Methodological Issues of Real Time Data Acquisition from Multiple Sources of Physiological Data

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Abstract

Safe and effective use of monitoring, scheduling, and action-guidance technologies is often dependent upon human operator agency. The cognitive ability of the human operator to control the environment varies depending on the individual’s affective and physiological state as well as on situation-dependent temporal and contextual factors. Clearly, there is a need for real-time assessment of cognitive load in order to increase operator effectiveness through adaptive filtering of information. In order to begin assessment of how to flexibly augment human operator capabilities in real time, a study to determine the best practices for intercepting and synchronizing biosensor information from operators engaged in visual search tasks was performed.

1. Introduction

Cognitive capability varies among individuals as well as for the same individual under different contexts and given different psychological and physiological states. Individual knowledge and experience levels impact performance. The potential effectiveness of human agents responsible for management of critical events under time constraint implies increased cognitive load. Under constant-watch conditions over extended periods of time, the cumulative stress of action or inaction leads to attention deficits, which may be detrimental to overall goals.

Given the nature of the described circumstance, it is critical that assessment of cognitive load be done in real-time and that an ideal operator support environment would include adaptive augmentation of the operator’s cognitive capabilities. The purpose of the described study was to determine best practices for using hardware and software designed to capture biosensor information indicative of operator physical and cognitive state. Types of physiological measures are summarized in Table 1 along with secondary measures, potential cognitive measures, equipment used and data specifications. The following discussion details the results of this effort.

2. Data Acquisition and Experimental Setup

The types of biometric data collected include: eye position tracking, pupil size, skin conductivity, peripheral temperature, relative blood flow and the pressure applied to a computer mouse. Test responses were also collected.

2.1. Eye tracking and pupil size

Applied Science Laboratories (ASL) Model 501 eye tracking mobile system was used to obtain gaze position and pupil size. The subject wore the head mounted tracking system. While sitting in front of the display screen, the subject’s chin rested in a chin rest to reduce head movement. Calibration of the subject’s eyes to a calibration chart shown on the screen was performed each time a subject began one of four test sets.

2.2. Custom biometric sensor system

A custom designed electrically isolated biometric sensor system was used to obtain skin conductivity, peripheral temperature, relative blood flow, and the
<table>
<thead>
<tr>
<th>Physiological Measures</th>
<th>Secondary Measures</th>
<th>Potential Cognitive Measures</th>
<th>Equipment Used</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Position Tracking</td>
<td>Gaze Position, Fixation Number, Fixation Duration, Repeat Fixations, Search Patterns</td>
<td>Difficulty, Attention, Stress, Relaxation, Successful Problem Solving, Successful Learner, During Problem Solving, Higher Level of Reading Skill [1]</td>
<td>ASL 501 Eye Tracker</td>
<td>8 bytes at 60 times per second</td>
</tr>
<tr>
<td>Pupil Size</td>
<td>Blink Rate, Blink Duration</td>
<td>Fatigue, Difficulty, Strong Emotion, Interest, Novelty, Mental Activity - Effort, Familiar Recall, Imagery, Abstract vs Concrete Words, Language, Processing, Affective Words, Shocking Photos, Positive / Negative Attitudes, Information Processing Speed [a]</td>
<td>Custom Biosensor</td>
<td>70 bytes at 13 times per second</td>
</tr>
<tr>
<td>Skin Conductivity</td>
<td>Tonic and Phasic Changes</td>
<td>Arousal [1]</td>
<td>Custom Biosensor</td>
<td>70 bytes at 13 times per second</td>
</tr>
<tr>
<td>Peripheral Temperature (Finger, Wrist and Ambient)</td>
<td>Heart Rate and Beat to Beat Heart Flow Change</td>
<td>Stress, Emotion Intensity [1]</td>
<td>Custom Biosensor</td>
<td>70 bytes at 13 times per second</td>
</tr>
<tr>
<td>Relative Blood Flow</td>
<td>Mose Pressure Sensors (Left/Right Buttons and Case)</td>
<td>Stress [3]</td>
<td>Custom Biosensor</td>
<td>70 bytes at 13 times per second</td>
</tr>
<tr>
<td>Survey Data (Question or Image Number, Responses and Time Stamp)</td>
<td>Response Time Taken, Correct/error Ratio, Cumulative Score</td>
<td>Difficulty</td>
<td>Custom Biosensor</td>
<td>16 to 24 bytes at fastest source (e.g., eye tracker is at 60 times per second)</td>
</tr>
</tbody>
</table>

A small amount of a conductive medical lubricant was applied to the palm of the participant's nondominant hand at points where pairs of electrodes were to be placed. Electrodes were arranged in a box pattern so that pairs of common electrodes were opposite each other. A wrist band which contained a temperature sensor was also placed around the wrist. A finger band with temperature and relative blood flow sensor was placed on the thumb (see Figure 1). The subject used a computer mouse equipped with pressure sensors with the dominant hand.

