Unobtrusive Computer Monitoring of Sensory-Motor Function

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Abstract —**Cognitive assessments and the early detection of dementia are an important component of clinical care. In this paper we describe an approach to continuous monitoring of sensory-motor function that corresponds to standard tests of cognitive function, but measured more frequently and in a natural home environment. The approach is based on monitoring human-computer interactions using standard devices such as keyboard and pointing devices.**

Keywords — **home health, aging, unobtrusive monitoring, computer interaction, cognitive assessment.**

I. INTRODUCTION

Many nations are facing severe economic and social problems associated with the health care needs of a rapidly growing elderly population [1]. With longer life expectancies come the increased possibility of cognitive decline and the resulting loss of independence. 10% of people over age 65 are afflicted with cognitive decline, increasing to 50% by age 85. Many require some level of assisted living, as even mild cognitive decline can result in a loss of independence and significantly reduced quality of life [2-4].

Maintaining independence is paramount to maintaining quality of life. With the advent of new medications, early detection and intervention allow the greatest opportunity for individuals to delay onset of dementia for elders and, with the help of their doctors and caregivers, to develop strategies for compensating and coping with deficiencies, thus allowing them to maintain independence. Ongoing cognitive monitoring would also enable detection of cognitive events due to medication effects, such as drug-drug interactions, adverse side effects, and missed dosages.

A. *Standard Cognitive Assessments*

In standard clinical practice, routine cognitive assessments are uncommon for screening purposes in advance of symptoms. In fact, screening for dementia or Alzheimer's disease is typically delayed until symptoms are advanced. In addition, follow-up monitoring after diagnosis occurs at infrequent intervals (often yearly, at best). Table 1 lists some standard cognitive tests that cover a spectrum of functions [5-7]. Although there is substantial overlap in the cognitive dimensions used in each of these tests, performance in these areas is predictive of both current and potentially future cognitive decline. The Finger Tap Test (highlighted in the table) is a motor task that has substantial predictive power. The test measures how quickly a patient is able to tap a pad or keyboard in a 10 second interval. The test is often performed on both the dominant and non-dominant hand. We have highlighted this task for our project because it is a simple motor task that likely corresponds with various computer interactions, such as typing speed and pointing device interactions.

Cognitive Domain	**Tests**
Attention & Concentration	WAIS-R Digit Span Crossing-off Test
Speed of Processing	Simple/Choice Reaction Time WAIS-R Digit Symbol **Finger Tap Test**
Memory	Letter-Number Sequencing CERAD Word List WMS-R Logical Memory CERAD Visual Figures Recall
Language	WRAT-R Verbal Fluency Boston Naming (CERAD)
Executive Function	Odd Man Out task
Spatial or Visual Perceptual	WAIS R Block Design

Table 1: Standard tests used to assess cognitive function for various domains of cognitive performance. The highlighted Finger Tap Test corresponds to the computer monitoring approach described in this paper.

B. *Background on the Finger Tap Test*

The Finger Tapping Test was originally developed as part of the Halstead Reitan Battery of neuropsychological tests. It is one of the most basic and frequently used measures of motor speed and motor control [8]. It has been shown to be a sensitive predictor of cognitive decline [9-10]. In addition to measuring direct motor performance, the Finger Tap Test

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measure is affected by levels of alertness, impaired ability to focus attention, or slowing of responses. A comparison of performance on dominant and non-dominant hands can be used as a measure of the integrity of brain function. Additionally, overall slow finger tap speeds have been shown to be associated with Alzheimer's disease [11], schizophrenia [12], and traumatic brain injury [13].

Several finger-tapping devices are in routine use for cognitive testing. The most commonly used device is a tapping lever mounted with a key driven mechanical counter. There are also electronic and software versions available in computer-based cognitive tests. However, as with paper-based tests, these are typically administered in a clinical setting, often after signs of cognitive decline are apparent, when opportunities for intervention or remediation are significantly diminished. Further, they compare subject performance at one point in time to norms for a similar population. In the approach to cognitive monitoring that we describe in this paper, we propose a method for continuous monitoring of sensory-motor interactions with routine computer use to observe performance trends and variability. This approach takes advantage of the growing use of computers by the elderly.

C. *Computer Use by the Elderly*

According to findings published in 2003 by Harris Interactive [14] 32% of adults 65 and over are online. Additionally, adults 65+ are participating at faster rates, and that trend is expected to continue. In a recent Pew Internet and American Life Survey [15], 93% of seniors with Internet access have sent or received email, and seniors are more inclined to go online and check email on any given day than any other group of Internet users. Second only to email in popularity is researching information, especially health topics, and over a third of this population goes online to play games.

This level of computer activity in elders provides an opportunity for the measurement of sensory-motor interactions on a regular basis. In this paper we discuss an approach for measuring keyboard and pointing device interactions as an indicator of sensory-motor / cognitive performance.

