Integrating Traditional Input Devices to Support Rapid Ideation in an Augmented-reality-based Brainstorming

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ABSTRACT

Augmented reality(AR) has the potential to address the limitations of in-person brainstorming, such as digitization and remote collaboration while preserving the spatial relationship between participants and their environments. However, current AR input methods are not sufficient for supporting rapid ideation compared to non-digital tools used in brainstorming: pen, paper, sticky notes, and whiteboards. To help users create comprehensible notes rapidly for AR-based collaborative brainstorming, we developed IdeaSpace, a system that allows users to use traditional tools like pens and sticky notes. We evaluated this input method through a user study (N=22) to assess the efficiency, usability, and comprehensibility of the approach. Our evaluation indicates that IdeaSpace input method outperforms the baseline method in all metrics.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in collaborative and social computing**.

KEYWORDS

Brainstorming, Collaboration, Creativity, Tangible

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1 INTRODUCTION

A brainstorming session often involves participants writing out ideas on sticky notes and placing them on a physical board to analyze with a group and draw connections from [6]. Brainstorming with augmented reality head-worn displays (AR HWDs) on can greatly improve collaborative brainstorming for the following reasons: preserving the spatial interaction [5] and digitization of the brainstorming environment [4]. However, the input techniques in AR can be slow and tedious [1, 7], hindering the ability to quickly generate and express ideas in a brainstorming session.

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In this paper, we propose to integrate physical traditional tools—pen and sticky notes—as an input method for AR HWDs. We designed and implemented IdeaSpace, an AR-based brainstorming application that allows users to use pens and sticky notes to create virtual sticky notes. Once a user writes down an idea on a physical sticky note, then IdeaSpace captures it using computer vision algorithms and inserts it into the virtual environment. We introduce the design of the system and the user study result as follows.

2 DESIGN AND IMPLEMENTATION

Efficiency (time to create notes) is one of our primary design goals. We designed the system to create virtual sticky notes within only marginally greater time—to capture the physical sticky notes and create virtual ones from them using embedded cameras in AR HWDs—than it takes to write a sticky note in real world. To create notes with our pen-and-paper input method, users first have to create a physical note with their pen and paper as tools. Then, users have to approach the physical sticky note in real life, look at it with their HoloLens HWD, and verbally utter the word "Capture", which makes the HoloLens capture an image after a three-second countdown. This image is sent to a remote server, which handles detecting the sticky note using OpenCV; we used Python with opencv-python, a wrapper hosted via PIP for OpenCV computer vision functions containing pre-built OpenCV binaries [2].

To detect sticky notes, we followed the following steps. First, we resize the image to downsample it so that edge and curve detection later would exclude visual artifacts. Second, we remove shadows from the image, because typically a user's head can occlude light and create a shadow on a surface that the sticky note is on, applying an existing algorithm to remove shadows [8]. Next, we blur the image with a Gaussian filter with kernel size 5x5 to reduce artifacts further. We then run Canny edge detection on the image, and find all curves in the image ("contours" in OpenCV) [2]. Then, we filter down to polygons that have a number of edges between a lower and upper limit, and which take up a minimum percentage of the area in the image. With these lower and upper x and y bounds from the down-sampled image, we scale the polygon back to the original image size and crop out the sticky note based on the found region so that the quality of the original image is preserved.

3 COMPARATIVE EVALUATION STUDY

To evaluate the pen-and-paper method implemented in IdeaSpace, we designed an in-lab study to compare the systems with existing methods in terms of efficiency, usability, and comprehensibility. We

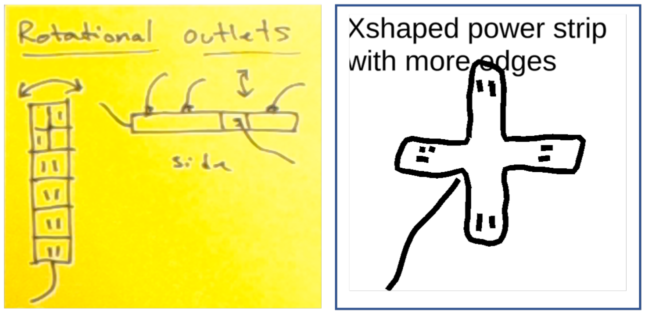

Figure 1: Sticky notes generated from IdeaSpace (Left) and from the baseline condition (Right)

implemented a baseline method using state-of-the-art input methods that HoloLens provides—hand-tracking and a virtual keyboard for sketching and writing text in AR.

