

LED Paper: Physical Computing with Handmade Paper

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Figure 1: Examples of hand-made paper that incorporates LEDs and wires into the paper.

ABSTRACT

Physical computing involves using embedded computing to interact with the physical world. It's a core technology for interactive computing. This assignment introduces physical computing through the incorporation of LEDs into handmade paper to make an interactive, visual, and physical artifact.

CCS CONCEPTS

• **Computing methodologies** → **Graphics systems and interfaces**; • **Computer systems organization** → **Embedded systems**; **Sensors and actuators**; • **Applied computing** → **Arts and humanities**.

KEYWORDS

physical computing, embedded systems, arts computing

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1 OVERVIEW

This Groovy Graphics Assignment lies at the intersection of physical computing, interactive techniques, and fine art. It uses a combination of embedded control, LEDs, and handmade fiber paper to introduce physical computing, interactive techniques, and data

representations to students ranging from non-majors learning computing, to fine art majors, to computer science students. This assignment was developed as a part of a cross-disciplinary course in Embedded Systems and Kinetic Art that I teach in collaboration with a colleague from the Department of Art and Art History at the University of Utah [Brunvand 2013; Brunvand and Stout 2011].

The definition of “computer graphics” as used by artists in new media and kinetic areas of the arts is much more expansive than simply rendering to a screen. A visit to the SIGGRAPH art gallery, for example, will showcase a wide variety of uses of computing, embedded control, sensors, and actuators in the service of art. Kinetic art using embedded control is a marriage of art and technology. Artistic sensibility and creativity are required for concept and planning, and computer science and engineering skills are required to realize the artistic vision [Candy and Edmonds 2002]. However, these different skills are often taught in extremely different parts of a university campus. As an attempt to bridge this gap, we have offered a cross-disciplinary collaborative course that pairs computer science students with art students to engage in joint engineering design and creative studio projects. These projects combine embedded system design with sculpture to create kinetic art. We believe that this is a natural pairing of two disparate disciplines, and one that provides distinct educational benefits to both groups of students.

The specific assignment highlighted here is to combine handmade fiber paper with LEDs, wires, and embedded control to make interactive, computer controlled, light-up paper. Note that by embedding the electronics directly into the hand-made paper, this is somewhat distinct from other, also interesting, approaches of using paper as a substrate for circuits using tape, stickers, and other applied components (e.g. [Hodges et al. 2014; Qi and Buechley 2014]). From an educational perspective, this assignment engages with the students’ artistic interests, and the goals of the class to produce physical artifacts that include physical computing. It also involves lessons in basic electronics for physical computing (wiring, LED current, current-limiting resistors), and basic programming using an embedded controller - Arduino in this case [Arduino 2014], but

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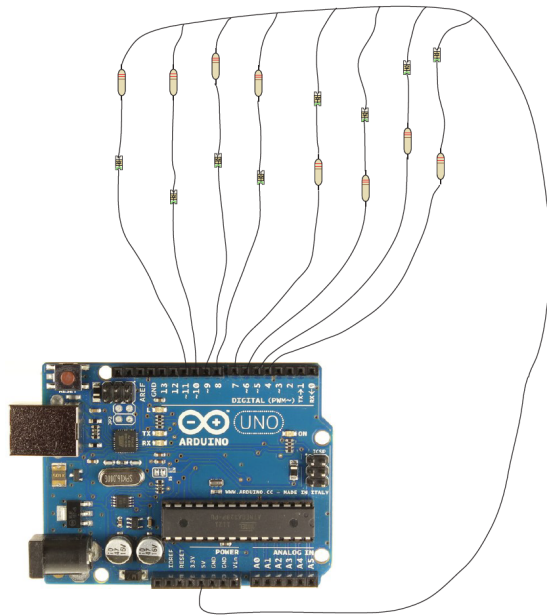


Figure 2: Diagram given to students showing Arduino connections to the LEDs that will be embedded in the paper.

Table 1: Metadata in tabular format

Summary	Hand-made paper with embedded LEDs and wires
Learning Outcomes	Physical computing, electronics, simple programming.
Classification	Fundamentals, physical computing, embedded control
Audience	CS0, CS1, embedded systems, Fine Arts
Dependencies	Basic electronics and simple embedded programming
Prerequisites	None
Strengths	Eye opening to non-CS students. Visually interesting artifacts.
Weaknesses	Requires paper-making supplies.
Variants	Many variations on combinations of LEDs and manipulation of the resulting paper into sculptural forms
Assessment	May be assessed as an aesthetic artifact, or technically on the embedded code.

practically any embedded controller can work. The assignment may be completed using all open-source tools.

2 LED PAPER MAKING PROCEDURE

This assignment requires some physical infrastructure in terms of paper-making supplies, but these are relatively easy to come by, even if one is not teaching in a studio situation. Hand-made paper is made by preparing a paper pulp. This pulp can be made by grinding plant fibers in a blender, or even by using a blender on scraps of

existing paper. There are many on-line sources for paper making instruction (e.g. [Instructables 2021; Network 2021]). In this case we used the “beater” in the Department of Art and Art History to beat Abaca fiber into pulp. Abaca is a plant related to the banana which is native to the Philippines [Wikipedia 2021]. It is a commonly used to make hand-made paper because the long fibers of the Abaca plant make a strong paper that also has a beautiful beige color.

Once the pulp has been prepared, paper is made by dipping a screen or form into the pulp. The resulting slurry is then pressed between sheets of felt to meld the pulp into paper. In our case, as the pulp is being transferred from the form to the felts (called “couching” by paper makers), we add pre-wired LEDs to the still wet paper pulp. When this is pressed in the paper press, the paper fibers conform around the wires and LEDs to completely encase the circuits into the structure of the paper. The result is a piece of (relatively thick) handmade paper with wires and LEDs incorporated into the structure of the paper.

To make this work, we use surface-mount-sized LEDs [Wikipedia 2017] and thin 30AWG “wire wrap” type wire. Figure 2 shows the wiring diagram that we hand out to students. Note that for every (tiny) LED, there is also a current-limiting resistor required. This is required to ensure that the current being provided by the Arduino I/O pins does not exceed the LED limit. It is also a perfect opportunity to discuss basic electronics with the students.

Once the wires and LEDs are embedded into the paper, the wires can be connected as shown to the controller, and using simple DigitalWrite commands the LEDs can be made to turn on or off under program control. This allows the students, who are likely not computer science majors, or even programmers at all, to learn the basics of physical computing in a friendly arts-based environment that also includes a physical computing artifact.

3 DISCUSSION

While not core computer graphics, this assignment is involved more generally with physical computing and interactive techniques. It has been a very popular assignment with students, and results in some wonderful artifacts. It is the type of hands-on assignment that engages with students both physically and mentally. It has also been a tremendous motivator for non-CS students to engage with programming as they refine their programs to make the LEDs light up in various ways.

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