Integrating Material-Centric Approaches in Innovative Prototyping Platforms

Electronics prototyping boards have brought a lot of versatility in the world of prototyping, allowing designers, researchers and makers to build a variety of digital artefacts. However we see an increase in Material-Centric approaches in which active materials are manipulated to create new digital contraptions. For example programmable ink can be used in combination with conductive and non-conductive material to create a display from scratch, rather than using off-the shelf components. While those new ways of prototyping can bring new form factors in the design of interactive devices, they also come with their challenges. To start identifying those challenges and discussing these at the workshop, we build a volumetric displays with electrochromic materials. The display is driven by a MSP430 microcontroller with pins controlling each voxel separately, and by controlling the display element matrix 3D images are generated. We learn from our experience in building such device to draw insights on the feasibility of using active material to create digital devices. We hope to initiate discussions about how Material-Centric processes must also be taken into consideration when rethinking the future of prototyping.

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1 INTRODUCTION

There are new approaches for prototyping in which active materials are used to create digital devices. Examples include a wild range of Material-Centric processes in which active ink, paint, liquid or sheets are used to created sensors, actuators or displays. Here we particularly look at the case of display fabrication because, when it comes to prototyping new interactive devices, our field still heavily relies on the procurement of pre-manufactured displays that are often limited in form factors. But in the last couple of years different strategies have been explored to enable more versatile form factors. For example techniques have been proposed to spray electroluminecent paint [13] [2]; to 3D print photochromic ink [3]; or to screen print electrochrotmic material [4].

If prototyping with active material offers the potential to designers to rethink the shape of our interactive devices, it, however, bring an entire set of challenges to tackle. This is mainly due to the fact that those material are still embryonic in nature, often relying on complex fabrication processes and relying on expertise that are often out of reach of typical makers. Additionally current prototyping platforms do not offer usable solutions to control those new artefacts and makers must often create bespoke platforms that are hardly scalable.

For these reasons we believe that there is a real opportunity to rethink what can be the future of prototyping by also considering how these Material-Centric processes comes into play in this bigger picture. We propose to discuss this challenges in the workshop and to start the discussion we looked at a very simple use case: we created a volumetric displays using electrochromic ink. From our experience in creating this prototype, we share the lessons we learned and discuss ideas to start developing research direction for the future of prototyping boards/platforms/environments.

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2 USE CASE: BUILDING A VOLUMETRIC DISPLAY USING ELECTROCHROMIC INK

We built a simplistic volumetric display using programmable ink. We picked this example because, to our knowledge, this was not attempted before. Thus we could not draw on previous experience. Our display consists of 3 layers of material stacked. Each layer contains 4 × 5 voxels. Each voxel is made of programmable ink which can change color. By changing the color of each voxel we can create a 3D pattern to create an image in 3D. The display system depicted in Figure 1 consists of three main parts: the display layer, the controlling circuit and the microcontroller.

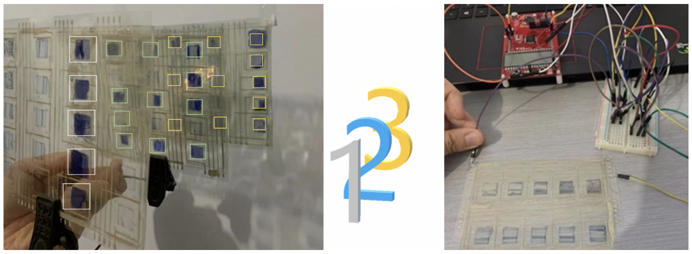
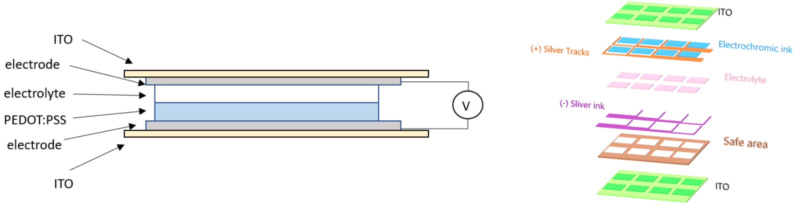


Fig. 1. (left) Our volumetric display representing a (middle) 3D image; (right) Our microcontroller, H circuit and voxel array.



(a) Side view of the electrochromic display

(b) Schematic diagram of different layers

Fig. 2. The design of a single layer of electrochromic voxels

2.1 Display layer and voxels

Figure 2 shows the detailed voxel design for a single layer. Each voxel measures 10mm by 10mm and is controlled by two electrodes. The voxel, which is the smallest addressable element of a the display, is made by organic material Poly-(3,4-ethylenedioxythiophene):polystyrenesulfonate (PEDOT:PSS) [9]. We used this active material due the simplicity of coating, its low-energy cost, its durability and the ability to print it without complex equipment. The colour of this electrochromic material changes from light blue to dark blue when external voltage is applied, and the process can also be reversed by reversing the polarity of the voltage applied [1] [14]. We made an electrochromic cell of ITO/PEDOT:PSS film / Lithium perchlorate based with propylene carbonate and 1,2-dimethoxyethane using electrolyte. To achieve ideal colour we tested three different voltage level to charge the PEDOT:PSS film (0.5V, 1.0V and 1.5V). 1.5V was the ideal voltage to drive the display as it allows best performance of the electrochromic film [12]. The display layers were manually screen printed. PEDOT:PSS films are very robust and does not require high precision in surface roughness to function normally [4]. The electrochromic ink and electrodes were isolated by safe area and we used electrolyte to cover the display area of the voxel to ensure the electrochromic ink is charged evenly.

