

PaperPixels : A Toolkit to Create Paper-based Displays

Roshan Lalintha Peiris
roshan_peiris@sutd.edu.sg

Suranga Nanayakkara
suranga@sutd.edu.sg

Augmented Senses Group, International Design Center, Singapore University of Technology and Design.



Figure 1. (a) The PaperPixels toolkit (b) Dotted circle shows the 5 animation frames of individual leaves appearing when the animation is switched off. (c) to (g) depicts animation of the painting every 3 seconds.

ABSTRACT

In this paper we present PaperPixels, a toolkit for creating subtle and ambient animations on regular paper. This toolkit consists of two main components: (1) a modularised plug and play type elements (PaperPixels elements) that can be attached on the back of regular paper; (2) a GUI (graphical user interface) that allows users to stage the animation in a time line format. A user would simply draw on regular paper, attach PaperPixels elements behind the regions that needs to be animated, and specify the sequence of appearing and disappearing by arranging icons on a simple GUI. Observations made during a workshop at a local maker faire showed the potential of PaperPixels being integrated in many different applications such as animated wallpapers, animated story books.

Author Keywords

paper display; peltier; thermochromic; toolkit; DIY

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Paper is a ubiquitous material that surrounds us in books, paintings, wallpapers, documents and even sticky notes. A toolkit that allows users to animate actual content of a paper would empower them to create paper-based displays. This enables displays to be seamlessly embodied in the environment without having to overlay digital layers on top of neutral architectural backgrounds [18]. As such, we developed PaperPixels, a toolkit for users such as makers and hobbyists to start crafting their own paper based displays. We

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use heat sensitive thermochromic inks as our main display base for PaperPixels. Thermochromic inks can be merged into paper material similar to any other ink by screen printing, painting or drawing with a thermochromic ink pen. These thermochromic ink-based drawings could be made visible or invisible in the form of a display by controlling the temperature of the ink, allowing the display to become a property of the paper itself.

Amongst many different actuators, the works by Peiris *et al.* suggest that the use of peltier elements as thermal actuators for heat sensitive thermochromic inks has a compelling advantage due to its ability to heat and cool at rapid rates [14, 11]. This allows a relatively fast and, more importantly, a controllable colour change of the thermochromic inks.

With PaperPixels, we develop the above technology into a modularised, plug and play toolkit that allow users to animate contents on regular paper. The active heating and cooling control system we developed allow the PaperPixels to achieve 0.33 animation frames per second.

PaperPixels was showcased at a local maker faire workshop where we observe various designs created by the participants within a 90 minute span of the workshop.

The main contributions of this work are as follows:

- Designing a toolkit that allow users to animate contents of a paper without being limited by the lack of knowledge of the technology. This includes:
 - Development of a modularised plug and play type display pixels that use thermochromic inks and peltier elements to produce paper based animations.
 - Development of an animation GUI that allow users to carefully plan the animation in a time line format.
- Insights from a workshop conducted at a local maker faire, implications and future usage scenarios of the toolkit.

RELATED WORKS

The scope of the development of PaperPixels draws upon literature from three key areas: Paper based displays;

Technologies related to animating paper; Paper based toolkits and technologies.

Paper based displays

In one of the early works, Wellner identified the paperless world as unrealistic and instead enhanced the paper with computation using projected images on paper [21]. With Flexpad [17] and Foldable Interactive Displays [8], authors transform a paper into a flexible, deformable, spatially aware display using projected images in real time. In Interactive Wallpapers [6], works by different artists were presented in attempting to fabricate interactive wall papers. In these works, artists use projectors, electroluminescent wires, and other techniques to present a variety of interactive wallpapers. In Living Wall [3], authors use conductive, resistive, and magnetic paints to construct programmable and reconfigurable wall paper by embedding various actuators and sensors. However, most of these works use emissive materials (LEDs, projectors, etc) as the display base. This results in the display being a digital overlay on top of the paper material instead of being an embodied property of it [18]. Therefore, we were motivated to look into materials such as thermochromic inks that can be seamlessly integrated into the paper material.