### 2.3. Computer hardware

A client-server computer configuration was used for the experiment. The client presented test scenes to each
Table 2.
Sequence of Tests for Control and Experimental Groups.

<table>
<thead>
<tr>
<th>Test #</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12 images (search/counting) 10 images (memory test) Self paced</td>
<td>12 images (search/counting) 10 images (memory test) Self paced</td>
</tr>
<tr>
<td>2</td>
<td>12 images (search/counting) 10 images (memory test) Self paced</td>
<td>12 images (search/counting) 10 images (memory test) Self paced</td>
</tr>
<tr>
<td>3</td>
<td>12 images (search/counting) 10 images (memory test) Self paced</td>
<td>12 images (search/counting) 10 images (memory test) Fixed Time</td>
</tr>
<tr>
<td>4</td>
<td>8 Question Test</td>
<td>8 Question Test</td>
</tr>
</tbody>
</table>

Figure 1. Biosensors placed on the nondominant hand of the subject.

Figure 2. Calibration image shown on the visual display.

2.4. Computer software

Software was written specifically for collection and synchronization of data capture and storage for this test application. The software, EventStream [4], ran on both the client and the server machines to present test scenes, capture participant responses, and synchronize this data with eye tracking and other biosensor data. Multiple samples per participant are captured in a single time-stamped file.

2.5. Pretest questionnaire

A pretest questionnaire was given to obtain basic demographic information from participants. More importantly, however, specific questions were asked regarding the normal hours of greatest alertness/fatigue, present levels of alertness/fatigue, and motivation for participating in the pilot study.

2.6. Tests

Subjects performed four tests (shown in Table 2). Each of the tests consisted of an initial calibration image (see Figure 2), instruction image, a set of 12 test images with one to six downwards pointing triangles (see Figure 3) and a set of 10 memory images and a final calibration image. The last test consisted of eight questions to be used in a future study.

For each of the first three tests, the subject was asked to count the number of downwards facing triangles. Of the set of 12 test images with one to six downwards pointing triangles, four images also contained upward pointing triangles (see Figure 4) and four images contained diagonal facing triangles (see Figure 5).
remaining four images had no distractors. (see Figure 3). Of the set of 12 test images, two images contained one downwards facing triangle, two images had two downward facing triangles, and two images had three downwards facing triangles with this pattern continuing up to six (see Table 2). Presentation of sets of test images was random. The set of test images covered a range of difficulty depending on the number of down-facing triangles and the type and number of distractors present in a scene.

For the set of 10 memory images, the participant was asked to determine whether or not a scene had been one of the just-viewed set of 12 test images. The subject indicated by number (i.e., -3, -2, -1, +1, +2, +3) the level of response certainty where “-3” meant definitely not seen before and “+3” meant definitely seen before. The set of 10 memory images contained five images previously seen in the set of 12 test images and five new images taken from the next test set. Each set of five images, previously seen and previously not seen, contain one through five downwards facing triangles. The set of ten memory images were presented in random order.

2.7. Post test questionnaire

A post test questionnaire was given to assess how the subject perceived their state of mind during the experiment. Each participant was asked to indicate level of alertness, interest and stress felt during the test, how difficult the test seemed, how challenging it was, and whether the duration of the test seemed about right or too long.

3. Issues

3.1. Eye tracking and pupil size

It is necessary to "calibrate" each participant accurately to specific target points covering the expanse of the screen image to be viewed. This enables capture of accurate tracking coordinates as the camera follows the participant's changing point of gaze. Properly calibrated, the eye tracking system is then able to capture a participant's pattern of fixations for a given scene. Calibration is done by locating stable, linked images of the participant's pupil and cornea for each of a set of pre-determined target points specified for the screen to be viewed. For these tests, we used nine points (Figure 2). Once the participant's pupil and cornea are clearly

Figure 3. Example of four downwards pointing triangles without distractors.

Figure 4. Three downwards pointing triangles with upwards pointing distractors.