2.2 Display controlling circuit

A H bridge circuit was built to reverse the polarity of voltage. This allows the PEDOT:PSS film to be charged or discharged quickly, leading to colour change of display. The voltage reverting circuit is also responsible to adjust voltage level controlling the voxel, as the microcontroller output voltage is 3.3V while voxel works under 1.5V DC. We used NPN TIP122 transistor to build the H bridge circuit. We used an MSP430FR6989 microcontroller to drive the display, and it is also responsible to generate controlling commands for output pins controlling the voltage and connected with voltage reverting circuit. Each voxel requires 4 pins to control: two output pins (for charging and discharging the voxel), one power source for reverting circuit, and one GND. The software we used to provide data for the system is Code Composer developed by Texas instruments. Each display element has two modes: charged or and discharged. In the program we build an array indicating the desired image, and the two modes are represented as 1 (the current direction is positive) and 0 (current direction is reversed or no current is provided).

We turned on the fabricated voxel array by driving it with the microcontroller. We observed that the three layers successfully displayed different images. Although limited by precision of manual screen print, the activated voxels could still be visually separated with inactive voxels due to its deeper colour.

3 LESSONS LEARNED FROM PROTOTYPING WITH ACTIVE MATERIALS

We now discuss the challenges that we faced in prototyping our volumetric displays and expand on the potential research directions this may open-up when rethinking the way we should design future prototyping platforms.

Difficulties to predict the final appearance of our display: The electrochromic layer was fabricated as a thin film and seemed to be transparent, but in reality they were not truly transparent. It is possible to solve this problem by using pellucid materials such as Transparent Conducting Electrodes (TCEs) and print electrochromic layer thinner [11]. Additionally one major problem was that the wiring of the voxels was opaque and blocked the view of images behind. To do a high-resolution displays, this means an increase in complexity in the way the electrode must be placed to avoid occlusion. This problem seems small but this is not necessarily an issue we expected to have at earlier stage of the project. The time it take to create an intial prototype was already long and we expected that working with active material will increase the need for trial-and-error which we should take into account in prototyping processes. This can be helped if we have a better characterisation of the material used and even possibly computational platforms (e.g. simulation) that can help predict the outcome of a particular design.

Lack of precision of the manual processes: We had issue with the manual screen printing process. The electrochromic ink was printed unevenly, which caused some voxels to have a deeper colour than others. Their time of response was also longer. Therefore not only this may cause issues in the final appearance of the prototype but also create a complex design in the drive of the voxel by the microcontroller. Some of the solution we could foresee would be to automatise such process, e.g. relying on equipment such as automatic screen printing devices or additive manufacturing tools specialised in depositing even layers of materials. While there are already research in active material 3D printed [10] [6] we feel there is opportunities to drive more research into this by also considering how the fabrication and the control of it are combined in a more seamless process.

Difficulties with wires and connections: We used ITO films as top and bottom electrodes. This provides sufficient flexibility and transparency, but it limited the choice for connecting the components. We used simple prototype crocodile clips acted as a low-cost solution because of the ITO films, or Indium Tin Oxide coated polyester (PET) film, cannot tolerate extreme temperatures, making connecting wires and pins by soldering difficult. It is still possible if low melting temperature solders are applied or using conductive glues such as bio plastics, at the cost of conductivity. This problem is common in stretchable, soft electronics fabrication and yet to be improved. With decade of experience in building prototypes using active material, we feel connections and wiring is often a problem that is overlooked at. There is certainly solutions the community should be able to provide.

Limitations with the bespoke controller: To generate animated images, the MSP430 has built-in clocks, and we used a simple program which allows the function of changing the status of output pins, triggered by clock signal [7]. That being said our design is hardly scalable to complex display design. Additionally, using output pins to control single display elements provides extreme precision, but it is also limited by number of pins. For each voxel at least two connections are needed, indicating a great number of pins or ports will be needed, usually multiple times more than the number of voxels. As a result, traditional single microprocessors or chipmicrocontrollers cannot meet such needs. One alternative way is using two step up-conversion, which uses ions excited by two intersecting IR-laser beams from two independent sources with different wavelengths and afterwards emit visible photons [5]. This method requires fewer input pins because the laser beam excites a whole row (or column) of voxels. There are disadvantages though, since laser is a potential hazard to human eye. It also needs continuous energy input to keep the display element stays in excited state which leads to higher energy costs.

Difficulties in increasing the complexity of the device: We also note that we create a very simple design with only single coloured images. As different kind of electrochromic materials show various ranges of colour when charged [8], it is possible to build a coloured display device by applying multiple electrochromic materials. However this would also substancially increase the complexity of the design. As we have seen, the manual process makes it complicated to get this smooth and thus it is a challenge when increasing the functionalities of prototypes. As such we feel that current opportunities for designing more complex devices with active material is still low.

4 CONCLUSION

In this paper we initiate discussions about how Material-Centric processes can be taken into consideration when rethinking the future of prototyping. We created a simplistic volumetric displays using electrochromic ink to start investigating the challenges that such new way of prototyping create. We discuss a few of the main drawbacks. We are conscious that many other issues are to be considered, but we hope this paper can sparkle interests at the workshop.

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