Technologies for animating paper

Hand Rewriting [5] and Transience [20] present paper based changeable displays implemented with heat sensitive thermochromic inks. In Hand Rewriting, authors introduced pen based erasable interactions to the paper. In Transience, authors created artistic interactions using heating elements embedded in the paper to actuate thermochromic inks. However, these and most other works that use thermochromic inks use only a heating element without an active cooling method. Therefore, the active control of the display is limited as the heated thermochromic inks have to be naturally cooled down to reverse the colour change of the ink. Hence, works such as Transience and Anabiosis are limited in the ability to actively control the display for fast animations. Furthermore, many works that use thermochromic inks on a variety of background materials such as textiles [1], soft materials [9], glass [10] also use heating elements such as conductive yarn, body heat, etc. without a cooling methodology. Recent works addressed this issue by using peltier elements as an active way of heating or cooling the thermochromic ink materials [14]. Therefore, PaperPixels toolkit uses active heating and cooling to achieve a controllable paper based display.

Paper based toolkits and technologies

The rise in do-it-yourself (DIY) culture has fostered a variety of toolkits that empower users to use technologies for their creations [19]. This has given rise to many paper based toolkits allowing users to merge technology with paper medium. Leah Beuchley *et al.* investigated the art for crafting with many materials including paper [4]. In this work, the authors experimented with different ways in which electronics technologies can be applied to paper material. In Electronics Poppables [15], the authors investigated integrating electronics in the form of poppables to achieve

various functions. Furthermore, with Interactive Paper Devices [16], authors investigated a generic paper toolkit that can integrate electronics in the form of paper robots, speakers or lamps. In another toolkit that focused on combining painting and programming with paper craft [2], authors investigated embedding interactive elements such as sensors, actuators, microcontrollers, etc. into paper. With Autogami [22], researchers developed a taxonomy for moving paper elements and integrating it with traditional origami to produced movable paper crafts, whereas Animated Paper [7] investigated animating paper with smart memory alloys and lasers. Even though most of these works focus on toolkits that embed generic interactive elements into paper or combining traditional paper crafts with new technologies, there is a lack of attention towards toolkits that focus on controlling the content on paper as an animatable display. Therefore, in this work we investigate the development of a paper based display technology in the form of a toolkit.

THE PAPERPIXELS TOOLKIT

Expected outcomes

We identified the following goals for designing the PaperPixels toolkit.

Enabling tool for makers: The motivation to present PaperPixels as a toolkit was inspired by the recent rise in popularity of the Maker movement [19]. As such, we aimed to develop PaperPixels in the form of a toolkit that enables such enthusiasts to play around, customise and improvise animated paper displays.

Interact with paper: Similar to Origami and paper crafts, another goal of this work is to engage users into using this toolkit as a craft. Thus, we intend to have this toolkit available in such a way that users would still be engaged in similar processes with the paper such as drawing, cutting, etc.

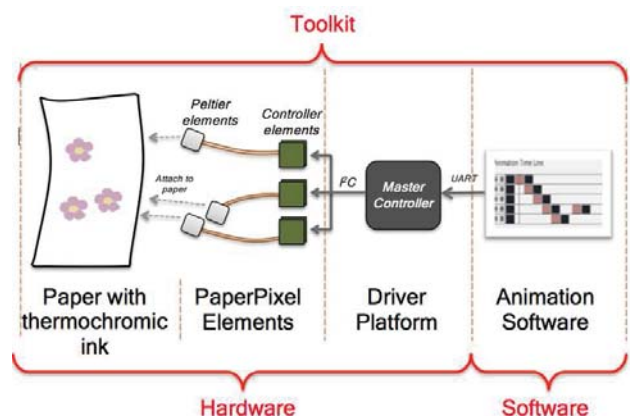


Figure 2. PaperPixels architecture

The main architecture of PaperPixels toolkit is shown in Figure 2. The hardware implementation is based on previous textile technology [14]. We focused on the customisation of the hardware to implement a plug and play toolkit. The software implementation discusses the design of a GUI to specify animation sequences intuitively.

