xPrint: A Modularized Liquid Printer for Smart Materials Deposition

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Figure 1: xPrint system. (a) Open hardware and software platform; (b) Magnet assembly based modular design and alignment; (c) Outcome of one user test: a sweat activated transformable garment; (d) Printed pH responsive calcium alginate gel sample; (e) Outcome of one user test: an animated painting on paper.

ABSTRACT
To meet the increasing requirements of HCI researchers who are looking into using liquid-based materials (e.g., hydrogels) to create novel interfaces, we present a design strategy for HCI researchers to build and customize a liquid-based smart material printing platform with off-the-shelf or easy-to-machine parts. For the hardware, we suggest a magnetic assembly–based modular design. These modularized parts can be easily and precisely reconfigured with off-the-shelf or easy-to-machine parts that can meet different processing requirements such as mechanical mixing, chemical reaction, light activation, and solution vaporization. In addition, xPrint supports an open-source, highly customizable software design and simulation platform, which is applicable for simulating and facilitating smart material constructions. Furthermore, compared to inkjet or pneumatic syringe–based printing systems, xPrint has a large range of printable materials from synthesized polymers to natural micro-organism-living cells with a printing resolution from 10μm up to 5mm (droplet size). In this paper, we will introduce the system design in detail and three use cases to demonstrate the material variability and the customizability for users with different demands (e.g., designers, scientific researchers, or artists).

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INTRODUCTION
Smart functional materials such as transformable living materials and shape memory polymers are gaining increasing attention from researchers in the fields of science, engineering, and design [4, 27]. In particular, in the human–computer interaction (HCI) community, active materials that could response to external controllable stimuli to create functional and interactive interfaces are emerging as research directions [22]. Meanwhile, there are an increasing number of new responsive liquid-state materials that are used for creating novel input and output devices [13, 30]. However, the toolsets that HCI community could choose from to process liquid-state raw materials are limited. Therefore, it is necessary to design a customized high-precision printing platform that can be used for depositing a variety of liquid materials at a wide range of viscosities that could effectively facilitate the design of interactive objects and promote the use of novel materials in HCI research.

The ideal platform should be able to shorten the time required to create smart material based interfaces, and to fabricate more precise prototypes. However, the ability to integrate multiple materials into one digital fabrication process remains a challenge with commercially available printing platforms. The major problems are unavoidable hardware configuration constraints and non-open sourced firmware [7, 26]. To solve these, the maker community has been exploring pneumatic syringe–based extrusion printing, especially for food printing [23]. In some engineering labs, they have built their own research tools (e.g. 3D bioprinting [17] and 3D-printing for chemical synthesis [28]). However, these sophisticated equipment or open-platform and high-precision liquid solution modeling (LSM) printing systems are not readily available for outsiders. Through this work, we hope to address those challenges and bring LSM-based 2D and 3D printing to the fab table.

In this paper, we present the xPrint system, a clear strategy for HCI researchers to build their own deposition digital printer to process liquid materials with off-the-shelf components and easily machinable parts in a short time. The key part of the approach is the magnetic assembly–based modular design, which makes it extendable and easy to reconfigure and align with high precision to meet different material requirements (e.g., mechanical mixing, chemical reaction, light activation, and solution vaporization). Furthermore, xPrint can process a wide range of printable materials with various viscosities from synthesized polymers to natural micro-organisms with its printing resolution from 10μm to 5mm (droplet size). In addition, we have developed an open-source, highly customizable software and simulation platform to help synchronize the changing of hardware components and the generation of G-codes for different 1D, 2D, and 3D printing path settings. To demonstrate the material variability and customizability for different users, we invited three users (a designer, a scientific researcher, and an artist) to test our system.

RELATED WORK

Bio-printing

Recently, bio-printing has become an emerging technology for constructing and fabricating biomaterials in the field of bioengineering. Most state-of-the-art bio-printing technologies are inkjet- or extrusion-based. Inkjet printers enable precise control over the locations of droplets and thus give users great flexibility. There are numerous research papers detailing the hardware technology [29, 30], demonstrating a step-by-step approach to integrating the inkjet head to a CNC router. Despite great progress in inkjet-based bio-printing, this technique still faces some limitations. One of the main restrictions is the low upper limit for the viscosity of bio-ink. Cell aggregation and sedimentation in the cartridge and clogging of the nozzles are limitations associated with this technique [6].

The method using a pressure- or extrusion-based printing system has been used for quite a long time. Extrusion-based bio-printing is a combination of a fluid-dispensing system that includes a pneumatic or mechanical system with an automated robotic system for extrusion and writing [12, 15]. For example, BioBot [3] is specifically designed for printing biological materials, which overcomes the viscosity limitation and clogging problem in an inkjet system. However, the trade-off is the printing precision and material portfolio, which can only be applied on a limited printing scale with specific materials.

Functional Material Printing Systems

Researchers in the field of additive manufacturing have been developing new instruments and platforms for printing materials beyond static plastic. Jennifer Lewis' group created a deposition method based on a 3D printing system that allows one to create 3D structures with conductive materials [9, 18]. However, their research focuses on material invention and characterization. The software and hardware setup of the printing system is less documented, making it difficult to rebuild such a system for printing other functional materials. More recently, a team at MIT presented a multi-materials printing system that prints liquid conductive and magnetic materials [25]. The system is built with off-the-shelf components and costs relatively little ($7000) compared to high-end multi-material printers. However, the system uses inkjet print heads for deposition, which only allow nanoparticles to pass through. This becomes a major constraint if one needs to print larger size particles such as cells or spores.

