Artificial Grapheme-Color Synesthesia for Wearable Task Support

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Abstract

This paper presents the benefits of generating an artificial visual synesthesia through a wearable computer. Following a short introduction to remind the need for seamless human-wearable computer interactions, this paper makes the case for drawing upon synesthesia, a combination of the senses naturally occurring in a small portion of the population, to augment everyday entities and more precisely to enrich written graphemes. We present the rationale behind our research and summarize the functionality, architecture and implementation of our current prototype. Preliminary results suggest that this kind of artificial synesthesia improves short term memory recall and visual information search times.

1. Introduction

A wearable computer is a truly personal computer. By providing a task-integrated assistance or by managing numerous minor or secondary activities in background, it can directly or indirectly support real-world tasks.

1.1. The gap between the real and the virtual

Many challenges like hardware and software design, energy consumption, social acceptance, etc. [15] have to be addressed to reach a wearable platform reflecting mobile users' needs. However, the main challenge remains the user interface, especially information presentation, as it should enhance a user's performance while minimizing the required amount of attention and avoiding constant back and forth between the real-world task and the interactions with the wearable computer [16].

By striving for a seamless integration of human-wearable computer interactions into the natural flow of user activities, we try to transform the wearable computer into a symbiotic tool augmenting human senses. The idea of augmenting a user's natural abilities through computational components isn't new and can partly be traced back to Douglas Engelbart [6]. To move toward such an augmentation, we turn to naturally occurring human physiological phenomena, behaviors, and habits and try to take advantage of them when designing wearable computers interfaces.

1.2. Synesthesia

Synesthesia [1, 12] is a neurological combination of the senses most likely caused by a cross-activation of brain regions. It can broadly be defined as the stimulation of one sensory modality by another but there are in fact numerous types of synesthesia. In its most common form, unique sounds or graphemes (i.e. atomic units in a written language) can be associated with specific colors. For example, when presented with the digit 3 written in black on a white sheet of paper a synesthete could experience it as being red. While this medical condition is rare (even though there is no consensus, about 1 in 2,000 people could be affected by some variation of the condition [1]), it is possible to view synesthesia as a form of augmented reality. As such, it can give us valuable insights into an innate augmented reality system.

What is most interesting is that synesthesia can be beneficial: studies have shown that grapheme-color synesthesia makes information more memorable as it can improve both short term and long term memory recall of lists or matrices of digits [14]. Synesthesia can also help detect and isolate anomalies among digit patterns as shown by Ramachandran's experiments [12]. Arithmetic operation times appear to benefit from synesthesia as well [3] as colors seem to evoke at least some magnitude information that can help synesthetes differentiate or recognize numbers [8]. To synesthetes, their unusual ability feels more like enhanced perception than a handicap. They often rely on these stable grapheme-color

This work was supported in part by two grants from the National Science and Engineering Research Council of Canada (NSERC).

associations to memorize and visualize names, word spellings, phone numbers, or even to solve equations.

Color is in fact a very powerful and salient visual cue that can significantly improve recall abilities when part of a memory representation, as well as visual search tasks' performance [5]. Children routinely try to "recreate" some form of synesthesia by using colors to help memorization. Colors can also help patients who suffered a traumatic brain injury relearn basic mental operations [4]. There is also a large body of research on the use of color in traditional human-computer interfaces.

What if we could artificially recreate synesthesia to enhance the performance of wearable computer users for specific tasks involving isolating real-world patterns or learning and remembering real-world information? We believe it could help improve low attention, overt, real-world information cuing on wearable computer displays.

2. Related work

The need for wearable computers to bridge the gap between the real and the virtual has led in recent years to advances in information presentation techniques like, for example, mobile augmented reality integrating three-dimensional data in the environment or just-in-time information retrieval and presentation [13]. In contrast to our overt approach to wearable task support, a recent research investigating subliminal cuing for memory support [2] suggested that it could be an effective way to reinforce learning while requiring very low attention.

Some forms of synthetic synesthesia have already been investigated. However, most experiments focused on completely transforming human perception by enabling wearable computer users to access data otherwise unavailable through their ordinary senses. For example, giving a user the ability to feel radar data converted into pressure stimuli [10] or to hear the mapping of a spectrometer's output into sound [7]. These interesting experiments open up new "senses" but we do not think of them as actual synesthesia as the starting modality (radar waves for example) can not be perceived by normal users. On the contrary, our research tries to draw upon the naturally occurring ability of some individuals to augment environmental artifacts, to enhance an existing sense. This overt augmentation, allowing a user to transparently access his/her wearable computer's functionalities through the real world, could be an essential part of a new breed of interaction mechanisms where real-world entities are the interface to the wearable computer [11].

