Issues in Implementing Augmented Cognition and Gamification on a Mobile Platform

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Abstract. There are two major trends in computing that will impact augmented cognition. The first is the shift in computing platform from the desktop to mobile computing (e.g., smartphone and tablet) because the user wants to be able to do computing tasks where ever they are. The second trend is the gamification of computer applications to keep the user engaged and motivated. Compared to a workstation, the mobile computing environment is a challenge because of limited computing power, storage capacity, internet connectivity and battery capacity. This paper discusses the issues involved in implementing augmented cognition activities on a mobile platform and the tradeoffs of gamifying augmented cognition activities. These issues are discussed in terms of two example mobile platform applications that implement internal and external sensors.

Keywords: mobile computing, augmented cognition, gamification, physiological sensors.

1 Introduction

There are two major trends in computing that will impact augmented cognition. The first is the shift in computing platform from the desktop to mobile computing (e.g., smartphone and tablet). "Mobile internet usage is predicted to overtake desktop usage as early as 2014."[1] Users enjoy the portability of mobile computing (e.g. smartphones and tablets). With 4G and Wi-Fi hot spots internet connectivity is almost ubiquitous. The second trend is gamification. Gamification is the incorporation of game elements into non-game applications to keep the user engaged and motivated.

1.1 Mobile Computing

With the availability of high speed wireless internet (e.g., 4G or Wi-Fi) and cloud computing the computing capacity of the mobile user has significantly increased. Organizations with traditional web services are becoming increasingly aware of the need to migrate or redesign their applications to the mobile computing platform. One of the primary concerns with the shift to mobile computing will be how to maintain and increase user productivity.

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1.2 Augmented Cognition

Maintaining and increasing user productivity, which is to increase task performance capacity, is a strategic goal of augmented cognition. This task performance capacity could be manifested by increasing the learning rate, increasing the ability to do a task, or maintaining continued task competence. In augmented cognition, increase task performance capacity is achieved by using physiological sensor feedback to adjust or modify the activity the user is performing.

To implement a real-time augmented cognition system on a workstation can be a challenge because of the streaming physiological sensor data that must be stored and processed while simultaneously running and modifying the application. Current mobile platforms in comparison are more limited in computing and storage capacity than the workstation and must also consider limited battery life. Regardless of these limitations of the mobile systems, computing power and storage increases seem to be following Moore's law [2]. Also, with the advent of higher wireless communication rates, both computing power and storage capacity could be off-loaded to the cloud. Preliminary research and methods developed now can be applied to future mobile devices with greater computing power, storage capacity, wireless speed and battery life.

Table 1. Mobile computing device sensors, physiological measures and potential cognitive measures

Sensors	Physiological Measure	Potential Cognitive Measure
Camera	Eyetracking : Gaze Position, Fixation Number, Fixation Duration, Repeat Fixations, Search Patterns, Pupil Size, Blink Rate, Blink Duration	Difficulty, Attention, Stress, Relaxation, Problem Solving, Successful Learner, Higher Level of Reading Skill [3] [4]
	Facial Recognition	Happiness, Sadness, Surprise, Anger, Disgust, and Fear [5]
Accelerometer, gyroscope, compass	Body Motion	Arousal [3]
Touch Screen	Pressures Applied to the Button	Stress, Certainty of Response, Cognitive Load [6], [7]
Microphone	Voice Characteristics	Depression [8]

At the core of augmented cognition research to increase task performance capacity is physiological sensor selection, data collection, data analysis, and then the modification of the activity guided by the analysis of the sensor data. Currently, mobile devices are equipped with a set of sensors that could be repurposed for augmented cognition (see Table 1). An eye-tracking application using the forward facing camera on an Android based tablet is described in this paper. Other sensors found on mobile devices are listed in Table 1 along with their potential cognitive measures that could be used with augmented cognition applications.

Almost all mobile devices have the option to have Bluetooth, Wi-Fi and 4G communication. Assuming Wi-Fi or 4G may be in use accessing cloud computing processing and data storage resources, Bluetooth would be the preferred interface approach for connecting sensors in close proximity. In this paper, an Android smart phone application is described to demonstrate how Bluetooth would be implemented on a mobile device to acquire sensor data.

1.3 Gamification

Gamification is a process of applying game elements to non-game applications to maintain a high level of user engagement and motivation to influence behavior.