We recruited 22 participants (age range 18-34, 13 female and one non-binary) from the authors' university. The pair of participants were invited to our lab to simulate a brainstorming environment in which participants need to exchange—externalize and comprehend—ideas. Each participant was asked to think of an idea per task and comprehend the ideas suggested by the other. We asked them to think of a new idea to solve two ideation problems (e.g., design a power strip that one can use all the outlets regardless of the shape and size of power plugs.) which had been used in a previous work [10] Then they were asked to express an idea on a virtual sticky note with a sketch and textual description explaining the idea. Figure 1 shows two notes that were submitted to the system using IdeaSpace (Left) and the baseline method (Right). Before the experiment begins, all participants went through tutorials and were given sufficient times to practice. After ideation, they were asked to comprehend each other's note and verbally externalize the idea.

We gathered the following metrics from video recordings, in-application logs, questionnaires, and an interview: Task Completion Time, Usability (System Usability Scale or SUS) [3], and Comprehensibility. Regarding the comprehensibility, we asked them to evaluate how easy it was to comprehend the idea (readers' ratings), the extent to which their partner's verbal description matches their ideas (authors' ratings) in 10 point-scale questions. We also recruited two external judge to rate the comprehensibility—how easy it was for them to comprehend the idea— of the generated notes from the study (external judges' ratings).

Each participant went through two tasks in two conditions (IdeaSpace vs. baseline). The order of the input methods used was counterbalanced. We analyzed data by running t-test for completion time and Mann-Whitney U test for ratings and SUS.

4 RESULT

We found evidence that integrating traditional tools in AR-based brainstorming can be beneficial for brainstorming. The result suggests that pen-and-paper input method was more efficient than the baseline method. The pen-and-paper input method (mean: 143.5s, stdev: 50.6s) took 143.7s less than the baseline input method (mean: 287.2s, stdev: 87.4s), taking only half the time on average. The difference was statistically significant(*t-test*, $p < 0.001$). Regarding usability, the SUS score for our pen-and-paper input method yielded higher score 70.79 on average than the baseline (mean: 55.23); the difference was statistically significant ($p < 0.01$). Lastly, our pen-and-paper input method resulted in more comprehensible notes for readers ($p < 0.01$) and external judges($p < 0.001$) than the ones generated from the baseline condition. However, the difference on the authors' rating was not significant ($p = 0.056$). This result indicates that the readers and the external judges perceived that sticky notes generated using IdeaSpace were easier to comprehend. The benefits in comprehensibility will also contribute to the efficiency by reducing communication cost (e.g., clarifying questions).

From the post-experiment interviews, all participants except two answered that our pen-and-paper input method felt more satisfying to use compared to our baseline. A number of participants said that the pen-and-paper input method in IdeaSpace is something that they were already familiar with with minimal extra step (verbal trigger). The participants pointed out that the baseline method felt slower and more physically demanding to use because of the mid-air gestures needed in the baseline method. While the participants who preferred the baseline condition indicated that it felt feels "much cooler" to draw with Hololens. More detailed result is elsewhere [9].

5 CONCLUSION AND FUTURE WORK

From our study, we found evidence that integrating traditional tools in AR-based brainstorming can be beneficial for brainstorming. In addition, our design process revealed the need to provide various functions for integrating physical tools to generate virtual objects — visual and auditory feedback such as countdown for capturing the image or points that users may get confused when a physical object (a sticky note) becomes virtual. We plan to explore collaborative brainstorming in AR that support co-located and remote collaboration in a shared physical and virtual environment. For such future hybrid system, we believe integrating physical objects and environments into an AR environment will be an essential step towards seamless collaboration.

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