Digital Fabrication Tools for Unconventional Materials

Previous research has led to a variety of fabrication processes and tools for smart or unconventional materials. PrintScreen [19] is a versatile platform to fabricate customized flexible interactive screens with thin-film electroluminescence characteristics. ShrinkyCircuits [11] uses an inexpensive pre-stressed polymer film to present a novel compositing prototyping technique that produces circuits in minutes. Protopiper [1] is introduced as a digital bending approach that allows users to sketch room-sized objects at actual scale with plastic tubes. Hudson creates a felting machine [10] with a solid additive manufacturing method to open new possibilities in the creation of interactive objects that are soft and flexible. To compensate existing toolsets and materials portfolios for creating interactive interfaces, we propose the development of a platform that can handle a large pool of novel smart materials in a liquid state.

Open Source Fabrication and Modular Printer

Modularization and open source systems are gaining increased attention in the field of digital fabrication and the maker movement. Peek introduces a method of making a desktop CNC machine with cardboard folding and HDPE snap fit as its supporting structure [21]. All designs being open source allows users to customize the gantry according to their individual needs. Fab@Home [5] is an open-source mass-collaboration developing personal fabrication technology aimed at bringing personal fabrication into homes. Moyer also introduced methods of customizing a digitally controlled dispenser [16]. For scientific research, modular science creates a modular hackable software and hardware system for lab automation to improve reproducibility and the exchange of scientific information

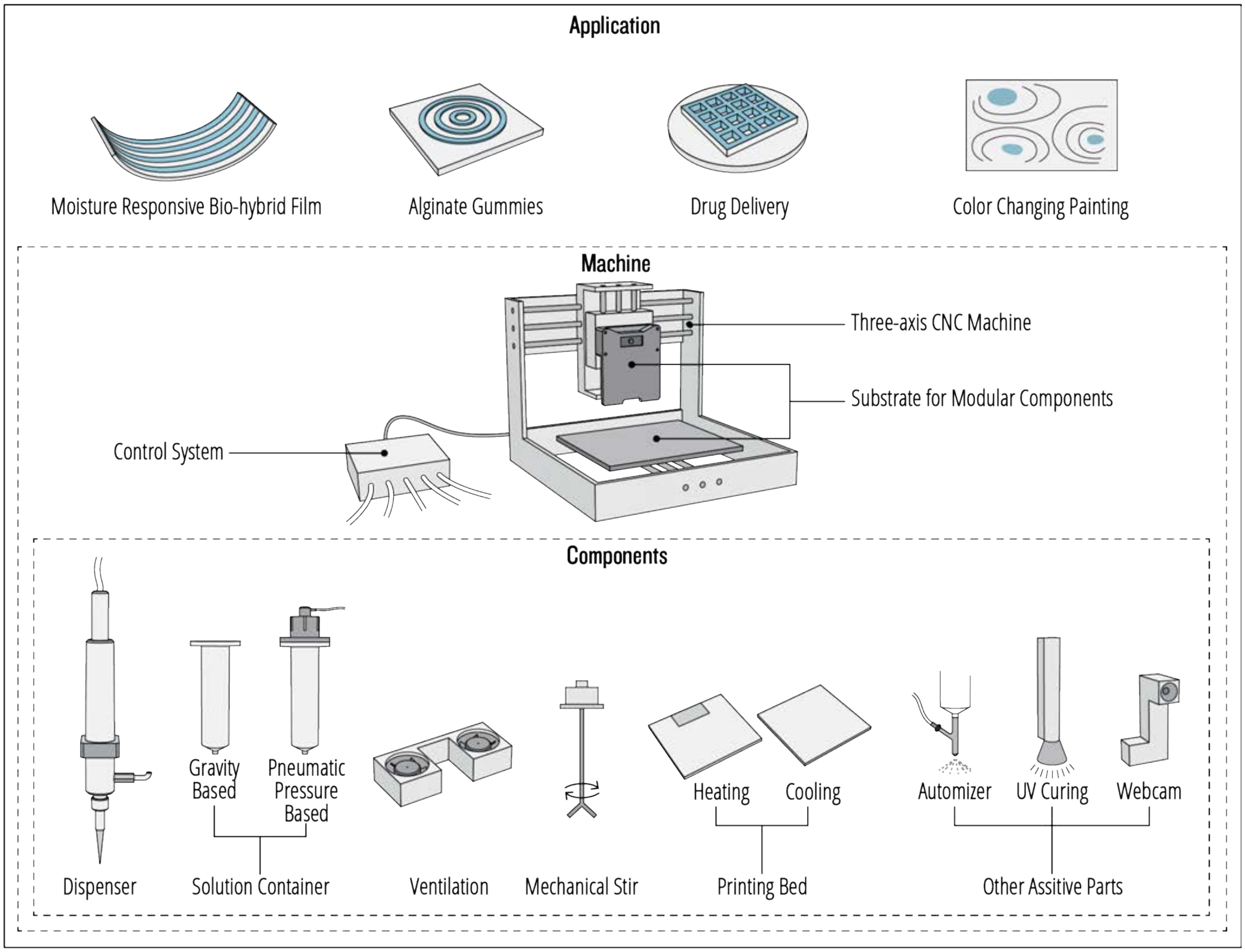

Figure 2: Hardware platform of xPrint: machine based and modular components.

