Constructive and functional particularities of 3D printers with applications in the food industry

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Abstract. The paper presents the construction and operation of a 3D printer that uses the principle of food raw material extrusion with possible applications in the food industry. The emergence of these additive technologies has led to the obtaining of complex customized three-dimensional products starting from a 3D CAD model. Among the advantages of this technology with applications in the food industry can be listed: obtaining personalized food products with innovative forms especially in the confectionery and pastry area; obtaining food products that have in the component known raw materials (allergies, intolerance), forms, colour, strictly controlled nutritional value; the possibility of integrating this technology in long-term space missions by creating foods of different shapes and compositions. Also, older people can be helped to deal with the problems of chewing and swallowing. The disadvantages of 3D printing technology with applications in the food industry are related to food safety, because strict hygiene conditions and working temperature control must be ensured. Also, the future development of this technology can lead to the saving of large quantities of food raw materials.

1. Introduction

Cooking is one of the most important activities in our lives, and a robotic chef able to follow recipes would have many applications in both domestic and industrial environments. For example, baking robots can find the ingredients, mix them in the correct order and place the resulting dough in an oven baking tray. These robotics-based techniques used in traditional food production for mass production are generally designed to automate manual processes. They can significantly reduce workload, save labor costs and improve food efficiency. Unlike robotics-based technologies, food printing integrates 3D printing (3DP) techniques also known as Food Layered Manufacture and digital gastronomy to produce food customized in shape, color, flavor, texture and even nutritional value. 3DP technology is a digitally controlled construction process that forms solid layers layer-by-layer and applies phase transitions or chemical reactions to the combined layers. The combination of 3DP techniques and digital gastronomy can digitally visualize food handling, thus creating a new space for the manufacture of new foods at an affordable price. As a result, a custom food design in the form of a digital 3D model will be directly transformed into a finished product in a layered structure.

The emergence of new additive technologies has led to new products, customized three-dimensional complexes starting from a 3D CAD model [17]. One of the challenges of this technology is its use in the food industry due to the complexity of the equipment used and the strict food
protection rules that must be observed but also to the spectacular results. 3D food printing offers a wide range of usable, fully customized foods that fit exactly the needs, tastes of people of different ages, occupations and lifestyles by adapting the composition, density, structure, color of food, adaptable to user preferences and needs [19].

![Dosing system of a food 3D printer](image)

**Figure 1.** Dosing system of a food 3D printer

The food raw material used with a high variability of physico-chemical properties both before and after printing must be able to ensure a continuous flow, to have the same structure can be used as an example chocolate, hummus, different mashed potatoes, peas, carrots, respectively different types of doughs [2, 3, 4].

The basic element in the case of 3D food printing is the construction of a certain product layer by layer based on a CAD model. The parameters to be controlled can be divided into two categories, namely: the parameters related to the printing machine, namely the control of the speed of its coordinates on the X, Y, Z axes and the movement of the extruder motor that drives the device in which the raw material to be printed is found (Figure 1) and the second category the parameters related to the food itself to be printed so as to obtain a correlation between the printing speed, the flow rate and the quality of the printed material in order to obtain a precise and pore-free final shape [16].

Also, the size of the nozzle is closely related to the structural properties of the extruded food products, determining the pressure exerted and affecting the resolution at extrusion. Another process parameter that critically determines the quality of the printed product is the distance between the nozzle and the printing bed, for each printed food product there is an optimal distance. with a good resolution it requires that the basic materials have a sufficiently high viscosity to support different successive layers, in this case different food additives can be used [13, 15].

2. Design and execution of 3D printer

Designed on a simple, reliable architecture, CAD programs with which the 3D printer was designed with applications in the food industry, Inventor and Catia have their own geometric core, with the integrated drawing module. The modelling strategy has as a starting point the design based on the constructive-technological characteristics of the parts, continuing with the realization of the assemblies, the functional dimension, having the ability to identify, modify and communicate the design intention throughout the entire construction process [5, 6, 7].

