SciSketch: A Tabletop Collaborative Sketching System

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ABSTRACT

Sketching is a vital process in scientific research and procedural learning. In educational contexts, sketching helps students visualize abstract concepts and facilitates communication with their instructors as well as with other students. Inspired by a problem-based learning science class in which students use papers and pens to collaboratively sketch diagrams and equations for given problems, we aim to provide a digital tabletop platform for collaborative learning and customization. Current tabletop systems are unaffordable to be widely adopted in the classroom and are unable to identify multiple pens. We propose a pen-based tabletop system that utilizes a low-cost high-frame-rate infrared camera and HTML5 web canvas programming, making it cheaper and easier to customize for specific uses.

Author Keywords

Sketching, Education, Tabletop, Design, HCI

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces---*input devices and strategies, interaction styles*

General Terms

Design, Human Factors

INTRODUCTION

Sketching is an important technique for science research and learning [1], and can facilitate better understanding of scientific concepts and procedures. In science classes such as chemistry, students sketch to help visualize abstract concepts and their problem solving process. Sketching also facilitates communication between students and teachers since it offers a clearer way to express problems and ideas. At Georgia Tech, students in biomedical engineering (BME) classes sketch collaboratively on large pads of paper while solving given problems. It is an effective way to support communication between students and instructors throughout the problem solving process, and helps students understand problems more thoroughly and learn better. However, it is hard for them to correct mistakes, share sketches, or save their problem-solving process for later review. There are interactive whiteboard applications on the market that could be used as alternatives to paper and pens, however they tend to be expensive. Typically no more than one or two such whiteboards are purchased per classroom, which does not support collaborative sketching by all students in the class. In addition, it is hard to customize those applications to make them more suitable for science education. Thus, we developed a pen-based tabletop application that is built with a low-cost high frame rate infrared camera and HTML5 web canvas, which is cheaper and easier to customize for specific uses. This approach supports collaborative sketching and archiving of sketches for the classroom context.

In this paper, we describe a preliminary study that enabled us to identify the technical requirements for the collaborative pen-based sketching system. We then describe the design and development of a system that meets these requirements using low-cost and off-the-shelf components, allowing easy integration into diverse contexts. Lastly, we provide a brief overview of preliminary applications that demonstrate potential uses of this approach.

GOALS AND TECHNICAL REQUIREMENTS

Findings from Preliminary Study

The Georgia Tech BME department is practices problem-based learning methods [3], in which students learn subject matter by solving problems. We observed the learning behavior in a BME class with 32 students. Groups of four students shared tables, working in pairs on large pads of paper. Students collaboratively drew diagrams, charts, and wrote equations on the pads to solve problems given by the professor. In addition to the pads, they also used textbooks, handouts with numeric tables, and the professor's notes made on the blackboard for reference. Calculators were also used frequently. An example of the sketch-based problem-solving approach is shown in Figure 1.

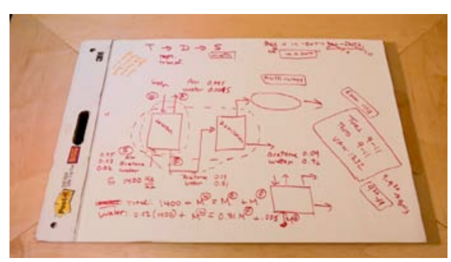

Figure 1. Professor's example of using large paper for solving biochemical reaction problems.

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We found several issues during our observation. Students' sketches on papers were disorganized and not reusable. They did not always use different pen colors to be able to identify their own contributions. If they made a mistake or filled a pad of paper, they simply tore it off and started over on a blank sheet rather than trying to understand where they went wrong. Students also did not keep their sketches for later review or assessment purposes.

Based on these findings, we identified several design criteria: the system should let users (1) sketch collaboratively, (2) save sketches, (3) erase and refine sketches, (4) iterate on previous sketches, (5) find external references, and (6) assess learning progress.

Technical Requirements

According to the findings from the preliminary study, the goal of this work is to develop an interactive tabletop sketching system that can facilitate science education in the classroom. The technical requirements for our system to be able to meet the design criteria are as follows:

(1) Low cost to equip a classroom with ~10-20 sets.

(2) Track and identify at least two pens/users.

(3) Avoid latency that affects sketching interaction.

(4) Allow easy sharing of work between groups.

(5) Provide a playback function.

BACKGROUND

Sketching and Education

Sketching is one of the oldest ways of information representation used by humans. Today, spoken and written language are predominantly used for communication. However this has not undermined the importance of drawing and sketching. In technical fields such as engineering and medical sciences, drawings are used to represent processes and structures, e.g. perspective views of mechanical devices. However, sketching is not limited to communication and representation. It also plays an important part in learning and problem solving. It engages the connection between the brain, eyes, and hands, thereby supporting the transformation of observations and ideas into abstract models. This is supported by research on embodied cognition, which holds that sensory and motor processes play significant roles in cognitive processes [11, 2].

Even though sketching can help students understand scientific concepts, students in the classroom rarely sketch themselves [9]. Research also shows that students can get a better understanding if they construct models by themselves rather than using others' models [7].