[14]. Inspired by those works, our goal is to create an open source hardware and software platform for depositing liquid-based smart materials.

XPRINT SYSTEM

xPrint contains off-the-shelf hardware components, and a software platform developed on top of open source plugins (Figure 3). xPrint is designed with a few goals in mind: A highly customizable modular design to accommodate different material printing requirements; an easy work flow from geometry design through G-code generation and machine control to material fabrication; a high-precision system that covers printing droplet width from 10µm up to 5mm; good usability for a large user group including designers, artists, and scientific researchers; and safety and hygiene.

Hardware Platform

The hardware system includes a machine base and modular components (Figure 2). It is built with off-the-shelf components and easily machinable parts.

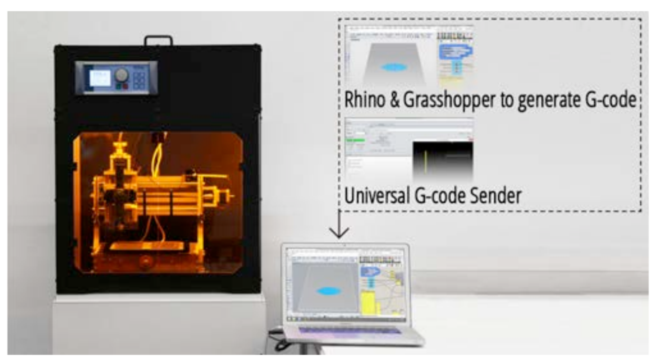

Figure 3: xPrint system: An integrated, customizable hardware and software platform

Machine Base

The machine includes a standard three-axis CNC platform, two mounting substrates for attaching modular components, and a central control system. In our demo system, we use a CNC kit (F8 version) from Zen Toolworks [31]. A higher end CNC platform will help increase the printing resolution. The mounting substrates are used to mount the central dispenser and other configurable modular components. They have embedded magnets at particular locations to hold all the modular components at the same places each time. The Breakout control board supports up to five one-axis stepper motors, five input ports, and five extra output ports to accept signals and send commands to the modular components.

Modular Components

We chose the essential modules based on the tasks required of our printer: Printing liquid solution–based smart material and forming 2D or 3D composite structures. The modularized parts can be reconfigured to meet different material requirements for solidification, such as mechanical mixing, chemical reaction, light activation, and solution vaporization.

All modular components are designed with specific mechanical structures and magnet assemblies for easy plugging/unplugging and configuration. To save space and keep them clean, all components can rest on top of the ceiling of the printer case (Figure 4-1). Figure 4-2 describes the locations of each component, and the corresponding magnet placements. All modules are designed in such a way that the magnets ensure the same exact placement location each time.

- The dispenser is the central component. It is a progressive cavity pump–based dispensing head (EcoPen 300 from ViscoTec-America Inc.) that covers droplet widths from 10μm up to 5mm. The dispenser is controlled by the central control system; customized G-code can turn the dispenser on and off on demand.
- Solution container: There are two types of solution container. Liquid that flows quickly with its own gravity can be loaded into the gravity-based container without a cap; a closed container with controllable pneumatic pressure is used for solutions with higher viscosity.
- Ventilation: Certain solutions only solidify when water or other chemicals evaporate. In this case, a ventilation module with two speed-tunable fans can be placed on top of the printing platform.
- Mechanical stir: Some materials are particles suspended inside a liquid. Those materials are not soluble and may form into sediment. This problem becomes very obvious when it comes to living cells printing [20]. Mechanical stirring is a useful approach to prevent sedimentation.
- Camera: We currently use a webcam to remotely track printing progress; however, more interesting work can be done with a live video stream if computer vision is combined. For example, an object can be detected and set to be the initial location of the printing path.
- UV Curing lamp: A large group of materials can be made UV-curable, the most common of which are resins. Under the scope of smart materials, we explore

