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Printable food: the technology and its application in human health

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Millions of Americans suffer from diseases and conditions that require careful control of their diet as part of treatment. The current solution is to have each person customize their own food choices. Food production automation can enable consumer specific data to be easily integrated into the food as it is being prepared. This would improve the quality and utility of the food without a cognitive burden on the consumer. 3D Printing is an ideal family of technologies for enabling such mass customization of food. Current efforts in 3D printing food are focused on improving the artistic quality of food in the short term and consumer health in the long term.

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Introduction

At first food may seem like an odd and potentially unappetizing application space for 3D Printing technologies started by some overly zealous futurists. 3D printing is commonly associated with extruded plastic, jetted monomers, and sintered metal powders, not Crème brûlée. It is done in engineering workshops and industrial spaces, a far cry from restaurant or home kitchens. 3D food printing is in fact an outgrowth of user driven interest and a reasonable use of 3D printing methods which may have beneficial effects on human health. By bringing together automation, and consumer driven data, 3D printing can offer food which is both visually appealing and customized to the wants and needs of consumers. In this paper we will discuss the motivations, technologies and recent developments behind 3D printing food and attempt to broaden the interest and efforts in this field.

3D printing is being adopted in most industries because of two key abilities it offers over other manufacturing techniques: geometric complexity and mass customization [1]. The layer by layer processes allow for material, and more importantly, information to be placed into a final object exactly where it is needed. This is an inversion of traditional manufacturing, where material is removed or formed by extrusion. For 3D printing processes, it is often cheaper to make highly complex forms than simple uniform filled shapes. This is because it uses less material and by extension less machine time to solidify a less dense, but more complex shape. When compared with rapid prototyping via machining, 3D printing can be several orders of magnitude cheaper for highly complex parts [2•]. Many processes can vary the materials and material properties across a 3D printed object; allowing for variations in stiffness, density, and even conductivity in a single part. Recent developments of the technology even allow for the combination of solid and liquid materials into a single part [3•]. This ability to make highly complex shapes and material property distributions allows for parts that have better performance than traditionally manufactured analogs.

Because 3D printing processes are a tooling-free technology which is computer driven, the setup costs for 3D printing different shapes is very low. Therefore, production costs scaling nearly linearly with the number of items being manufactured. Because it's a computer driven technology with a well-developed shape processing software for each machine, it's possible to drive the process directly from 3D designs, voxelized data structures or pure functional code [1]. This is what enables mass customization via 3D printing. Each design can be generated via computer code and produced at roughly the same cost as a producing a copy of another design. Items made can be customized from data about the consumer. In the case of Invisalign, each braces set is designed based on data on the consumer's teeth and inputs from an orthodontist [4]. The same technologies which have the potential to enable mass customization of consumer products in other fields, may hold the key to enabling the mass customization of food.

Motivations

There are two main reasons to customize food for each consumer: health and preference. Millions of Americans have conditions which are treated by, sensitive to or caused by foods. According to the CDC and recent studies, 4% of the US population has food allergies, the vast majority of which are caused by peanuts, tree nuts, soy, wheat, eggs, milk, fish and shellfish, which are often stables of the US diet [5,6]. Many more people have food digestion problems. According to the NIH, 65% of the world's population is lactose intolerant in adulthood [7]. 60–70 million people in the US are affected by dietary diseases such as Celiac Disease, Crohn's Disease, GERD, Diverticulitis, and Irritable Bowel Syndrome. This lead to 21.7 million hospitalizations in 2010 alone [8]. Many people have other conditions that limit their ability to swallow food. GERD, Scleroderma, and strokes can all limit a person's ability to swallow whole foods later in life, limiting the range of foods they can eat. 68.8 percent of adults in the United States are overweight or obese [9].

Each of these diseases and conditions requires adjustment of diet as part of treatment and management. However, the standard for delivering such treatment is to give the patient a paper print-out of foods to avoid and meals to prepare. The patient must then exercise willpower every time they are to consume food and must advocate their needs explicitly to all producers of food they interact with. According to the American Psychological Association, willpower may be a finite resource that can be depleted [10,11]. It is no wonder that without the fear of death or pain that some conditions cause, most people have trouble adjusting their diets through self-advocacy alone. What is needed in food and diet is the injection of consumer data through automation to automatically adjust foods to the consumer's needs.

Mass customization of food through automation would enable the consumer data driven production of foods. This would have a potentially transformative effect on human health. Automation in the production of custom on demand food items would help eliminate the spread of foodborne disease by eliminating disease vectors. Computer control also reduces the likelihood of accidental cross contamination. Automation also allows for the easy integration of consumer data. By allowing food ingredients and preparation to be automatically adjusted to the consumer's information, it would be possible to have diets which enforce themselves without the need to exercising will power. The world is currently awash in information about consumers. From digitally recorded transactions to log consumption patterns, to exercise tracking wearables, to electronic medical records and online calendars, a person's current, past, and future caloric and nutritional consumption and requirements can be estimated. 3D printing and robotic fabrication technologies will enable this automatic food production system.

The technologies

There is no one technology that is 3D printing. 3D printing is a family of additive manufacturing technologies that tend to involve solidifying powders, liquids or slurries. Each technique has its own technical challenges and applicability to food. Stereolithography (SLA) is the oldest and least applicable to food. It uses a laser to cure material into solid form. While some have used this to cook egg whites, no large scale application has been developed in the food space with this technique [12••]. Powder based techniques such as 3DP are the most mature in terms of ability to produce geometrically complex foodstuffs. This process requires recipe developers to make a two-part chemistry system for their foods. The powder is bound together by a jetted liquid. The liquid is patterned using ink jetting heads for each layer of the foodstuff. The liquid can also carry flavoring and coloring agents into the food. The ChefJet system currently represents the most complex food printing system developed using this technique [13]. PolyJet processes use ink jetting to directly deposit material which is then solidified. This process allows for very different materials to be placed next to each other in complex patterns in traditional applications. Biozoon with FoodJet have used this technique to make gelatin based foodstuffs. The jetting and setting process can be a difficult process to properly develop for foods [12••].

Robocasting or extrusion 3D printing is the easiest to develop and has the widest set of foods made with it. A robotic arm moves along a surface, extruding material. When done with a layer, it lifts up to extrude the next layer. These arms can be gantry systems to industrial robotic arms. Each extruder uses a cartridge of food. The food is extruded from an opening and either cool to a solid state or are made of a self-supporting slurry. To produce a self-supporting material, the material must be shear thinning. Therefore it must have a Shear modulus G which can be represented as a complex number G^*, where $G^* = G' + iG''$. G' is the shear storage modulus and G'' is the shear loss modulus. When a pressure is applied the values of G' and G'' change. If G'' becomes greater than G', the system can flow and be extruded [14]. This limits the pressure the unset material can withstand before collapsing. To facilitate making larger structures, the foodstuffs should solidify via coagulation, gelation, evaporation, or freezing the resolution of the printer determines the homogeneity of the food stuff required. This process often requires the modification of traditional foodstuffs with visco-modifiers such as xanthium gum or pectin. This method has been used to make chocolates, pizzas, gelatins, cookies and many other food stuffs. It's the easiest for a chef to develop new recipes for since it only requires modifying viscosity, which is a process most chefs are familiar with [12••].

Previous work

3D food printing is a field dominated by secretive corporate research projects, sponsored research and startups. These groups tend to publish their work less frequently and provide few technical details to maintain competitive advantage. This may enable capitalization of innovation,