food flow inside a helical structure, and the associated cleaning process for food residue within the structure.

For food printing applications, dynamic mixing ratio will be of great value in order to extrude food materials with continuous color changes or composition changes. The agitated mixing has attracted people’s attention since it can adjust mixing ratios dynamically.

*2) Agitated mixing*

For agitated mixing, the helical element of the static mixer rotates. Similar applications can be found in extrusion molding process where the geometries of rotors or screws are specially designed to provide driving forces for extrusion [14].

In this study, we would combine both static mixing and agitated mixing for food material extrusion-based mixing. Our idea is to rotate the helical mixing element (green piece) inside the static mixer chamber as shown in the Fig. 4. The helical mixing element which has the same geometric profile as the one inside the static mixer, would be connected to a drive shaft and work as the rotating part.

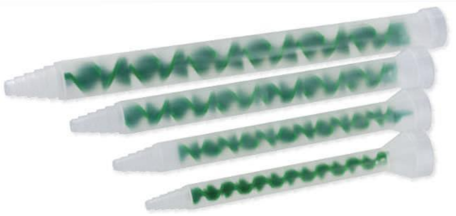


Figure 4. Rotary mixing nozzle model

### *B. Design Consideration*

The mixing printhead as household appliances should be rigid and durable. Thus, such printhead design should consider three factors:

*1) Ease of cleaning*

Since the extrusion-based food mixing involves food material storage and refill, hygienic environment is a must. Ease of cleaning should be considered as the first priority. Materials used for mixing may contain fat-soluble ingredients that cannot be simply flushed by water. Therefore, the enclosed chamber inside the print head and the openings in each part should be easily accessible for cleaning purpose.

*2) Sealing*

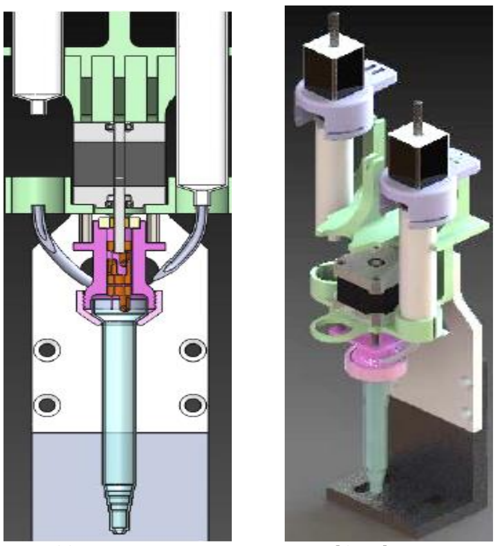
For fluids or semisolid fluids, decent sealing among parts can prevent the leakage of sticky food materials, and also provide a stable condition for better mixing.

*3) Compact design*

Home or office users prefer a neat and compact design. Therefore, we need to minimize the volume of the mixing chamber and the length of tubing system for material transmission. This can reduce the pressure drop and create a neat design presentation.

## V. Mixing Printhead Design Overview

### *A. Mixing PrintHead Design(1st version)*



(a)Front view (b) Side view

Figure 5. First mixing printhead CAD Model

Based on the above discussion, we have developed our first extrusion-based mixing printhead design, with the focuses on the realization of mixing function. As shown in the CAD model in Fig. 5, the mixing printhead includes two capsules for two types of material storing and pumping, a tubing system to connect each capsule and the mixing chamber, and a rotary mixing element with driving shaft linked to an actuation mechanism.

*1) Materials pumping and refilling*

For extrusion-based actuation, each motor is mounted to a syringe holder, which can be hooked to the stand behind. In material pumping, the actuation motor will be activated, and the driven shaft will push the capsule's piston and feed the material into the tubing system. The module of the motors and capsules can be easily replaced.

The refilling system is still a manual process. The capsule will be inserted from the side way and fixed by the rotating flange.

*2) Mixing chamber*

The mixing chamber is designed to be as compact as possible to push the extruded materials leaving the tubes and heading to the mixer quickly and smoothly. To disassemble mixer easily and prevent the leakage of materials, screw threads are applied in this chamber design.

*3) Mixer actuation system*

A universal joint is used to couple the rotating mixing element inside the mixer and the shaft of the motor actuator. A stepper motor is used to generate rotating actuation. This misalignment between the motor shaft and mixing element can lead to unnecessary close contact and high friction during mixing, which in turns generates higher torque to the motor. Thus, the universal coupling is applied for compensation.