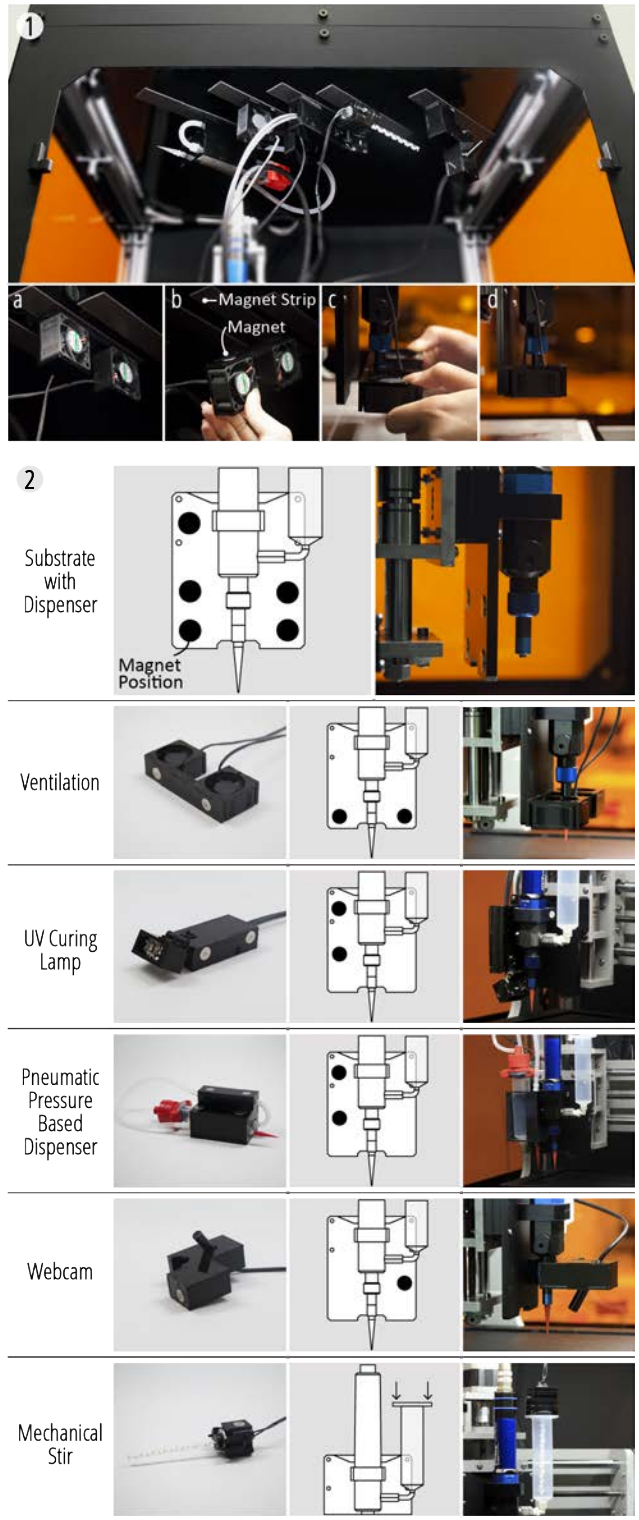

Figure 4: Modular components with magnetic assembly

color-changing resin, and moisture-responsive hydrogel.

- Pneumatic atomizer: Coating is a universal process for both material and chemical research, and industrial layered composite materials. For liquid solutions, we use atomization to coat the surface evenly, or coat the surface with pre-mounted masks.

Software

In a software system, the workflow includes design, simulation, and communication (Figure 5). Since our targeted use cases involve people with different levels of digital design and modeling skills, and different software feature requirements to design different printing paths, we decided our software design strategy as follows: A set of parametric tools based on the most commonly used printing path; customizable with parameter sliders.

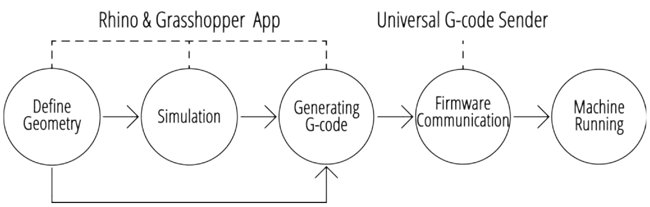

Figure 5: Workflow of the xPrint software platform.

The software platform is built on top of an open source algorithmic modeling platform, Grasshopper [8], which enables both graphic programming and a visual user interface. Thus far, we have the basic toolsets to handle 1D, 2D and 3D structures; more customized variations can be easily developed on top of the current platform.

Since different materials require specific hardware configurations and control settings, we suggest a customized software platform to facilitate the G-code generation process. The customized G-code controls the CNC platforms and some modular components that need synchronization, such as the dispenser and the UV curable light.

- 1D Tool – Offsetting a line path

If the goal is to print one open or closed line, once or multiple times, with a certain width, this is the correct tool to use. Since the print head has maximum line width (~5mm), if the targeted width is larger than 5mm, a more offset line path can be generated with a slider (Figure 6).

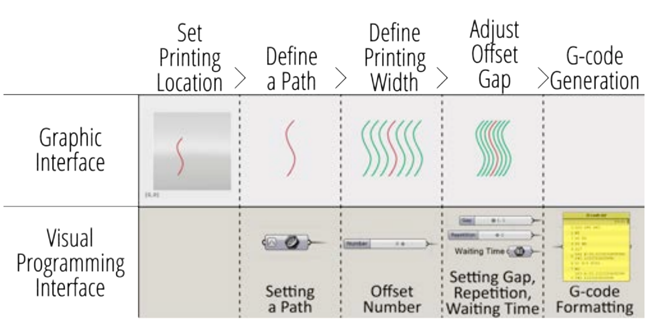

Figure 6: Graphic user interface for offsetting a 1D line.

- 2D Tool – Filling a geometry

The user draws a closed curve to indicate the region for printing, and then the tool will generate a printing path to fill the region; the distance, or line gap is adjustable through a slider. If the printing needs to be looped a few times, the time of looping and waiting time in between can be adjusted (Figure 7).