Technologies for Pen-Based Interactive Tabletops

We reviewed different technologies for digital tabletop and pen interactions that could be used for our project.

One well-known product is Samsung SUR40 or Microsoft PixelSense (formally called Microsoft Surface). Wacom's Cintiq also allows users to draw directly on the display surface. In terms of hardware, these devices are both suitable for sketching, but they are too expensive to be deployed in the classroom en masse.

Another popular approach is to use a camera to detect objects and a projector to display the image. Some systems mount the camera and the projector on top of a tabletop and project the image from the top. Some put the camera and the projector behind a diffused screen for rear-projection (e.g., ReacTIVision [4]), which is not easily deployed in an ordinary classroom environment in which standard tables are used. PlayAnywhere employs a camera and projector sitting off to the side of the active surface [10]. Researchers at the MIT Media Lab combine this kind of system with a desk lamp by putting the Kinect and a projector in standard fixtures and lampshades and try to adhere to the power standard of bulbs [6]. This idea provides a good example about how to set up this kind of system easily and quickly.

Johnny Lee has done several projects using Wii Remotes and projectors [5]. Since one Wii Remote can track four infrared light dots, he built a low-cost multi-point interactive whiteboard. It is a cheap solution for sketching applications, but it cannot distinguish different pens/users, which doesn't fit our user needs.

Unlike the above technologies, Anoto makes digital pens with a camera, processor, memory, and a Bluetooth module. The pen takes pictures using the built-in camera, saves the data and sends it to other devices such as computers and mobile phones. But the pen and an additional displace device are also too expensive for classroom use.

IMPLEMENTATION

Hardware

The following system was built to achieve our goals. A Wii Remote is used as the infrared radiation (IR) sensor and IR pens serve as input devices to write on a whiteboard (e.g., a plain sheet of white paper, a white table surface, or a piece of white foam core). Wii Remote whiteboard software receives the data from the Wii Remote and distinguishes different pens/users. A HTML5 web sketching application was designed to display, record, and playback the sketches. A projector displays the processed image on the white board (see Figure 2). In our first prototype, the Wii Remote and projector hang above the table, aiming down at its surface. We also designed a stand for the projector and Wii Remote that can be placed on the edge of the table, making it easier to deploy the system in environments that don't allow hanging from above.

As a whole, the system is easily deployed in the classroom or any environment that already has a table in it. The components used also keep the cost low.

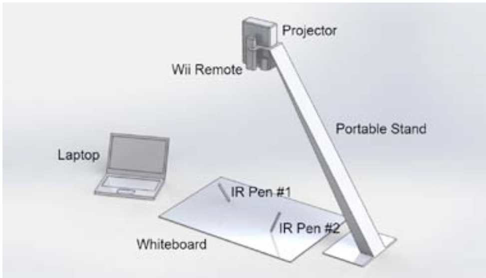

Figure 2. The system includes a Wii Remote, a projector, a computer, IR pens, a whiteboard and a portable stand.

Wii Remote

Frame rate is a key specification for detecting handwriting. Therefore, the Wii Remote was chosen due to its high frame rate (about 100 frames per second) at a 1024x768 resolution. To clearly detect the IR dot on the whiteboard, the Wii Remote is placed on top. The Wii Remote can detect up to 4 IR dots, which is acceptable for multiple pens working at the same time. In this system, it works in extended mode and returns the X and Y locations, with a rough size value (from 0 to 15) for each IR dot, which can be used to distinguish different pens/users.

Another important consideration of the Wii Remote is its affordable price. As we mentioned before, PixelSense or Cintiq are too expensive to be deployed in a classroom if one is needed for each student pair or group of four.

IR Pen Design

SciSketch uses IR pens as writing tools. Multiple users can use different IR pens, which are distinguished by the system using the sizes of the IR LEDs. The angle of the pen is about 45 degrees downward when a user holds a pen and writes on the whiteboard. Therefore, the IR dot detected by the Wii Remote is actually the combination of the reflection of the IR light on the whiteboard and the IR light itself. The IR pen is assembled of one or multiple IR LED bulbs, a pushbutton, a battery, and the pen body. When the user writes on the white board, the pressure triggers the pushbutton, which activates the IR LEDs.

Different pens are distinguished by the software based on the different IR dot sizes they have. To make the tracking and identification of different pens easy and clear, two IR pens were made to have distinct IR dot sizes from 0 to 0.2. To get different IR dot sizes for one LED pen, the voltage across the IR LED can be adjusted using a small rheostat. In this study, specifically for the same IR LED, 1.2V and 1.5V provide different sizes if the angle between the pen and the whiteboard is fixed. Another method to differentiate pens is to have multiple LEDs on one pen. In this way, it generates a more stable IR dot in a bigger size compared to the IR dot generated by one single LED powered by a higher voltage.

Several tests were done to find out how the number of and distance between IR LEDs affect the size detected by the Wii Remote. IR Pens with 1, 2 and 4 IR LEDs were tested (see Figure 3). Combining two or more LEDs in one pen with a small distance between them can make the Wii Remote recognize them as one dot and increase the dot size.