3. Emulating synesthesia

Emulating synesthesia could give us insights on how to improve wearable display systems by integrating subtle additional information to the real-world as efficiently as possible. The purpose of this overt information cuing is of course to enhance the task's performance without monopolizing the user's attention. Moreover, emulating synesthesia could also contribute to the study of real synesthesia by allowing comparisons between natural synesthetes and artificial synesthetes, the association and search strategies they adopt, their mnemonic techniques, the effect of sustained synesthesia on short and long term visual memory, etc. We present here the general hardware and software architecture we implemented to artificially reproduce synesthesia through a wearable computer.

3.1. Sample application

The sample application we developed tries to replicate one of the most common forms of synesthesia: digit-color synesthesia. In this form of synesthesia, each digit brings out a unique color (i.e. a photism) that clearly influences the user's perception. The rationale is that the photisms, which add distinguishing features to digits, can help the user locate numbers more efficiently and remember specific digit patterns by creating distinctive structures.

Our application is focused toward personal use and, though now limited to a controlled environment, it could enhance the user's perception in everyday tasks involving reading and writing. Thanks to a worn camera, our application analyzes symbols written on a conventional notepad. If a digit is recognized, its color is altered in the current video frame which is then shown on the wearable computer display to emulate digit-color synesthesia.

The color associated to each digit is based on the synesthete's color scheme of Smilek's study [14]. Figure 1b shows an example of video see-through synesthesia.

3.2. Wearable computing platform

Our wearable computing platform is integrated into a vest and is built around a PC-104+ core module, with a Transmeta Crusoe 1.0GHz and 256MB of RAM, and an add-on video capture board. A MicroOptical SV6 monocular opaque display (18 bits colors and a resolution of 640x480 pixels at 60Hz) was used as the video see-through device. Finally, a low power miniature point-of-view video camera with a color CCD was mounted on the user's glasses to acquire live video for digit recognition.

3.3. Software architecture

Our C++ application relies on Intel™ OpenCV library [9] for image processing. The main processing loop is built around a simple "offline" (i.e. each image acquired by the frame grabber is processed independently) real-time character recognition algorithm. First, each image is segmented to isolate pixels matching the ink's color. Entities of interest are then located by recursively following the 8-connected neighbors of the remaining pixels. Each isolated entity is then normalized to a 16x16 matrix and binarized to obtain a feature vector which is classified by means of a traditional 1-NN classifier using Euclidean distance (to reject entities not corresponding to any digit, a threshold is set for this distance). When a match is found for a given entity, the pixels of the recognized digit are colored using a simple lookup table. The altered image is finally presented to the user. Our current digit database only contains a limited number of samples and our digit recognition is essentially user specific as two users can draw very different glyphs (i.e. symbols) to represent a given grapheme (i.e. digit).

4. Preliminary experiments and results

We tested our prototype application with 8 subjects (undergraduate and graduate students) sitting at a desk. Figure 1 presents a participant during a test (a) and screen captures for each of the two experiments (b and c).

Figure 1. User at work (a) and screen captures in the first (b) and second (c) experiments

4.1. First experiment

In our first experiment, we asked each participant to memorize 5x5 matrices of random digits (uniform distribution of digits from 0 to 9). We performed two tests per participant, each time with a fresh random matrix (as there was no simple way to quantify the "memorization difficulty" of a matrix): one test with a simple pass-through feed from the video camera to the wearable computer display and the other test with our artificial synesthesia application running. For each participant, the order of the tests was chosen randomly to minimize practice effects. For each test, two minutes were allowed to memorize as many matrix digits as possible. Two minutes after the end of a memorization phase, each participant had one minute to write the memorized digits in an empty matrix (without the wearable computer). The number of correctly remembered digits was then recorded.

As figure 2a shows, artificial synesthesia seems to enhance the average performance of participants by 30.8% (the average matrix recall percentage increasing from 47% to 61.5%). A one-tailed paired T-test with α=0.05 led to a p-value equal to 0.023 showing that the increased performance is statistically significant. Finally, the majority of participants (6 out of 8) also reported in the subsequent debriefing that they perceived the task as being easier with artificial synesthesia.