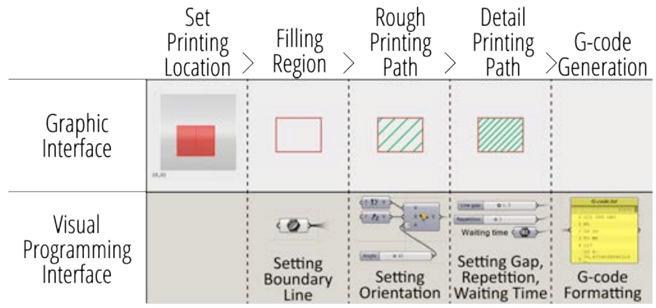

Figure 7: Graphic user interface for filling a 2D geometry.

- 3D Tool – Slicing and filling each layer

This tool slices the model vertically, and then fills each slice with a line path. It enables a user to define the height gap between each slide, and the gap between each line (Figure 8).

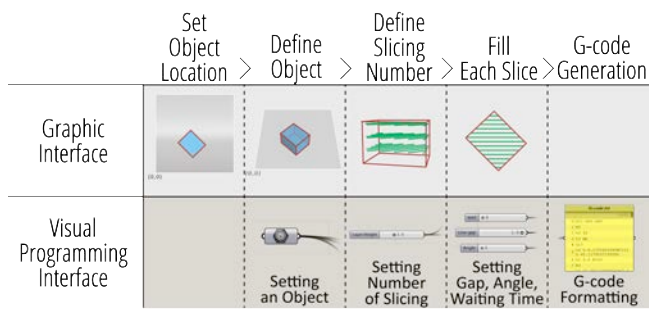

Figure 8: Graphic user interface for slicing a 3D model

- Customized G-code

We assigned some G-code with new functions, to gain extra controllability over the extra modular components (Table 1).

Table 1: G-code customization

G-code	Old function	New Function	Control Circuit
M3	Turn the spindle clockwise	Turn on the trigger for the Dispenser Module	Output a high signal to the dispenser control board
M5	Stop the spindle	Turn off the trigger for the Dispenser Module	Output a low signal to the dispenser control board
UV0	NA	Turn on the UV light	Output a high signal to the UV light control board
UV1	NA	Turn off the UV light	Output a low signal to the UV light control board

- Simulation

Simulation is tightly related to the specific material's responsiveness, and the printing structure. We implemented one tool, which simulates a hinge folding–based transformation if an actuator material is printed on a bi-layer structure. Measurements of the bending curvature from the material sample sets are fed into the Stoney formula, which serves as the modeling basis for simulating the material's behavior; the evolutionary computing method is used to speed up the real-time simulation. Further simulation can be developed, and this is to demonstrate the feasibility of an integrated system with the same software platform (Figure 9).

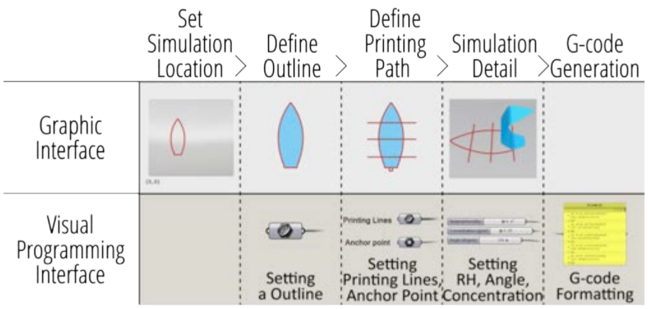

Figure 9: Simulating a bi-layer hinge folding structure

PRINTING MATERIAL OPTIONS

xPrint focuses on printing smart, particularly active materials, which come in a liquid solution and solidify under particular chemical reactions or physical transformations. Although mainstream 3D printers do not support many smart materials, there is a big pool of commercial and research materials that we can choose from to test our printer. The relevant properties of the candidate smart material solution include particle sizes, means of solidification, and responsiveness. Figure 10 highlights the smart materials that we have tested using xPrint; it also maps its potential to handle other smart materials in the future.

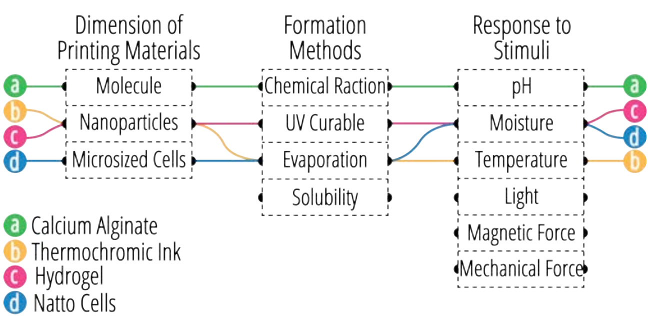

Figure 10: The space of solution based smart materials

In Figure 10, we presented three different levels. 1) The dimension information of the liquid starting materials (material science level); 2) solidification or formation methods for materials processing (fabrication level); and 3) the responsiveness of the fabricated objects (application level). In our paper, we have explored the intersection between the three rows and mapped the current printing examples with the different colors emphasized in the use case.

To demonstrate the system's flexibility to accommodate different types of smart material, we chose four materials from either commercial sources or research publications, or designed four different system configurations to print them (Figure 11).