Jane McGonigal identified four game traits: goals, rules, feedback, and voluntary participation [9] (p. 21). Werbach and Hunter [10] (p. 77-82) proposed a large list of game elements broken down into three levels of elements: dynamics, mechanics and components. Reeves and Read [11] identified the ten ingredients or game elements of great games (Table 2). Game elements place demands on computing, data storage, and wireless connectivity. Table 2 used Reeves and Read's list and is not exhaustive, but provides linkages between game elements and the resources that could be needed. Note that all resources (i.e., computing, storage, connectivity and sensors) reduce battery life. In the mobile environment, gamification has several benefits that must be weighed against the drawbacks.

Gamification Benefits

- A high level of user engagement and motivation.
- Gamification can be enhanced by tapping into the physiological sensors used in augmented cognition.
  - Sensor data can be used to direct real-time feedback to the user.
  - Adjustments to rewards and the difficulty of the activity can be based on the cognitive state derived from sensor data. Currently, gamification relies on the user actions or overall performance to adjust rewards and activity difficulty.

Table 2. "Ten Ingredients of Great Games" Reeves and Read [11] and resources used

	Ingredients (Game Elements)	Computing	Data Storage	Wireless Connectivity	Sensors
1	Self representation with avatars	To display of the avatar.	To store multiple avatars.		
2	Three-dimensional environments	To display the environment.	To store the environment.		
3	Narrative context		To store the narrative.		To adjust the challenge.
4	Feedback	To ascertain performance and provide feedback.	To record performance history.		To adjust feedback.
5	Reputations, ranks, and levels		To record reputations, ranks, and levels.	To display for other players	To adjust the rewards.
6	Marketplaces and economies		To store marketplace information.	To display for other players.	
7	Competition under rules that are explicit and enforced			To transfer information between competitors.	
8	Teams			To transfer information between collaborators.	
9	Parallel communication systems that can be easily configured			To provide communications between players.	
10	Time pressure.	To run the task at a rapid pace.			

Gamification Drawbacks

- Adding game elements could degrade the performance of the non-game activity being gamified. Sensor data could overwhelm limited computing, storage and connectivity resources. Battery life could also be significantly reduced. In some cases, to increase battery life, wireless connectivity to the cloud could be used to supplement or replace computing and data storage.
- Extensive testing may be required to fine tune the gamification of an activity. It is unclear which combination of game elements produces the best results and

individual differences may play a significant role in determining the optimum combination of game elements. Also, the combination of game elements may need to dynamically change with the individual's predisposition.

2 Examples of Sensors for Mobile Applications

2.1 Using the Front Facing Camera of a Mobile Device for Eye Tracking

Many smartphones and tablets have forward facing cameras (i.e., cameras that face the user) for video conferencing. Although these cameras have a lower resolution than the rear facing camera they are of sufficient quality to do eye-tracking. Although the pupil-center/corneal-reflection eye tracking technique using both the pupil location and a reflected glint from the eye is more accurate, the less accurate pupil-center only approach is possible with a mobile device.

The first step of locating the two pupils of the user's eyes begins with capturing and image of the user facing the display. The second step is to locate the face. The third step is to locate the eyes. The fourth step is to locate the pupils of both eyes. A calibration procedure is required for each user where the user looks at specific locations on the screen and the pupil location is recorded. Once that calibration information is available, an algorithm can be used to determine the rough location of the gaze of the user. The following gives more detail on the eye-tracking process using the camera image.

An Android tablet (Eee Pad Transformer TF101) was programmed based on the OpenCV class for face detection using JAVA as the programming language. "OpenCV (Open Source Computer Vision Library) is an open source computer vision and machine learning software library" [12]. A Local Binary Patterns (LBP) cascade classifier is used to do face detection. "LBP features are integer in contrast to Haar features, so both training and detection with LBP are several times faster than with Harr features." [13] Algorithm efficiency is critical with a mobile device since an efficient algorithm would increase the speed of computational and reduced power consumption.

To locate the eyes in the face a Harr cascade classifier is used. Image processing ". . . detectors based on these Haar-like features work well with 'blocky' features such as eyes, mouth, face, and hairline . . . " [14] (p. 510).

Locating the pupils is more complicated. There are many issues including eyelids, eyelashes, corneal reflections, shadows, and blinking. Having an algorithm to deal with all these factors is beyond the scope of this paper, but researchers have been working on these problems. Even with a less robust pupil detection method used, the pupil is difficult to locate and requires several image processing steps. Figure 1 shows the end result of the image processing steps below.