Hardware Implementation

The hardware implementation consists of three main components: thermochromic inks, PaperPixels element, and the driver platform.

Thermochromic inks: For the scope of the PaperPixels toolkit we use heat sensitive thermochromic ink pens¹ with an actuation temperature range of 27⁰C to 31⁰C. This specifies that the inks change colour to another colour above 31⁰C and regain the original colour below 27⁰C. The pens we used contained colours that change from black to orange, orange to green and purple to pink.

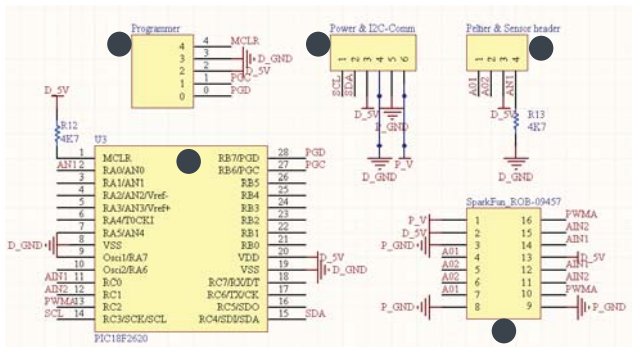


Figure 3. Circuit schematic of a PaperPixelElement (A) Programmer header for the microcontroller (B) Header for power supply and communication for the PaperPixels element (C) Header to connect the peltier element and the thermistor (D) PIC18F2620 microcontroller (E) SparkFun ROB-09457 full bridge controller

PaperPixels element: The PaperPixels element consists of few modules/headers to facilitate plug and play use. The controller module (PIC 18f2620² - Figure 3(d)) implements a closed loop PID (proportional, integral, derivative) temperature controller. The full bridge controller module (SparkFun ROB-09457³ - Figure 3(e)) allows switching of current through a peltier element to switch between heating and cooling. The full bridge controller module can be replaced by the user if required to facilitate different specifications for their design. The current version of the controller is able to change the colour of the above inks approximately in 3 seconds allowing a 0.33 frames per second display.

Since peltier elements are available in a variety of sizes, we added a header to the PaperPixels element such that any peltier element can be plugged into it (Figure 3(c)).

Irrespective of the size of the peltier element, the PID controller will achieve and maintain the temperature accurately. On the other end, the peltier element can be attached to the paper simply by thin double sided adhesive tape. For the scope of the toolkit and the workshop, we used 25mm X 25mm peltier elements together with NTSA0XV103FE1B0 thermistor.

¹<http://www.ctiinks.com/products/temperature-activated-pens/>

²<http://www.microchip.com/>

³<https://www.sparkfun.com/products/9457>

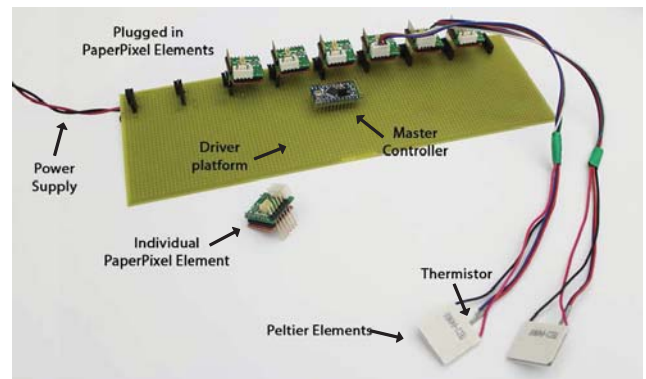


Figure 4. Driver platform for the PaperPixels elements

The driver platform: For the current version of PaperPixels, we designed a main driver platform that allow users to plug in multiple PaperPixels elements (Figure 4). If users require more pixels to animate on their designs, they can plug-in the Power and I²C-comm header of the PaperPixel element (Figure 3(b)) to one of the 10 receptor headers on the main driver platform.

