Sensing pixels: Enabling novel applications with two-way displays

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Abstract—Sensing pixels is an idea to put a light sensor behind each pixel in a display. This would allow displays to react to and interact with their physical environment, making them behave more like everyday object, while enabling a novel set of applications. Examples include adapting to shadows, displaying fluorescent colours, or sensing temperature and pulse in healthcare.

I. Introduction

Despite displays having become a ubiquitous part of human life, they are in many aspects unnatural and fairly limited compared to human perception of the world. They form imaginary 2D surfaces that emit light with no regards for the surrounding environment, and the range of colours and materials that can be reproduced on screens this way is fairly limited. Displays primarily work as light sources, yet they are used as reproduction devices, historically replacing paper and film media.

A fundamentally limiting factor is the display's inability to sense the environment. The peak of technical innovation in this area is adding ambient light sensors to the devices and automatically adjusting the brightness of the display so that it can be legible in bright sunlight and dimmed in dark conditions.

This paper proposes to rethink the conventional role and abilities of displays by supplementing each output pixel with an input channel. The display output can then react in real-time to the light conditions in the display's environment on per-pixel basis, in a transparent manner to the application.

II. Applications

Displays with sensing pixels could have an interesting range of novel applications as described in the examples below.

A. *Adapting to local viewing conditions*

Sensing pixels can detect any shadows or light rays locally affecting the display surface and compensate for them to improve legibility of the content, or interact with them to provide engaging experiences (such as virtual plant growth).

B. *Fluorescent and other materials*

A completely new set of materials with special optical properties can be shown on displays with sensing pixels. These sensors can extend beyond the visible spectrum and provide the necessary information to render various optical effects, e.g. fluorescent colours or thermochromic materials.

The ability to display fluorescent colours can be utilized for example by the textile industry (e.g. for evaluating safety wear designs) or game industry (e.g. for discovering evidence in detective games).

C. *Biometric sensing*

On the other side sensing in the infrared spectrum can provide data for several healthcare applications, including body temperature and blood pulse measurements.

The presence of human touch can also trigger further interactions from the applications on the display, such as rearranging user interface so that the contact areas are avoided.

III. Related Work

Due to its complexity, display prototyping in HCI tends to be limited to low-fidelity, special purpose applications. Examples include ECPlotter for electrochromic [1] or Stretchis for electroluminescent displays [2]. In the electrical engineering field, there have been attempts to augment TFT displays with sensing capabilities [3, 4], although the application aim at applications sensing light reflected from the display itself, such as scanning or fingerprint reading. Surprisingly little literature explores modifying OLED displays or their manufacturing process [5]. Samsung recently announced Sensor OLED Display [6], but again for reflective sensing applications.

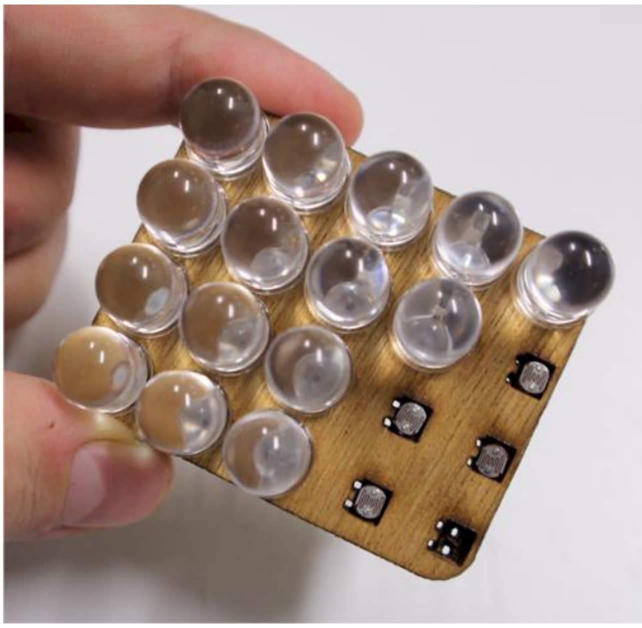
Ambient light has been utilized to enhance user experience with displays [7] and now most commercial mobile devices offer this technology (Apple's True Tone, Microsoft's Adaptive Color etc.). However, the extent to which the display is adapted is fairly limited and spread over time. My previous work demonstrates real-time adaptation to the environmental conditions can achieve paper-like emissive displays [8]. The proposed prototype would allow to apply this behaviour on per pixel basis rather than globally.