- Natto cells as RH responsive actuators (Figure 11-1): Natto cells are reported as nanoactuators [30]; the cells can be suspended in water and deposited onto latex to form bi-layer thin films upon water evaporation. In the xPrint system, a Natto cell and water solution requires the central dispenser module, the gravity-based container module, the ventilation module, and the heating plate module to speed up the evaporation process. The outcome is a bi-layer origami structure that reversibly folds and unfolds based on changes in the surrounding relative humidity.
- Calcium alginate as a pH responsive material (Figure 11-2): Alginate is a well-known low-cost pH responsive polymer [24]. The liquid sodium alginate solution can form a gel when it meets a calcium solution. The gel forms due to the replacement of alginate ions with calcium ions when the two liquid solutions meet. In the xPrint system, we use the central dispenser module to first deposit a thin line of liquid alginate, then use the pneumatically controlled container module with a luer fitting brush tip to deposit calcium solution following the same printing path. The gel forms immediately as the brush passes by the liquid alginate lines. 3D structures can thus be formed layer by layer.

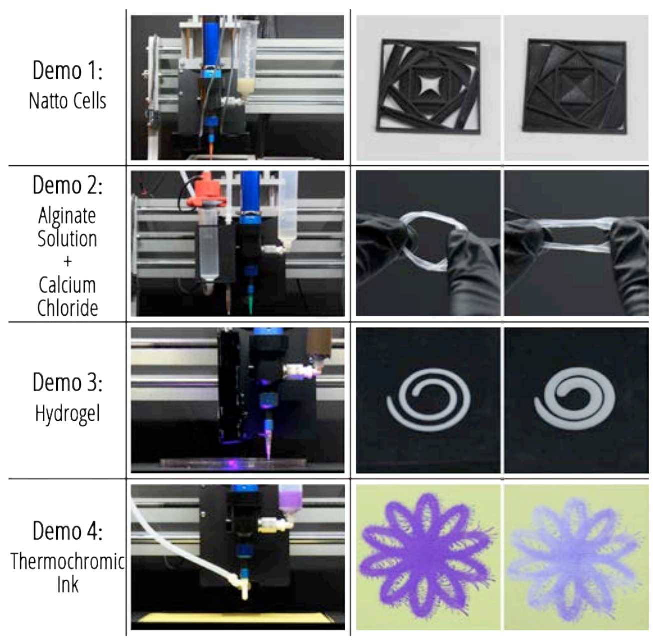

Figure 11: Four different modular configurations are used to print four different functional materials. Demo 1: Natto cells form humidity responsive films; Demo 2: Calcium alginate gels are stretchy and responsive to PH; Demo 3: UV-curable hydrogels swell in water; Demo 4: Thermochromic ink printed on paper.

- Hydrogel swells in water (Figure 11-3): The solution we used is poly(ethylene glycol) di(meth)acrylate

(PEGDA), a UV curable hydrogel [2]. In its gel phase, it can swell up to 42% when submerged in water. PEGDA has been used for several bio-applications, particularly in the field of tissue engineering and drug delivery, due to the advantages of its 3D structure, biocompatibility, and biodegradability. The hydrogel formation is trigged by UV radiation, where free radicals are released from the initiator resulting in the gels crosslinking. The pre-polymer solidifies within 10 seconds when high intensity and focused UV light is applied. In xPrint, we use the central dispenser module and the UV curing lamp module to print the hydrogel.

- Thermochromic film that changes color with temperature (Figure 11-4): We suspended commercial thermochromic powder into a water solution, and coated it on top of paper or other films. With xPrint, we use the atomizer dispensing module to spray the coating. The atomizer is controlled by positive air pressure.

USE CASES

We invited three users with different backgrounds (one fashion designer, one scientist, and one artist) to design and fabricate, with our tested material options to test the usability of the xPrint system and the quality of work that can be produced by our targeted users. No participant had prior experience of using this platform, and each had little experience using 3D modeling or parametric design software. We gave them 1.5 hours training on the hardware and software platforms, covering workflow and safety measures. Following half an hour of practice, all three users were able to use the platform by themselves. We then allowed each participant a maximum of two weeks to design and fabricate their objects.

Figure 12: The sweat-actuated flaps on the back of a garment.

Fashion Designer: Transformable Garment with Natto Cells Printing

Oksana is a fashion designer from the Royal College of Art. She has over five years of female garment design experience, and her design interest is adaptive and responsive clothing. She was inspired by the Natto cell–actuated film, and decided to design her own transformable garment. The garment reacts to body sweat and the flaps on the back open up to accelerate the sweat vaporization process (Figure 12).

Tools

She used the central dispenser, the ventilation module, the mechanical stirrer, and the heating plate. For software, she used the 2D line filling tool.

Workflow

She combined the traditional garment manufacturing process with the new material fabrication. She started from hand sketches and thermal fusing tests to combine the responsive film with fabric, then printed film sheets, laser cut the films into units, assembled the back panel, and sewed the garment.