The purpose of this platform is to facilitate communication between the animation GUI and PaperPixel elements via the master controller. In addition, the driver platform provides the power supply for the PaperPixels elements. The commands issued by the animation GUI are received by the master controller via Serial UART communication and re-issued to the relevant PaperPixels elements via the I²C communication protocol.

Software implementation

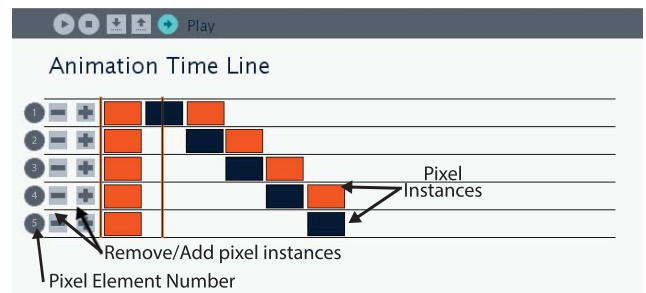


Figure 5. PaperPixels animation GUI (denotes the timeline arrangement for animation in Figure 1)

The animation GUI (Figure 5) is developed based on Processing platform⁴. Each pixel element has a unique number visible on both physical element and on the pixel instance in GUI (Figure 5). The purpose of this is to provide an intuitive interface that allows users plan and arrange the animation sequence of the pixels on a timeline. When the animation is 'played', as the cursor reaches the beginning of a pixel instance, the GUI sends temperature settings for that pixel to the master controller on the driver platform. In addition, this sequence can be downloaded onto the master controller to operate without the presence of the computer.

⁴<http://processing.org/>

Software Usage: New animation states for each pixel can be added or removed by clicking on the Plus or Minus icons. Next, users can specify the state of each animation frame (hot or cold, i.e. color/colorless or the original color) by clicking on a pixel instance (Figure 5). The animation pixel instances denote where a PaperPixel will change from one color to another. Users can drag the pixel instances along the time line to arrange the animation sequence. The color change occurs during the duration of the cursor passing over the pixel instance. The current version of the animation software was kept simple to only let the users ‘sequence’ the animations and thus, does not allow more complicated functions like controlling the speed of color change. This feature will be added in the future versions.

New animation states for each pixel can be added or removed by clicking on the *Plus* or *Minus* icons. Next, users can specify the state of each animation frame (hot or cold, i.e. colour/colourless or the original colour) by clicking on a pixel instance (Figure 5). The animation pixel instances denote where a PaperPixel will change from one colour to another. The colour change occurs during the length of the pixel instance. However, the current version of the animation software does not allow control over the speed of colour change. This feature will be added in the future versions. Users can drag the pixel instances along the time line to arrange the animation sequence.

The PaperPixel toolkit

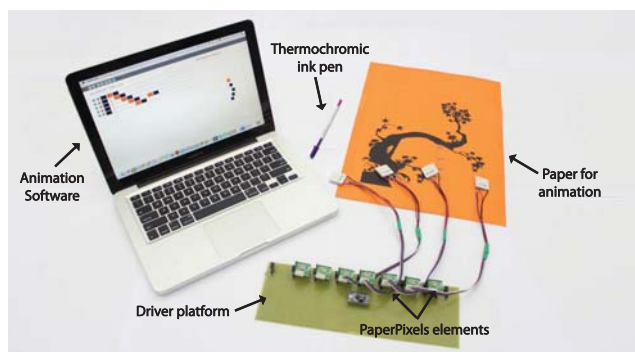


Figure 6. PaperPixels toolkit

The PaperPixel toolkit is shown in Figure 6. The animation frames drawn with thermochromic inks can be animated by placing the PaperPixels element directly behind the paper. Each PaperPixels element accounts for a single pixel on the display that can be controlled to appear or disappear. In the current version, users of the PaperPixel system are shielded from technical details such as the temperature controller algorithm, I²C communication protocol between the main controller and the PaperPixel elements.

