Trace: Embedded Adaptive Devices in Public Spaces

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ABSTRACT

In this paper, we present a mobile communication and display device that learns gesture and color information collected by the user. We introduce the design prototype of a display that combines multi-modal sensing, embedded adaptive algorithms and a flexible color display. We propose an approach to the exchange of inter-personal information through transient public interfaces.

Keywords

Interpersonal communication, tangible user interface, learning algorithm, gesture recognition, public interface.

INTRODUCTION

Trace is a small mobile device for use by the general public in shared spaces. Trace captures gestures and colors created by a person from his/her environment through a process of training sequences of colors to the object. Trace combines the exploration and design of a tangible user interface device capable of learning, relearning and recalling a mapping from gestural and color input to an output of color and motion.

In this project we seek to design a medium in a particular area rather than a device to solve a particular problem. We take some general human needs and desires — the desire to communicate in public and in private, and the need to play a part in shaping, owning and occupying shared spaces — as constants for the purposes of this paper. When left in public spaces, Trace can provide a communication medium between people sharing these spaces; messages and signals spanning the continuum between secret and shared codes can be located in these devices. Our initial implementations demonstrate that algorithms and designs can be found that encourage the exploration and storage of information in such devices.

RELATED WORK

A number of projects have sought to embed digital information into shared spaces. Of the explorations in the field of augmented reality, the research most similar to our work might be *An Augmented Reality System of Linked Audio* by Rozier et al [5],who placed audio into a space using the global position system. However, all projects to our knowledge use centralized databases of information. Where distributed tangible interface components are present, these act as a 'digital pointer' metaphor where objects merely point to centralized digital data rather than actually storing the data. While centralization clearly simplifies the implementation of these schemes, it is important to note that there are significant social and artistic ramifications in distribution of information in centralized systems.

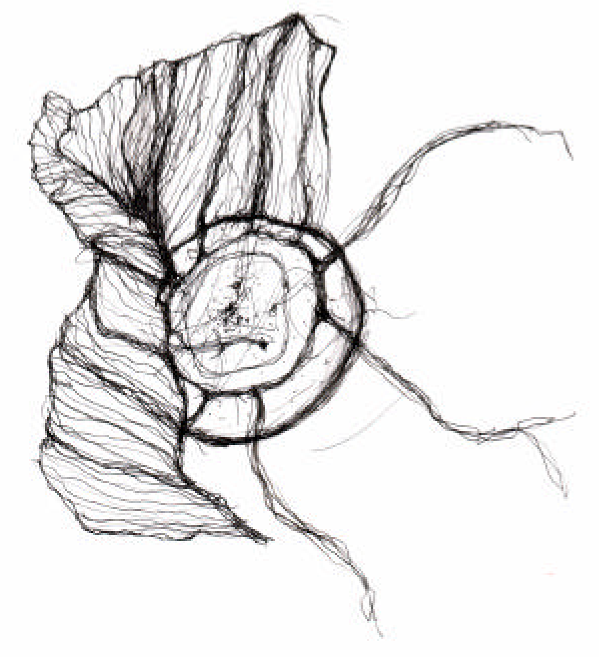

Figure 1. Sketch of proposed device

Another related field is underground public art. *Sticker Shock: Artists' Stickers*, an exhibition at Institute for Contemporary Art [3] displayed the ‘underground subculture’ of stickers art which had previously been posted and read in public urban areas. These projects are fuelled by desires to *encode*, *occupy* and *examine* shared spaces. They, perhaps more than other projects, support our assumptions that a new medium can be forged out of these basic needs.

Figure 2. As the device captures a more precise gesture / color mapping, the device's color display becomes more stable and coherent

Much work has been done on the kinds of technologies that underpin this project. Specifically we draw on, but go beyond, hardware discussed in Benbasat and Paradiso's *Compact, Configurable Inertial Gesture Recognition*[1]. It is also important to note that only recently has embedding both computation and output into the gesture recognition device become either possible in practice or discussed in the literature. These explorations have typically been fuelled either by artistic goals[5] or by tele-medicine applications. Relationships and applications to digital artistic practices and health sciences are also mentioned in this paper.

IMPLEMENTATION

Inertial measurement components, which sense either acceleration or angular rate, are being embedded into common user interface devices more frequently as their cost continues to drop. These devices hold a number of advantages over other sensing technologies: they directly measure important parameters for human interfaces and can easily be embedded into mobile platforms.

Our proposed system consists of a compact inertial measurement unit [1], a light-weight atomic gesture analysis algorithm, a photo-diode based color capture system, and an LED based color display.

The Design

The LED based display is made of a copper mesh and flexible silicone encasement to enable bending, folding, twisting and manipulation of the display. The display can be molded to most surfaces. Small surface-mount LEDs are fixed to the copper mesh to create a full-color diffuse display. An optically clear silicone spherical object is attached to the display via flexible wires woven between the spherical object and the center of one side of the display. Color and gesture information are captured by three photo diodes and a compact inertial measurement unit [1] that are placed inside the clear spherical object.