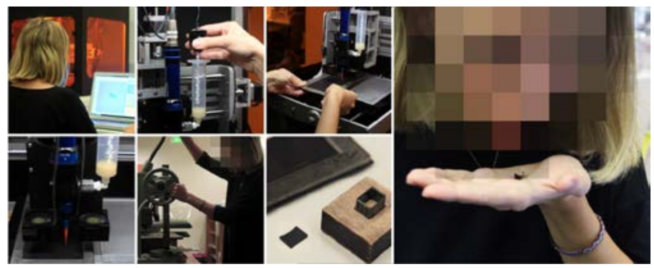

Figure 13: Workflow of a fashion designer, printing her sweat-responsive garment with Natto cells

User Experience

In the process, Oksana tried to print the Natto cell solution in multiple layers to enhance the biofilm responsive effect. When the machine printed the second time before the original printing had evaporated completely in previous trials, the newly printed solution was dragged by the tip of the dispenser, which resulted in uneven evaporation and defects in the biofilm. We reminded her to adjust the speed of the fan and the temperature of the heating plate to make sure that the first-layer solution evaporated more rapidly, and she followed our suggestions; however, the new biofilm cracked due to the over-dehydration caused by the strong wind and high temperature. After 1.5 hours of experimenting, she finally got an appropriate setting to ensure that the solution evaporated just enough before the next layer was printed.

User Feedback

She commented that the integration of a printer required higher precision in terms of fabrication and composite fabric assembly, while traditional garments are usually done in a more casual way; she found the printer very easy to use, although the speed was still too slow for daily design use. After two weeks of intensively working on the garment, she mentioned that she now felt her colleagues back at her home school "are doing things that are so boring." She suggested that integrating responsiveness into fashion is very powerful, and the xPrint enables precise control of the film making process.

Scientist: Drug delivery with Hydrogel Printing

Eve is a postdoc working in the field of biological engineering. Her research focus is the use of multi-functional materials to study the response of living systems; she hopes to apply her ideas in biomedical applications. In this study, her research interest is to print hydrogel capsules and study drug delivery effects. The biocompatible hydrogel has a dual function; first, it is a carrier of a sample drug that needs to be tested for toxicity in living cells. Second, the swelling response of the hydrogel towards water is an interesting effect to study, and is related to the drug release rate. She hopes to use a simple instrument to demonstrate the drug delivery concept and measure the speed for different volumes of gel to optimize the dosing rate.

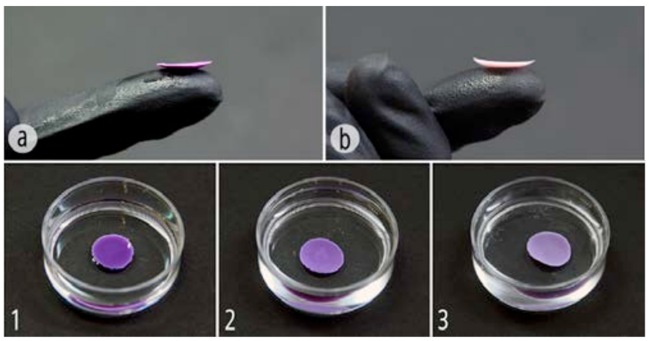

Figure 14: Printed water-responsive hydrogel structures for drug delivery. a) Drug capsule in its unswollen state; b) Drug capsule in its swollen state

Tools

For materials, she chose to use a conventional UV curing biocompatible hydrogel.

For hardware configuration, she chose the central dispenser and the UV curing lamp module. The printing bed is a petri-dish for hygiene purposes; she used the 3D slicing tool to generate the G-code for printing.

Workflow

She started by brainstorming ideas of how such a hydrogel material can be printed in terms of the processing time and feasible pattern. It took her a slightly longer time to finish a relatively simple geometry. She seemed very used to the machine operation processes, including loading material, cleaning the printing bed, and adjusting flow rate. After printing, she tested the hydrogel transformation and drug release in a solvent in terms of both the shape and color of the drug. She used the data to estimate a rough range for the drug release rate, and she mentioned that she is very used to procedural operation in her lab (Figure 15).

User Experience

Eve wanted to print a 3D structure like a piece of a pill. In the beginning, she was unfamiliar with the quantity of printing and the power of UV curing. For instance, the hydrogel would be stiffer with a thinner layer and the UV curing time was extended between each run. However, the hydrogel would become softer as the quantity of deposited materials increased or the UV curing time shortened. In addition, since Eve utilized multiple-layer printing, the UV curing time would affect the original layers' stiffness indirectly. Then, to achieve suitable stiffness in the drug carrier structure, she spent more time precisely adjusting the curing time setting and the quantity of printing. After testing for 3 hours, she printed satisfactory samples with various sizes and thicknesses.

Figure 15: Workflow of the scientific user, printing her water-responsive drug capsules.

User Feedback

Eve mentioned that it is a "very useful" platform, and she asked how much such a platform would cost, and was very surprised by how little people might need to spend to have such a platform. She noted that she had heard of hydrogel printing systems in her field, but noted that it is still just emerging as a technology. It is either built by another engineering lab that has collaborations going on, or it will "cost a ton." "Any scientific research equipment costs a lot!" She was also surprised by the simplicity of the software platform. In addition, the printing platform normally occupies a large lab space and is not portable. It is difficult to move the whole instrument into a small biological safety cabinet for *in situ* printing and testing. "Our instruments usually have very complicated control software, which takes days of training and learning". Finally, she suggested that although the resolution is yet to be improved for printing high resolution structures and scaffolds, which bioprinters often claim as a capability, it can be a "very useful" low end printing system for chemistry or biology research labs to test their ideas. It can also be adjusted to print different materials for other purposes.