Usage of the PaperPixels toolkit :

The basic usage of PaperPixels is outlined in Figure 7. To effectively construct an animated paper display, users are expected to follow a set of instructions. These instructions are a basic guideline for a first time user to prevent the possibility of misaligning and overlapping peltier elements.

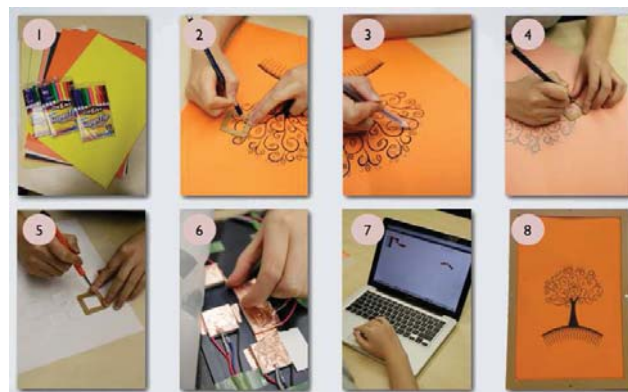


Figure 7. PaperPixels usage guide

Step 1: *Selecting the materials* : Users are free to select any type of paper of any colour. In addition, they can select a paper with an existing background image or draw any illustrations they wish. However, when selecting the thermochromic inks, the users should note the colour change characteristics of the inks, i.e. from one colour to another or from one colour to colourless. For example, inks that change from one colour to another could be used to create an effect of tree leaves and flowers changing colour as the seasons change. Inks that change from one colour to colourless could be featured to illustrate an animal moving across the paper.

Step 2: *Mark the pixels* : The pixels are marked with a pencil (to be erased later) on the illustration according to the size of the peltier element. This would help prevent overlapping of the peltier elements.

Step 3: *Drawing the animation frames* : Users can draw the animation frames within the marked pixel squares using the thermochromic inks. It should be noted that the thermochromic ink frames may not be erasable after drawing.

Step 4: *Marking the pixels on a tracing paper* : Use tracing paper to mark the pixels similar to Step 2. This paper can be used later to position the PaperPixel elements precisely behind the animation frame.

Step 5: *Cut out the pixels from the tracing paper* : Cut out the pixels as shown in the Figure 7 and use it as a stencil to draw the placement of the animation frames behind the paper.

Step 6: *Place the PaperPixels elements* : The PaperPixel elements can now be attached via double sided adhesive tape to the paper according to the animation frames (traced locations in step 5). The paper can be attached to a photo frame or any flat surface as required by the user. The PaperPixels elements (peltier modules) needs to be plugged into the main controller board and the main controller board can be plugged into the computer.

Step 7: *Specify the animation sequence* : The animation sequence can be specified using the GUI. Users can select to play the animation using the computer or download it onto the driver platform for operation without attaching to computer.

Step 8: *Play the animation* : The animation will be played on the paper.

Users can remove existing peltier elements and repeat steps 2 through 6 to restructure the elements if they wish to re-adjust their drawings. Figure 1 shows an example of an animated paper display. We have drawn 5 animation frames to denote a leaf falling down from a tree. We used a thermochromic ink pen that changes colour from Black to Orange. Therefore, drawing on an orange coloured paper allowed us to get the effect of colour changing from black to colourless. With the GUI, we animated it to play a sequence where each frame appears immediately after the other to show a smooth animation.

INITIAL EXPLORATIONS

We conducted a workshop to explore the potential of PaperPixels as a toolkit.

The workshop was conducted at a local Mini MakerFaire which gathers makers and hobbyists around the region to exhibit and explore a variety of gadgets, skills, workshops, etc. We conducted the workshop at this venue as it gathered our targeted DIY community. Our workshop had total of 15 participants consisting of 5 males and 10 females with ages ranging from 11 to 50 years. The average age was 28 years (SD=6.04). Participants were supplied with the PaperPixels toolkit with 10 pixels and thermochromic ink pens.