- Turn the color image containing the eye into gray scale.
- Eliminate unnecessary pixels above the eye area.
- Histogram Equalization to increase black and white contrast to make the black pupil the dominant in terms of pixel intensity.

- Invert pixel intensity to make the black pupil white.
- Use erosion to "eat away" the distracting white areas.
- Threshold the picture into binary to make the image only black and white.
- Take the center of the bounding box of the contour as the center of the pupil.

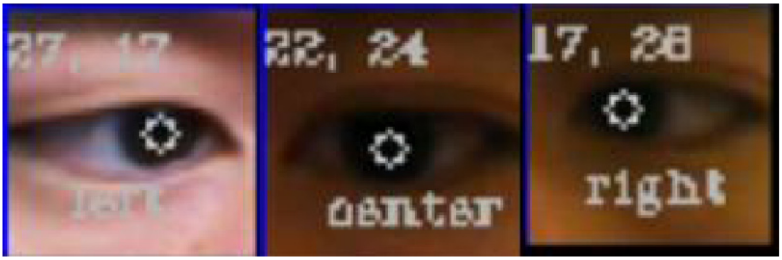

Fig. 1. The location of the pupil looking left, center and right

The horizontal location of the pupil can be determined more accurately than the vertical location because there is a clear image change when moving the eyes from left to right on the display than up and down on the display. Figure 2 shows the face location, eye location and pupil location. Note that the pupil position on the left eye is not centered since the pupil detection algorithm used becomes less accurate when there is a corneal reflection on the pupil.

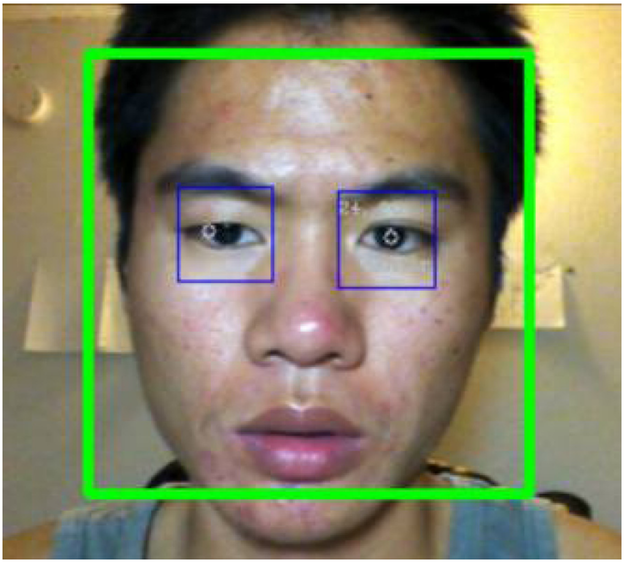

Fig. 2. Eyes and face are detected. Note that the pupil position on the left eye is not centered since the algorithm used becomes inaccurate when there is a corneal reflection on pupil.

With the pupil location accurately determined calibration of the user can be performed. Both calibration data and the data from the real-time location of the two pupils can be used to determine where the user is looking at on the screen.

2.2 A Smartphone Application Using External Sensors Connected via Bluetooth

At times, it is desirable to have sensors that are not located on the device or different sensors are needed. Described is a simple application demonstrating the potential of an external sensor connected via Bluetooth. The system consists of an Android smartphone and Bluetooth system with several sensors (see Figure 3). Bluetooth communication allows the Bluetooth system to be placed up to several feet away from the smartphone. A mathematics game for children written in JAVA based on comparing fractions is implemented on the smartphone and light sensors connected through Bluetooth are used to indicate the relationship between the two fractions (i.e., larger, smaller or equal).

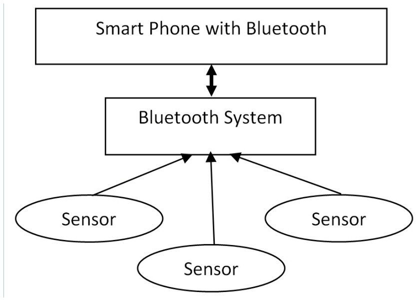

Fig. 3. The system consists of an Android smartphone, Bluetooth link and several sensors

An Arduino UNO with Bluetooth (i.e., the Bluetooth system) is connected to three Arduino Pro Minis connected to light sensors (see Figure 4). Inter-Integrated Circuit (I2C), a two wire protocol, is used to allow the Arduino devices to communicate with each other.