*4) Jigs and fixtures*

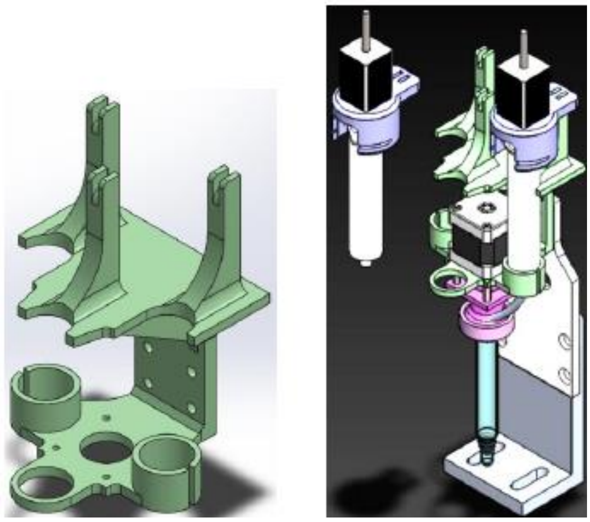


Figure 6. Mounting structure design for printhead holder

The mixing chamber, two feeding capsules and the mixing actuator are all fixed onto a 3D printed mounting structure, i.e. a two-layer unibody design. As shown in Fig. 6, the top layer contains three sets of capsule holder plus feeding capsule stand. Therefore, the three material capsules with their corresponding extrusion structure can be hooked onto the mounting plate with the proper alignment. The bottom layer consists of the mounting holes for the mixing stepper motor and three adjustable cylindrical shells to position the capsules. This two-layer unibody design is installed onto the moving printer stage along Z axis.

*5) Testing result*

The material used for this extrusion-based mixing test is a mixture of plain wheat flour and water with the ratio of 1:1 by weight. The mixing material is evenly divided into two portions: sample A with green food coloring, and sample B without coloring. The two samples are fed into their individual capsules and the mixing samples are shown in Table I, where the color scale is determined by mixing ratio. It can be seen that with the increasing ratio of sample A, the color of the mixing samples becomes greener.

TABLE I. COLOR SCALE FOR MIXING TEST

| Ratio | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| A: B (%) | 0:100 | 25:75 | 50:50 | 75:25 | 100:0 |
| |  |  |  |  |  |

From the results, it can be seen that the color of mixing samples is quite uniform. The mixing performance in terms of consistency and stability as well as time delay due to each material pumping, requires further experiments.

### B. Mixing Print Head Design(2nd version)

Since the first design looks bulky and clumsy with weak pumping power, the improved extrusion-based mixing printhead design is proposed.

*1) Materials pumping and refilling system*

The new design shifts the two material capsules onto the stationary frame of the printer. Only the mixer and mixing chamber are loaded on the printing stage. From the illustration in Fig. 7(a), the frame design of this printhead is optimized to have a lightweight structure and compact size.

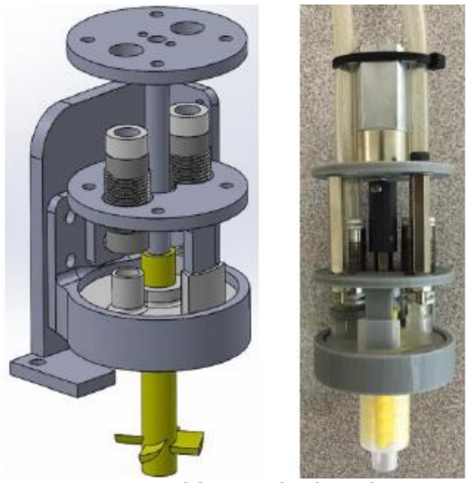
*2) Mixing chamber*

The physical prototype of the 2nd printhead design is shown in Fig. 7(b). The mixer is improved in terms of compactness and the sealing. The rotating mixing element has a hexagonal hole on the top for the shaft to slot in, and the metal spacers are used to position three layers and two inlets.

*3) Mixer actuation system*

A more powerful DC motor is selected to drive the mixing element in the new design. The size of the motor is reduced to one quarter of the previous design. The holding torque almost doubles as compared to that of the stepper motor used in the 1st mixing printhead design.

The testing of the second design has not been performed yet due to the time constraint. While, we believe the second mixing printhead design will be more likely to have a better mixing performance due to the improved sealing design and pumping mechanism.



(a) CAD Model, (b) Physical prototype

Figure 7. Improved mixing printhead design

## VI. CONCLUSION AND FUTURE WORK

3D food printing has demonstrated its capability of making personalized chocolates and producing simple homogenous snacks. Many 3D printing of food projects have been carried out from printer development, material research to product commercialization. However, these applications are still primitive with limited internal structures or monotonous textures. To achieve diversity in food fabrication, it is necessary to systematically investigate the extrusion mechanism, and extrusion-based mixing printhead. Two types of food material mixing printhead are designed and tested in this study. The 2nd design is believed to have better performance in terms of mixing capability and mixer size. Diverse types of extrusion structures and mixing mechanism would be investigated at the next stage.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