Workshop Procedures

The workshop was held approximately for 90 minutes. It was conducted in the following three sessions:

1. Introduction (15 minutes): A brief introduction and a demonstration of the eight steps of PaperPixels toolkit usage (Figure 7) was given.
The objective was to give the participants a brief understanding of the toolkit and the technology. Participants were also given a printed tutorial on how to make an animated paper.
2. Free Task (40 minutes): After being introduced to PaperPixels, participants were asked to explore their creativity and imagination by creating a form of animation on regular paper. They could select a paper with an existing background image or draw any illustrations as they wish. By following the usage tutorial, participants were asked to finish the following steps (Step 1 to Step 6): marking the pixels on the selected paper, drawing the animation frames, marking the pixels on a tracing paper, and cutting out the pixels from the tracing paper.
3. Demonstration (35 minutes): After making the animated paper, with the help from the workshop facilitator, each participant was asked to show a demo (Step 7 and 8) by specifying the animation sequence and displaying the animation on the paper.

Observations

At the end of the workshop, all the participants created many interesting animated paintings (Figure 8). These designs

indicate interesting ideas of paintings with subtle animations. One participant even had an idea to animate the painting while music was being played in the background, thus, adding another dimension to the paper (Figure 8 (c)).

Based on observations from the workshop and discussions with the participants, we discovered the following points about the PaperPixels toolkit.

Easiness to learn and to use:

Three of the participants (undergraduate design students) gave us interesting feedback on the workshop steps. After they completed their design they asked us if they could skip steps 2, 4 and 5 (Figure 7) for future designs. One of these three participants asked us “*Is it always necessary to follow all the steps? Can I skip some of the steps if I do a simple design?*”. This was an indication that they were able to grasp the concept and the usage of the toolkit.

Enjoyment with the craft: Some participants mentioned that they still enjoyed engaging with the paper as a craft since the steps require processes such as drawing, cutting, etc. One participant mentioned “*It was fun to use traditional techniques with the paper even though we were trying to integrate it with high tech*”.

Attractiveness for children: The workshop participants included three children of ages 11, 12 and 13. These children also found the toolkit easy to use as it did not require them to understand the backbone technology. In fact, the children were more engaged with the drawings and planning their animation sequence. Thus, we believe that this toolkit could be very attractive to children.

Software usage: Almost all the participants found the animation GUI to be intuitive. One of them had difficulty in associating the timeline space with the physical pixels. Often, it took her a few attempts to get the timing and the sequence correct.

USAGE SCENARIOS

A main feature of PaperPixels is its ability to animate the paper material itself where the display and the paper is the same. This is a key characteristic that allows PaperPixels to be an ambient display in the environment. Therefore, based on the feedback of participants and observations from demonstrations, we present possible usage scenarios to highlight the potential of PaperPixels.

Animated storybooks

John is the father of a 3 year old child, Julie. Everyday after work, instead of watching TV or cartoons on the tablet, John loves to read stories to Julie so that he can spend some quality time with her. However, he has a hard time trying to keep her focused and interested while he is reading the book. Therefore, John recently attained the PaperPixels book that animates the stories. The stories are animated in frames and the required story page can be placed on the PaperPixels story book for animation while John tells her the story. For each new story John simply needs to buy the booklet that contains the animation pages from the bookstore. Because Julie can



Figure 8. (a) Workshop at the Mini MakerFaire (b)-(g) Scanned images of few interesting animatable paintings by the workshop participants (some of the inks were heated during the scanning process) (b) A cat jumping on to a boat from a bridge (c) Notes appearing as the music is being played (to associate the picture with music) (d) Scene of a sunset with birds flying by and vehicles driving into the sunset (e) Leaves changing colour in autumn (f) Cat jumping on to the food plate (g) Flashing flower with animated petals.

now see the story being played while listening to John, she seems to be more engaged and focused on learning the story. Now, John even tries to draw up new stories for Julie and keep her entertained and focused while John gets to spend more time with her.