Artist: Animated painting with Thermochromic Ink Printing

Samuel is a freelance artist, good at graphic design and creative painting. He likes to explore new ways of drawing in his work, and has used thermochromic ink in his painting previously. In this user study, he created a "digital style" color changing painting (Figure 16).

Tools

The hardware modules he used were a dispenser and the ventilation module. In addition, he used the 1D tool to generate his line drawing.

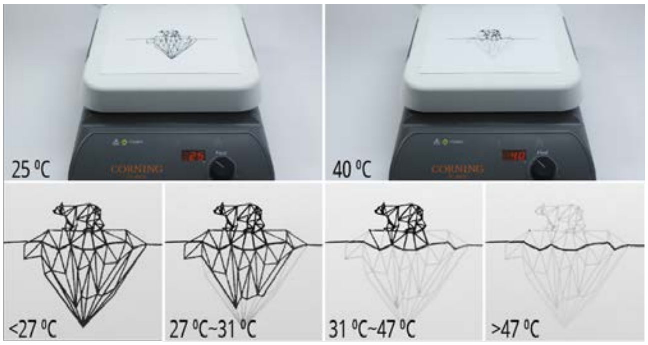

Figure 16: Melting Iceberg, the visual elements of the digital painting disappears sequentially.

Workflow

It took him two days to finish the design and fabrication of the painting. He spent one day getting familiar with the effects of thermochromic ink deposition, and he explored the effects when a few parameters were changed during the printing process such as the distance between the dispenser and the paper and the flow rate of the dispenser. On the second day he focused on the creation of the line drawing in the software and the actual printing of the drawing.

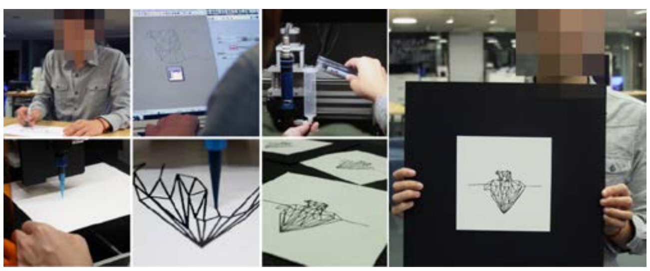

Figure 17: Workflow of an artist, printing his animated painting with thermochromic ink

User Experience

Samuel had a higher requirement for the effect of curves. He spent two hours printing the same single line square by changing to different types of nozzle (e.g., normal nozzle, brush, and atomizer) and different nozzle sizes to achieve satisfactory results. Evenly, he tried to control the air pressure in different powers for the atomizer and different distances between the brush dispenser and the paper in the process of printing.

Feedback

He mentioned he felt a sense of “co-creation” with the machine. He could never create a “digital but tangible” drawing without the assistance of the machine. It was “like a copy you print out of your inkjet printer after you draw it in Illustrator,” but it had a level of interactivity. When he commented on that, he placed his painting on top of a hot plate and demonstrated how the different components disappeared as he turned up the temperature. Finally, he suggested that the software should add one more function that can preview the final line effects with different printing settings, such as the dispenser flow rate, the distance between the dispenser and the paper, and the different nozzle dimensions.

CHALLENGES AND FUTURE WORK

Fine-tune the material properties and control the machine modules for printing.

The viscosity and curing time of the material is critical. For example, the hydrogel material we used had a very low viscosity; it flowed a bit around the edges before solidifying on the printing bed, which affects its final printing resolution and quality. Fine tuning the viscosity and the UV light intensity are key in this case. In theory, the current xPrint should work for almost all liquid smart material solution, as long as they solidify under certain environmental conditions once printed. However, in reality, the machine and material parameters have to be finely tuned and adjusted, sometimes with the help of experts from chemistry or material science fields.

Control axis and CNC moving speed.

During our use study, we learned about how printing on both sides of a thin film to create composite structures is desirable. For improvement, we would like to build a rotatory printing platform that can flip the printing bed upside down; we would also like to increase the printing speed by replacing the current servo motors with faster steadier ones.

Multi-material printing with customized central dispenser.

We currently use an off-the-shelf central dispenser; it is very precise, but costly and limited to one print head. For the next step, we would like to develop our own open source progressive cavity pump–based dispensing system. We would like to have multiple containers that can print more than one material simultaneously. This will open doors for 3D printing with supporting structures and composite material printing with embedded functions.

Open source hardware and software.

Although this paper details all of our design principles, we would like to construct a wiki page to share our source code for the software design and simulation platform, and document our machine design process. Community has a strong power to improve such systems through practice and comments.

CONCLUSION

In this paper, we presented a liquid depositing modeling printing system. We emphasized its wide coverage of printing resolutions and its modular design to accommodate liquid material solutions that solidify under different environment stimuli such as mechanical mixing, chemical reaction, and ambient vaporization. We hope such a platform can be a helpful toolkit for those who are interested in conducting design and research in the area of fabricating smart materials and transformable, especially for shape changing interfaces.

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