The structure of the 3D printer presented in the article is of the Cartesian type, due to the advantages that this type of structure has [10]. The 3D printer was made of aluminum profiles with the size of 20 x 20 mm, the subassemblies of the axes of movement "OX" and "OY" allow a translational movement. The transmission of the movement from the motor shaft to the mobile subassembly was
made by means of a belt toothed with a pitch of 2 mm, which is stretched on the 2 toothed pulleys and embedded in the movable subassembly [14].

Figure 2. CAD design of some 3D printer subassemblies with applications in the food industry: a - stepper motor - guide axis, Y axis subassembly; b - subassembly of guide axes with linear bearings, X axis; c - Z axis platform assembly; d - 3D printer assembly with X, Y, Z axis guide axes; e - Z axis extruder assembly

Figure 3. Deposition table: 1 - stainless steel support plate; 2 - Peltier resistors; 3 – thermal insulator; 4 – support; 5 - aluminium radiator; 6 - fan
The constructive novelty is the realization of a structure in which the diagonal movement is made by operating a single motor, which is achieved by mounting the toothed belt in the shape of "H" – Figure 4. In this way a structure is obtained in which the displacement of the "OX" and "OY" axes have a low inertia and as a result a good dynamics. Therefore the printhead moves on the coplanar axes "OX" and "OY" and the displacement axis "OZ" will perform a translational movement, with a stroke of 50 mm, provided by a screw-nut mechanism and the two rods guidance with linear bearings, which have the role of supporting and moving the surface on which the food material will be deposited by the method of depositing successive layers (layer by layer) [10]. The printing surface in the XOY plane is made of plastic over which a stainless steel sheet was fixed with the printing size being limited to 210 x 210 mm. In order to ensure an optimal adhesion temperature for different materials such as chocolate, sugar mixtures, starch, mashed potatoes, the deposition table was adapted by inserting under the stainless steel platform two PELTIER heaters that ensure the cooling and properly ventilated capacity – Figure 3 [4].

The Hypercube 3D printers have the advantage of using a larger print area and a higher print speed. The Hypercube system usually has a much lower inertia, and when the same motors and the same forces are used, a faster acceleration results. Among the disadvantages of the system can be listed the transmission belts are not kept parallel to the guide rails causing a tension of the belt depending on the position of the trolley. Also, long straps can cause vibration and create resonance problems. The equations of motion are described below.

\[
\Delta X = \frac{1}{2} (\Delta A + \Delta B) \quad (1)
\]

\[
\Delta Y = \frac{1}{2} (\Delta A - \Delta B) \quad (2)
\]

\[
\Delta A = (\Delta X + \Delta Y) \quad (3)
\]

\[
\Delta B = (\Delta X - \Delta Y) \quad (4)
\]

The positioning accuracy is given by the assembly of the drive mechanisms by means of the stepper motors, of the sliding guides respectively of the toothed belt transmission. Stepper motors are motors that operate on the principle of shape anisotropy. In general, they have two phases that can be controlled by a single phase (single sequence) or by two phases fed simultaneously (double sequence). In order to reduce the pitch angle, 5 stator teeth are processed on each stator pole, and in this way, if there are 50 teeth on the rotor, the pitch between 2 rotor teeth will now be equal to the pitch between 2 stator teeth. By decreasing the step, the angle at the center is practically reduced, ie the motor pitch.
\[ \theta_p = \frac{360}{p_s \cdot z_r} = \frac{360}{4 \cdot 50} = 1.8^\circ \] (5)

\( p_s \) = the number of stator poles \\
\( z_r \) = the number of rotor teeth

Advantages:
- the maximum control frequency has high values resulting in high speed
- can be made with different step angles
- simple mechanical construction
- bidirectional

Disadvantages:
- does not memorize the position (a transducer must be used each time to know the exact starting position).
- does not develop electromagnetic torque in the absence of control current (when the motor is stopped, the shaft can still rotate from the outside).
- if it is fed in a simple sequence, then due to the friction torque, the step is performed with significant oscillations at stop.