Animated wallpapers

Luxuriates is a high end boutique hotel that tries to create unique in-room experiences for its clientele. However, constant changes of the interior decor was an expensive and a difficult task of its staff. Recently, Luxuriates integrated the PaperPixels technology into their wallpapers. Now, the wallpapers can be changed to create various ambiances to suit various themes. In its default mode it displays subtle animations on its walls such as birds and butterflies flying across the room to depict a beautiful garden or leaves falling and starting to snow to depict changing seasons. In addition, the clients themselves can customise the wallpapers to: customise the theme of the room upon booking (business, family, nature, etc); upload paintings or pictures onto their room's wallpapers; and even change the theme to suit their needs each day. This experience has led Luxuriates to gain positive feedback as a hotel that adopts to the client resulting in a significant increase in its popularity.

Animated paintings

Maiko is a hardworking Japanese artist who is trying to make more sales of her paintings despite the tremendous competition she faces from other similar artists. She came across the PaperPixels toolkit when she has been trying to differentiate herself from the rest. Due to the simplicity of its use, she was quickly able to add animations and interactions to her paintings while painting her art with thermochromic inks. This has led to the increase of her popularity where she is making more sales and even displaying her interactive and animated art at popular galleries.

LIMITATIONS OF THE CURRENT SYSTEM

Simple animations: Currently a main limitation of the technology is its ability to animate a frame to only appear or disappear. Due to this, complex animations are difficult to realise. Even though the pixels can be re-arranged to form pixelated displays, the size of the peltier elements limits the usage to low resolution images. We have identified the usage of miniature peltier elements that can significantly improve the resolution of a textile display [11]. This technology can

be directly applied to PaperPixels to have multiple miniature peltier elements on a PaperPixels element. In this version of the PaperPixels, we aimed to simplify the toolkit such that the users can quickly grasp and understand the concept of the PaperPixels toolkit. We plan to explore using miniature peltier elements in future versions of Paperpixels.

Paper flexibility: Due to the rigidness of the peltier elements, the current PaperPixels are intended for flat displays. However, the use of miniature peltier elements has the potential to increase the flexibility of the PaperPixels displays.

Power consumption: The current power characteristics of the PaperPixels requires approximately 1W per peltier element during animation. After transition the power consumption is approximately, 0.2W per peltier element. We did not focus on power optimisation; however, the usage of miniature peltier elements can significantly reduce the power consumption characteristics [11].

FUTURE WORKS

We intend to focus on the following directions for future versions of the PaperPixels.

Open source toolkit: The workshop results and observations have motivated us to make this toolkit into a completely open sourced technology. With this, we expect to look at ways that the design can be generalised so that any user can customise and reuse PaperPixel's underlying technologies.

Usage of miniature peltier elements: Even though the current setup of the PaperPixels system has yielded favourable results, we intend to explore the potential of PaperPixels in a more flexible and mobile context. To achieve this, we intend to integrate miniature peltier elements in the next version of PaperPixels.

Enhancements: To further enhance the toolkit, we intend to look into developing pixels as an individual simplified package that contains the peltier element, and the other hardware elements with batteries. The driver platform can be replaced via wireless communication. These PaperPixels 'cubes' can be used in a variety of applications as mentioned earlier.

Integrating a sensing modality: Recent works presented a novel way in which peltier based temperature controllers can be enhanced to become temperature based touch sensors

without any need for additional hardware [12, 13]. We intend to integrate this function into our PaperPixels elements in order to make them touch sensitive display pixels. This would open up another dimension for interaction with the PaperPixels display.

CONCLUSION

This paper presents PaperPixels, a toolkit that allows construction of ambient animatable paper displays. The main motivations behind this work includes presenting a technology in the form of a toolkit to empower non-expert users to construct their own paper based displays. We discuss the hardware, software implementations and present the usage of the toolkit.

We conducted a workshop in a local maker fair where many participants came up with interesting and original designs in a short period of time. Considering the workshop observations and other comments received, we envision that PaperPixels may open up a new generation of ambient paper based displays that will be seamlessly integrated into our environment.

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