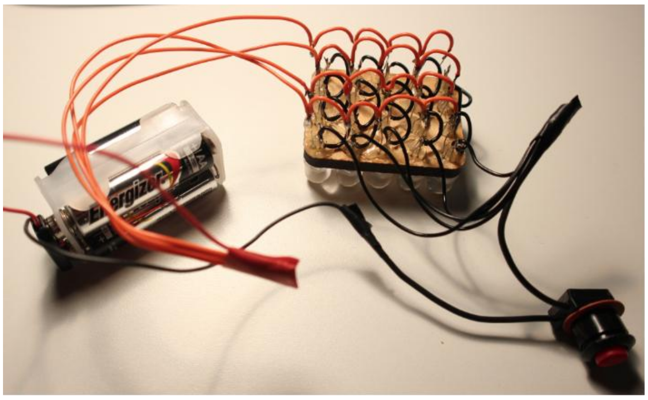
Simulating fluorescence and other optical phenomena is the subject of predictive rendering [9]. A completely different graphics pipeline could be built on top of the sensing pixels.

Finally, some of the work in healthcare applications focuses on repurposing existing devices for basic diagnose tools, such as using camera to measure heart rate [10]. This enables to providing healthcare in remote and rural communities [11]. Displays with sensing pixels could provide better accuracy of the same measurements using much less power.

IV. Existing Prototype

A few approaches can be taken to realize sensing pixels. The first option is to rely on transparent LEDs. Since they emit light only to the front, a photo-resistor can be put behind them and sense the incoming light. I have prototyped this option using a laser cutter and big clear LEDs.

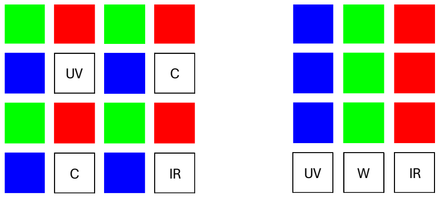




Each LED is connected directly to the photoresistor underneath it, letting more current through as more light is cast onto it. This way, individual pixels can adapt to shadows in real-time, without any processing power.

Another other option is take advantage of the LEDs under reverse-bias condition where they can themselves work as light sensors. One could imagine time multiplexing forward and reverse-bias conditions to achieve the functionality on existing displays. Since the light sensitivity tends to correspond to the wavelength of the LED, this can provide RGB sensing too.

However, these approaches might not be viable for commercially available displays. In order to be able to test the envisioned applications in real-world scenarios, it will be necessary to have pixel sensing integrated in higher resolution displays, at least as are available for the hobby market. The most straightforward solution would be to intersperse light sensors among the LEDs in OLED displays.



While this might be not difficult to manufacture from technological perspective, it is out of reach of an average academic lab.

V. Responsible Innovation

The advantage of rethinking an existing interface is that it can take advantage of established processes and thus involves fewer costs compared to introducing a new one. Furthermore, local dimming (and replacing portion of LEDs with a light sensor) has the potential to save energy consumption in OLED displays. However, depending on the application, the extra data processing might outweigh any such savings.

Some of the envisioned applications offer extra values for the society. Faithfully representing product designs is a critical cost-saving ability for the industry and being able to show new materials further extends this process into even more areas. Temperature sensing can pick up health indicators not only in specialized healthcare applications, but also continuously during everyday device usage.

Finally, providing fun experiences and arousing curiosity in technological advances contributes not only to the well-being of the users, but also motivates further research.

VI. Author Bio

I am currently a post-doc researcher in human vision and colour science at the Institute of Neuroscience, Newcastle University. I enjoy bringing technical and prototyping skills into fields where they are often overlooked, including humanities and natural sciences.

I have experience with both hardware and software prototyping, from assembly for Microchip PICs to C# running on .NET Micro Framework and .NET Gadgeteer, which I contributed to during my internship at Microsoft Research in Cambridge. I'm capable of soldering by hand, designing basic PCB layouts and working with laser cutters and 3D printers.

VII. Acknowledgements

The idea for this prototype comes from my work on paper-like emissive displays I did for my PhD partially funded by Microsoft. I am thankful to my wife for proof-reading this paper and the idea of applications reacting to where users are touching the device.

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