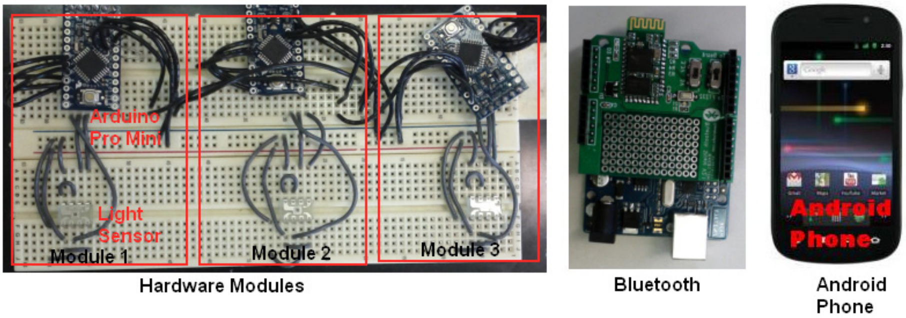

Fig. 4. Complete system with sensor hardware, processor with Bluetooth and Android phone

The power is turned on for the Bluetooth system with sensors then the smartphone is set to search for Bluetooth devices. Once the devices are linked the fraction game can begin. The fraction game shows two fractions and asked the player to determine if the first fraction is larger, smaller or equal to the bottom fraction (see Figure 5). The player blocks the appropriate light sensor in response to the displayed question.

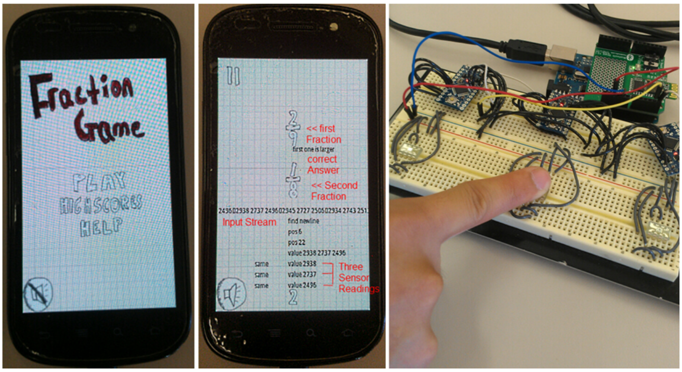

Fig. 5. Left - Prototype display. Center - Prototype display with fractions and debugging information. Right - The player is blocking the light sensor to indicate that the fraction values are equal.

This system uses the I2C communications protocol allowing any number of sensors and indicators (i.e. LED, lights, motors) can be connected to this system. The I2C communications protocol is also used by the Plug-n-Play Wearable Computing Framework [15] which has sensors and indicators integrated into clothing.

The Arduino UNO with Bluetooth also has processing and storage capacity. This processing and storage capacity can be used to reduce mobile device resource requirements.

Bluetooth Issues

There are several versions of Bluetooth. The current version 4.0 is becoming more common on current mobile computing devices. Bluetooth version 2.0 has a "... theoretical maximum useful data transfer rate of approximately 2.1 Megabits per second (Mbps)." [16] Bluetooth version 3.0 + HS has a data transfer speed of up to 24 Mbit/s over a collocated 802.11 link. Bluetooth version 4.0 includes Classic Bluetooth (version 1 & 2), Bluetooth high speed (version 3) and Bluetooth low energy protocols. A Bluetooth version 4 device that implements only the low energy protocol may not be compatible with earlier Bluetooth versions.

Besides version, Bluetooth uses a variety of different protocol stacks to exchange data. What this means is that both mobile and sensor device must support the same protocol stack. For example, the Apple iPhone 4 with Bluetooth v4.0 supports these protocols: A2DP, AVRCP, HFP, HID, MAP, PAN, and PBAP.

3 Discussion

Using internal or external sensors on mobile devices, although not trivial as demonstrated with eye-tracking, can be done. These sensors systems can be used to support augmented cognition on mobile devices. Doing augmented cognition on a mobile device has many challenges. These challenges relate primarily to limited computing power, storage capacity, internet connectivity and battery capacity. Gamification has the benefit of motivating the user and improving performance by appropriately inserting game elements into the mobile application, but gamification consumes resources that can exacerbate the mobile device challenges. The mobile computing platform is a fundamentally different computing experience than the workstation experience since mobile computing can occur in almost any environment. Understanding this fundamental difference is why research on mobile computing devices implementing augmented cognition and gamification, though challenging, needs to move forward.

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