Software

Raw data sent from the Wii Remote is decoded by a connector program on a computer, which broadcasts converted coordinates and a unique identification number to a local browser. Once the web page receives the packages, JavaScript is executed to start lining up each coordinate.

Figure 3. Pen prototypes used for testing (left); final battery-powered IR pens with 1 and 2 LEDs (right).

Wii Remote Connector

A java-based connector, a modified version of the Wii Remote Whiteboard program [8], receives and decodes data transmitted from the Wii Remote IR camera. It registers each IR signal according to its unique dot size and relative distance to last recognized dot. After filtering them out of the broadcasts, the normalized two-dimensional coordinates are sent to a plugin running on the local web browser. The web plugin listens to the packages sent from Wii Remote Connector and triggers conversion from the IR camera coordinate system to actual canvas scale.

Unique Identification Tracking Algorithm

In order to prevent false recognition resulting from unstable current and signal blocking, x-y position and dot size of each IR source are stored and compared frame by frame. The false rate without optimization is 16%. From our tests, every 7 consecutive same-size packets are considered a stable source, leading to a lower false rate at 7%.

SciSketch Web Interface

The web interface exploits an HTML5 canvas element as the main sketching area. Each pair of converted coordinates represents x-y position on the canvas and lines up between two dots, resulting in a similar sketch path as physical drawing. Color is determined based on the registration ID assigned by the Wii Remote Connector to distinguish between different IR pens. For replay functionality, all dots are stored in a client-side database so that users can access their previous sketches and review their thinking process.

PERFORMANCE AND CHALLENGES

Performance

SciSketch can currently track two different pens by their unique dot sizes (see Figure 4). It means that two users can sketch collaboratively with 2 distinct pens. We successfully reproduced what users write or draw sequentially.

The tracking resolution is 1024x768. The display resolution depends on the computer and projector settings. We use a 1024x768 display resolution as well. The frame rate of the hardware is 100 fps while the canvas frame rate is a little lower. The pressure and angle of the pen can't be detected.

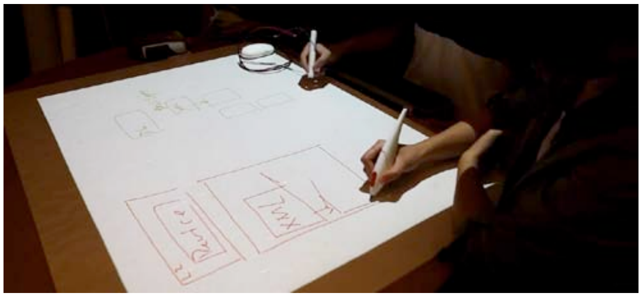

Figure 4. Two users solving a problem together.

Challenges

Robustness: Ideally, the signal emitted from each IR pen should be consistent, and we can differentiate any IR pens based on their light dot sizes. However, from our tests, the IR light dots did not always remain the same size when we drew because different users hold the pen at different angles. The reflection dot size changes a lot when the angle changes, which can cause instability because it falsely recognizes one pen as another pen.

Latency: Latency is another very important factor. We noticed that if the frame rate of the camera dropped under 70 frames per second, the detection is unbearable. Currently, a latency of about 0.15 second was detected in the drawing tests. It may partly be explained by the speed of Bluetooth connection and the software.

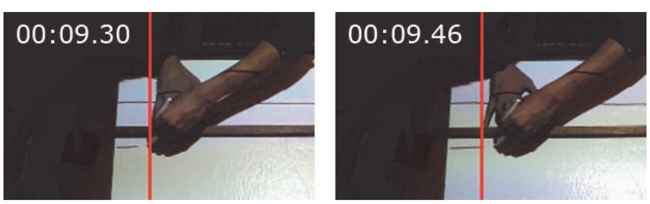

Figure 5. In our tests, the line displayed on the whiteboard usually falls behind the IR led bulb about 0.15 second.

APPLICATIONS AND FUTURE WORK

In addition to the sketching interface, we designed and developed two 3D interactive web applications to explore different applications of the SciSketch platform. The first application is a tweaked version of "Periodic Table", which allows students to interact with each element instead of pictures from textbooks. By clicking on an element, it flips over and displays details and a 3D model of the element. The other application is "Assembly", which allows users to use IR pens to zoom in, rotate, and inspect 3D models while assembling from scratch. Both the sketching application and these applications received positive feedback from informal user testing at demo showcase events.

Our next steps include running user studies to evaluate the system. This could include: 1) evaluating the writing experience with the IR Pens, 2) exploring the BME students' needs for the application, and 3) comparing the collaborative sketching process using traditional paper-pen with our IR pen system. After getting enough feedback from user testing, we'll develop functions to support enhanced teaching methods, such as history of drawing, sketch recognition, simulation, and assessment tools.

We believe SciSketch provides a low-cost platform on which tabletop applications can be deployed seamlessly with pen-based interactions, especially for those needing to distinguish between multiple pens or users.

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