Figure 5. One downwards pointing triangle with diagonal pointing distractors.
linked to each target point, gaze is synchronized with
the range of view and the participant's viewing pattern
can be tracked. Participants were re-calibrated just
prior to each of the four test series to confirm that
calibration coordinates were still correct for accurate
gaze tracking.

Accurate calibration is not always possible. It is
highly dependent on individual eye movement
characteristics. In some cases, it is difficult (or
impossible) to set accurate tracking coordinates. This
can occur for any number of reasons. For example, an
individual's eyes may be tired or irritated on a specific
occasion. Calibration time for an individual whose pupil
and corneal reflections were consistent over the nine test
locations, ranged from 2.5 to 4 minutes. Should the
subject not initially calibrate after three attempts or 10
minutes the experimenter made a note and proceeded
with the experiment.

It is critical to keep the calibration time to a minimum
since eye fatigue increases calibration time and
calibration delays increase eye fatigue. Also, the testing
period needs to be short since general fatigue though the
course of the experiment can affect eye measurements.

Longer calibration times occurred for some subjects
with contact lenses. In the first case, it was noticed that
an ill fitted contact which covered a portion of the pupil
produced a non-spherical pupil reflection which
increased the adjustment time for the operator. In the
second case, a contact lens that floats on the surface of
the eye continues to move after the eye has stopped
moving. Since this movement of the floating contact is
detected by the eye tracker, the operator must wait up to
two seconds after the eye has stopped moving for the
contact to stop moving. The delay caused by the floating
contact has a significant effect on the accuracy of
subsequent eye tracking data.

Proper calibration is also unique to the kind of eye
tracking equipment being used. While the "floating
contact lens" was problematic when using the portable
Model 501 eye tracker, we did not encounter this
problem when using the Model 504 desktop eye tracker.
On the other hand, using the Model 504 generated
extraneous corneal images due to light reflections from
the frames of participants who wore glasses with shiny
frames. This was not a problem with the portable Model
501 since the eye image can be adjusted so that the
frames of glasses are not within the view of the camera.

The Model 501 tracker has both eye tracking camera
and scene camera mounted on the subject’s head. When
eye tracking camera and scene camera position varies
relative to the display, as the Model 501 mobile eye
tracker, the subject’s head needs to be known in order to
determine the gaze position relative to calibration
locations on the display. This problem is better resolved
by the Model 504 desk model where both eye tracker
camera and scene camera are in a fixed position relative
to the display.

With the Model 501 mobile unit camera position is
critical since the camera is mounted close to the
subject’s eye. An adjustable sliding track is provided to
make this adjustment. Should the camera even move
slightly due to slippage, eye tracking may become unreliable.

3.2. Custom biometric sensor system

The sensors for the biometric sensor system take less
than three minutes to attach. The palm of the hand
should be wiped clean with alcohol to remove oils that
may interfere with the skin conductance sensors.

Subjects have a tendency to keep the instrumented
nondominant hand immobile during the entire
experiment, possibly because the hand feels somewhat
bound. The subject should be prompted to move that
hand between tests to reduce the chance of muscle
stiffness. Removal of the sensors is quick, but all of the
conductive lubricant should be removed with an alcohol
swab and the subject should be asked to wash their
hands subsequently since the conductive lubricant easily
transfers to clothes.

3.3. Computer hardware and software

The array of sensors and the tests produce large data
files even for short test periods. For example, in five
minutes, the eye tracker can produce 18,000 data packets
of 8 bytes. The data file size grows by about 0.5
megabytes per minute with eye tracker, biometric sensor
data, subject responses to the tests, and time stamp data.

Computer hardware problems quickly become
apparent given the speed and file size demands. Both
server and client computer require a large amount of
memory to store the test data and contain the
EventStream program. The speed of data transfer to a
file is not sufficient to maintain data collection integrity.
To solve the problem of transferring data, temporary
storage of the data in computer memory is necessary.
Upon test completion, the data is transferred to a disk file.

Data acquisition through the internet or serial ports require special consideration. A direct computer to computer internet connection would be preferred to reduce the effects on transmission speed that external data traffic may have.

An unbuffered serial port generates an interrupt each time a byte comes in. A software routine must collect this data and store it into a software buffer. It is likely that with data coming in from two serial ports excessive computer interrupt handling will cause data loss. To resolve this problem, it is recommended that hardware buffers of 64 to 128 bytes for serial port cards be used to prevent data loss especially when data is coming in from two different serial ports.