There are two values for frequency, called resonant frequencies, at which the sudden decrease in motor torque occurs - Equation (6).

\[ f_{rez} = \frac{1}{2 \cdot \pi \sqrt{\frac{p \cdot M}{J_{red}}}} \] (6)

\( p \) = the number of rotor steps \\
\( M \) = maximum torque \\
\( J_{red} \) = reduced moment of inertia, the only quantity that can be acted upon

For the control of stepper motors model 17 HS4401 the DRV8825 driver was used, the device has two H-bridges and a micro-stepping indexer being dedicated for the control of bipolar stepper motors. To determine the actuation stroke of the dynamic elements in relation to the printing surface of the structure, mechanical limit switches are used, they are connected to the hardware component from the Figure 5, together with the drivers for controlling the stepper motors.

The electronic components of the 3D printer consist of the 8-bit ATmel microcontroller, the latter being integrated on the Arduino Mega 2560 development board, this is a multifunctional board that supports serial communication, analog acquisition, PWM control, generic communications of digital I/O [9, 11, 12].

The frameware used (Figure 6) is "open sources" called "Repeater", this is a complex program written in C++, which communicates between the dynamics of the printer and the extruder defined by lines of code "G-code". The latter generating trajectories to achieve the projected piece. Therefore, the frameware consists of subprograms that allow the user to operate quickly in order to adapt it to the type of printer, to the print dimensions, to the establishment of the starting position, as well as the configuration of all process parameters [8]. The software is the basic component that transforms the designed part into "G-code" in order to control the stepper motors and execute the work trajectories.

The software used is Repeater-Host (Figure 8), it offers the setting of several parameters that will influence the general properties of 3D printed parts such as: the size of the deposited layers that may vary depending on the diameter of the nozzle, density of material used in building the part, operating temperature, dimensional scaling of the part on three dimensions, delimitation of the printing space, etc.
Figure 5. Control system hardware diagram

Figure 6. Frameware configuration with determination of the travel of the three axes of movement "x", "y" and "z".
The design of the 3D circle and square model was made with the help of Catia software that allows saving files with the extension .stl [5,6] – Figure 7.

**Figure 7.** CAD design of the 3D model and saving the stl file: a-circle; b - square

**Figure 8.** Interface of the Repetier Host program and generation of G-code programs

**Figure 9.** Z axis subassembly: 1- stepper motor, 2- flexible coupling; 3 - screw-nut mechanism; 4-rod; 5- food print tank; 6 - nozzle
Figure 10. Food industry 3D printer prototype overview

The food composition can be deposited layer by layer according to the 3D CAD model created by the designer, with the help of the 3D printer used in the food industry – Figure 10. The print head (Figure 9), works on the principle of the syringe type device, the stepper motor on the Z axis acts on a piston that pushes through the outlet nozzle the food raw material in the tank.

In the experiments performed were used four types of creams for cakes that were prepared according to the manufacturer's recipe: chocolate cream, whipped cream, vanilla cream and mustard (Figure 11).

Figure 11. Raw materials used in experiments: a – chocolate; b – whipped cream; c – vanilla cream; d - mustard
Figure 12. Experimental results obtained for the raw material of vanilla and chocolate

Figure 12 and Figure 13 show the experimental results obtained for the four types of food products used in the food industry, the experiment proposing the realization of simple geometric shapes - circle and square (circular interpolation and linear interpolation) with a height of 5 mm.

Figure 13. Experimental results obtained for the raw material of whipped cream and mustard
3. Conclusions
The implementation of the concept of three-dimensional printing of food products can contribute to improving the quality of food, reducing its price, eliminating the costs of transport, packaging and prevention of unnecessary consumption. From the experiments it can be seen that the first base layer is not firm, the deposition of the second layer leading to flattening of the construction, the viscosity of the food must be correlated with the diameter of the syringe nozzle and the rotation speed of the stepper motor that drives the syringe piston to obtain 3D food models with appropriate shapes and appearance. Also, the entire work enclosure must be sterile, closed and maintained at a low temperature of 2-4° C to prevent on the one hand the appearance of microorganisms but also to ensure the stability of the deposited layers. A barrier in the development of 3D food technologies is the composition of materials (ingredients and their structure, texture and taste), due to various combinations, handling in non-sterile conditions that can damage the final product. That is why in the construction of 3D printers with uses in the food industry must take into account the materials used, usually stainless steel surfaces for the support table and plastics used in the construction of the dosing system that can be easily washed, cleaned and disinfected. In the future, these 3D technologies can offer more freedom in design, shapes, colors and flavors for home users.

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