4.2. Second experiment

In our second experiment, we asked each participant to search an irregular pattern to find the correct number of abnormal digits hidden among numerous digits of similar shape (4 to 8 digits "5" hidden among 60 to 80 digits "2", all randomly placed but never overlapping). Here again, we performed two tests per participant, each time with a fresh random pattern (for a grand total of 16 patterns): one test with the pass-through feed and the other with our application running. For each participant, the order of the tests was chosen randomly. We recorded the time taken to give the correct answer for these visual search tasks.

As figure 2b shows, artificial synesthesia seems on average to greatly decrease the response time (the average visual search time decreasing from 6.81 to 3.58 seconds, a reduction of 47.4%). A one-tailed paired T-test with α=0.05 led to a p-value equal to 0.0015 which shows that the increased performance is statistically significant.

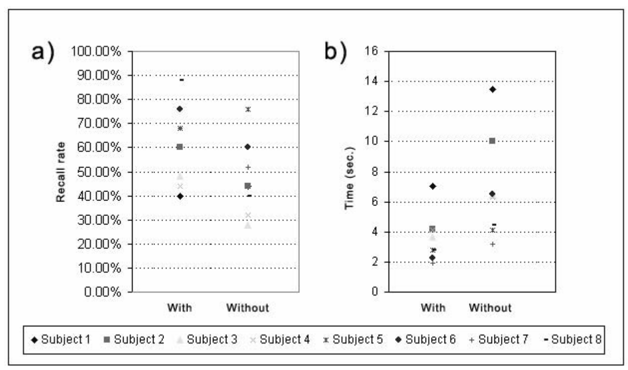

Figure 2. a) Matrix recall rate & b) visual search task times with and without artificial synesthesia

5. Discussion and future work

According to our first observations, our artificial synesthesia seems to exhibit all the major characteristics of real synesthesia [1]: 1) it is involuntary and passive as the wearable computer processes every digit present in front of the user; 2) it is perceived to take place in the user's personal space as it is experienced through the wearable computer display; 3) it is stable over time as the color associations do not change.

Our preliminary results are promising. We will definitely need to conduct more tests to further validate them and to truly assess the benefits and limits of artificial synesthesia. We are planning a more extensive test phase with a larger number of subjects, in part to obtain an unbiased distribution of the level of "difficulty" of the randomly generated matrices and patterns between the two kinds of tests for each experiment.

Coloring objects like digits on a 2D plane in a static and controlled environment is a relatively easy problem. In the long run, artificial synesthesia should be generalized as an overt cuing tool to augment 3D objects in mobile settings and real-world environments. It could be used to highlight task related information or objects to improve search tasks (locating a specific street address or virtually linking mechanical parts for example), to support or enhance human cognition or memory (mental processing or teaching aids for example), to attract human attention, or to suggest entry points for augmented interactions in the real world. However, subtly "altering" the properties of task related real-world objects in a mobile setting is a difficult problem: it requires small registration errors and latencies, while identifying objects and keeping a consistent perceived color can be harder due to environmental lighting conditions. These problems will need to be addressed to bring artificial synesthesia to the real-world and our application will certainly have to be extended to general settings and natural conditions.

Besides the data about the viability and performance of artificial synesthesia, a more comprehensive evaluation could lead to insights about the "learning curve" of this new "sense", about differences and similarities in operating modes between artificial and real synesthetes, about optimum color tables for memorization, etc. The implications of artificial synesthesia could be far reaching and its long term effects could be interesting. Can digit-color associations enhance an average user's ability to carry out arithmetic operations once the relationships are internalized? Can artificial synesthesia induce some kind of natural synesthesia after a long term use? It will certainly lead to some user behavior modifications: new ways to accomplish tasks will emerge and new mental models linked to augmented objects will be introduced. In the end, we will most likely seamlessly use the synthetic functionalities provided by our wearable computers.

6. Conclusion

The main contribution of this paper was to propose a low attention, overt, real-world information cuing system for wearable computers which improves simple tasks' performance. Our preliminary results seem to indicate that artificial digit-color synesthesia could indeed improve memory recall rates, at least for short term memory, as well as visual search times. In our opinion, the proof of concept we presented could help bridge the gap between the real and the virtual and maybe enable more transparent human-wearable computer interactions. However, our system is only a first step and more work is needed to develop and study artificial synesthesia.

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