The design of Trace is inspired by a biological system metaphor. Principles behind biological adaptation are suited to the low computational complexity and to the high level of robustness required in unpredictable environments.

Embedded Algorithms

We propose building into these devices dynamically created *associative memories*. These memories are *associative* because they serve as mappings from a gestural space into a color space. Upon generating a gesture, our device responds with the associated, coordinated color display. These memories are *dynamic* because these associations can be learnt by the device. Color is sampled from the environment of the device and is recorded during the training of a gesture. It seems appropriate to call this stored knowledge a *memory* because it can be persistent, robust and recallable over timescales vastly longer than the length of time taken to learn the mapping.

Regardless of the benefits that such embedded learning may have over statically defined mappings, embedded learning provides a number of user interface problems. These problems provide specific constraints towards the design of our system.

The first problem consists of users conflating learning and recall. We could solve this problem by making a modal device and an explicit way of changing between our two modes — learning a gesture / color mapping and recalling a color sequence based on gesture. However, here we choose to have learning algorithms that can have their learning rates modulated by an external source. Thus, by tying an estimation of current motion energy to the rate at which our device learns, we can build a system that adapts to the repeated movements that are characteristic of training, but responds with little adaptation to the occasional interaction designed to recall what was previously there.

The second problem is of users being unsure if they have succeeded in actually embedding information into the device. We address this problem by using a learning algorithm that can provide feedback as to how well stabilized a memory is. Specifically, we display on the device an environment around the recalled color information. If this environment is smooth and uniform, then a user can know that the teaching process has been successful; however, if this display consists of a number of different colors that change incoherently, then the user can tell that their training of the device must continue.

The final problem that users of embedded learning systems face is finding stored information. We propose a solution based again on the coherence of the color display. By using this feedback, users can "go in search" of stored gestural patterns using the stability and the coherence of the color response to guide their search. Precision, therefore, is not important from an algorithmic perspective — and we hypothesize that our devices, once taught are capable, to some degree, of teaching users. Figure 2 shows a schematic of the display while training.

We argue that, in designing such a device, that the principles of *adaptive systems* (in the widest sense) are central to the problem: we seek devices that *change*, devices that *remember* (change back), devices that *couple timescales* (interaction, recall and termination). An extensive body of literature is concerned with these problems.

A full and self-contained description of the specifics of our algorithm is beyond the scope of this paper and we leave illustrative material supporting this explanation to our 'video figure'. We have built a specialized learning algorithm that is suited for embedding in a gesture responsive device and is capable of addressing these problems taken biologically-informed learning literature. This algorithm is based upon a robust associative learning algorithm, the *neural gas model*, modified to be better suited for learning and responding to time series input. This algorithm can learn distributions and mappings with little prior knowledge of either the content of an input (gesture, color) space or the topology of the space. This latter feature is critical to support the maintenance of multiple gestural memories and the efficient allocation of all-too-finite computational resources found on an embedded device.

APPLICATIONS

Although, as discussed in the introduction, we present this work as medium rather than device, a number of possible applications of this class of device present themselves. A first application concerns the construction of a shoe-based physical therapy system which cues the wearer to awkward movements. The example based learning that our system is capable of can be coupled to the physical therapy practice itself. While demonstrating the correct forms of actions the therapist could be storing the knowledge inside the device. We hypothesize that the rapid and exploratory nature of the device's feedback will further make it suitable for this task.

A second application is to be found in dance. While there are clearly potential for embedded gesture responsive devices in general in dance as a finished form, and clear attractions for embedded devices that can be taught as part of an artistic process, it is our belief that these devices can find a role in dance practice at a different level. Choreography is perhaps the most transient of all art forms, and the problems that this poses for the preservation and communication of choreographic knowledge have attracted considerable interest. Embedded devices that can capture, learn and communicate gesture may have a role to play in this effort.

ONGOING WORK

Each of the components of this project have been constructed and tested, albeit often isolated from each other. The next stages are therefore the construction of a complete prototype; the deployment in more controlled, semi-public spaces where the devices can be monitored and maintained; and the construction of a new version, ready for distribution into the public domain.

A number of physical design opportunities continue to present themselves. We have seen that the underlying algorithms allow considerable flexibility and generality in terms of input and output modalities. For example, we can consider devices with sound input and sound output with little change to the core learning algorithms. If sound acts as trigger for the stored associative memories is radically different than gesture: sound can be broadcast over a wide range whereas it is hard to perform a gesture to more than one device simultaneously. Embedded devices can also *create* sound far more easily than can create movement. This allows the creation and maintenance of dense forests of intercommunicating devices, chattering away at and in response to each other.

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