As mentioned before, data file size can become very large, easily 10 megabytes after a few tests. It is recommended that the computer system have a large hard drive and the capacity to archive all data on a CD. Also, a systematic labeling system which contains at least the subject and test number is recommended.

Although a software issue, the software data buffer size of the serial port should be matched to the length of the incoming data. Too small a software data buffer will cause excessive data collection slowing other programs running on the system such as the data collection program. Too large a buffer will result in the time stamp being the same for a large array of data since the time stamp is attached to the data upon acquisition from the software data buffer.

Data acquisition from multiple sources has the problem of aliasing when being combined into a single file. Aliasing is the result of the lack of synchronization between the sources which is common with discrete multisensor systems. Two sources of data coming in at nearly the same moment must be time stamped and stored. The question is, does each piece of data get its own time stamp, causing a list of data from multiple sources that do not appear to be synchronized or does all data being received get the same time stamp associated with a fixed sampling interval? For our purposes, the eye tracking data which is received at 60 times per second is used as the fixed sampling interval. All other data is stamped with the next available time stamp. This causes aliasing of the eye tracking data with all other sampled data, especially the biometric sensor data which is received at 13 samples per second. In our case, the 60 samples per second exceeds the minimum Nyquist sampling value for the biometric sensor so aliasing is minimized. It would be recommended that the highest possible fixed sampling interval be used, which should be a multiple of the highest sampled data source, to reduce the effects of aliasing with other data sources.

Another problem with data received from multiple sources is that data from different sources can be systematically delayed by a fraction of a second. For example, the serial transmission of 70 bytes of biometric sensor data at 9600 baud takes a little more than 7 milliseconds. This means that all data collected at the server computer is time stamped at least 7 milliseconds later. The biometric data is not seriously compromised by this delay since it is sampled at a rate 10 times slower than the systematic error, but other types of high speed input could be significantly affected.

With all new custom designed computer software there were some user interface difficulties which increased the testing time. In the future, a user interface that reduces setup time will be implemented minimizing subject fatigue caused by increased test time.

### 3.4. Test Construction

Tests should be constructed to minimize experiment time. Two reasons for this are that reduced test time reduces subject fatigue improving subsequent results. The second reason is that large data files are created when long test periods occur. With the exception of the data source with the highest sample output, all other data is over sampled and may need to be reduced if analyzed separately.

Self-paced tests are initially useful for establishing the normal range of test performance times. Once normal tests times are established, fixed time tests are preferred to self-paced tests since same time scale data sets are easily comparable. For example, when comparing blinks of a self-paced test from different people, each of the different time lengths require computing the blink rate during a test session versus the simpler comparison of blink count per test session. Also, when looking at the test performance of two people where multiple tests occurred, the fixed time of each test makes comparison simple. Self-paced data would require the experimenter to individually match each corresponding test.
3.5. Subjects

Subject treatment must meet the standards of the institution’s committee for human studies. The procedure of the experiment should be practiced ahead of time by the experimenters to expedite the completion of the experiment. Experiments are time consuming since subjects must be individually tested and two experimenters are required to manage the setup and execution of the experiment.

The preferred subject would be a person that does not require vision correction, is in general good health and does not have any difficulty with donning the apparatus. Subjects should be warned not to consume anything, unless necessary, that could affect biometric sensor readings like caffeine, alcohol or medication. Subjects should be allowed a resting period of at least three to five minutes before starting any test to stabilize their physiology.

3.6. Questionnaires

The pre-questionnaire and post questionnaire are invaluable to assessing the predisposition of the subject and the subject’s quality of experience during the experiment. In the future, the time of recent consumption of caffeine, alcohol or medication will be included in the prequestionnaire.

3.7. Data

Each of the four tests took approximately 1.5 to 4 minute. File size ranged from 650K bytes to 2.7M bytes. Each subject generates approximately 5M bytes of data after completing the four tests of the experiment.

There are a multitude of potential methods which can be used to analyze the data from descriptive statistics to the more cutting edge use of a support vector machine for pattern discrimination. Our laboratory is currently exploring several analysis options which will be reported in subsequent papers.

4. Discussion

The reliable collection of valid data for subsequent augmented cognition implementation is extremely resource intensive. Hardware design and setup, custom software testing and implementation, along with experimenter and subject time are the components of the data acquisition process.

This paper describes the current state of data acquisition for the Adaptive Multimodal Interaction (AMI) Laboratory, June 2002. Future improvement mentioned are expected to speed reliable and valid data acquisition.

5. References


6. Acknowledgments

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