II. DATA COLLECTION

To test our approach to monitoring sensory-motor interactions with elders, we recruited 9 elderly residents (mean age 79.5 ± 8.5) in a senior residential facility, where they used computers in the facility's library setting with four computers. Each of these computers had a trackball as a pointing device. We installed monitoring software on each of the four computers. The software recorded all keyboard entries, all trackball movements, and time spent in each computer application. For each event, the date, time and interval since last event was recorded.

The monitoring software was completely invisible to the elderly users of the computers. It started up by itself whenever there was a system reboot, and it uploaded the data to a secure server at Oregon Health & Science University each night at approximately 2:00 am, after determining that the system was free. Also, the monitoring software did not display any new windows, thus minimizing the chance of being turned off by a user.

The subjects were also given a battery of standard cognitive tests as part of the experiment. Based on their performance on Logical Memory II (delayed paragraph recall) the subjects were classified as normal (n=6) or MCI (mild cognitive impairment) (n=3).

III. ANALYSIS OF KEYBOARD INTERACTIONS

The goal of our work with an analysis of individuals' interaction with a keyboard on a day-to-day basis was to approximate the Finger Tap Test and the assessments represented with that test. Most computer users spend a great deal of time in word processing activities, such as email and document creation. Our objective in this work is to develop a measure of typing speed that is as reliable and consistent as possible. Clearly, under normal conditions, a computer user's typing speed will vary, depending on distractions, pausing when thinking of what to type, etc. In addition, people have varying typing abilities. Our exploration of measures to minimize this unwanted variability has led us to considering speed of typing during consistent periods of word processing and considering repeated keyboard events, such as logins.

An advantage of measuring login speed is that it is relatively free of contamination with context, distractions, language abilities, and typing abilities. Additionally, it is a short, easily-distinguishable repeated event that can be quickly selected from the large data files and averaged for mean estimates.

Figure 1 shows median inter-stroke intervals on logins for three of the subjects in our experiment. A larger inter-stroke interval is indicative of slower typing speed. We took the median value for login speed for each day, as the most robust measure of typing speed. Another important variable to consider in predicting cognitive problems is the variability in scores over time. In many cognitive monitoring tests we have performed, we have noticed that subjects with cognitive impairment have both lower scores on average, and also a much higher variability from day to day. In Figure 1, the lower two lines represent two cognitively healthy elders whose data on average is both low (faster typing speed) and stable from day to day. The top line is data from a subject with mild cognitive impairment.

The speed of typing for this person is highly variable from day-to-day and on average slower. Thus, the simple measure of login speed seems to be a promising indicator of cognitive performance.

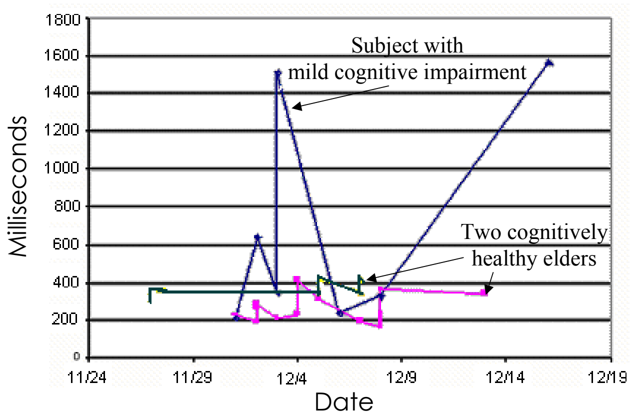

Figure 1: Plot of median interstroke interval on login for 3 elderly subjects. The lower 2 lines show cognitively healthy subjects with low variability in their typing speed. The line on top is a plot of a subject with mild cognitive impairment (slower typing – i.e., greater interstroke interval, and greater variability in performance).

IV. ANALYSIS OF POINTING DEVICE INTERACTIONS

Another source of useful sensory-motor information involves interactions with pointing devices such as mouse or trackball. These interactions require the user to execute visually-guided movements. Our initial investigations are focused on the idea that the trajectories executed by the user may provide useful information regarding his or her cognitive processes.

In a similar manner to the keyboard-based interactions, the context of the interaction may greatly influence the trajectories and their interpretations. To sidestep the issue for the purpose of this paper, we focused our analysis on the interactions with pointing devices during the game of FreeCell. In this situation, it is possible to assess the context of the moves from the state of the game.

The basic data consist of point-to-point movements, where each move is represented by samples in time corresponding to the locations of the cursor on the computer screen. An example of a trajectory of a move is shown in Figure 2.

A key question involves how best to represent the trajectories in terms of a small number of parameters that would capture the performance of the subjects in a way that would most likely relate to their cognitive ability. This representation should, of course, be rotation and scale invariant and capture characteristics such as tremor and inaccurate aiming. In previous research, we and others [16] used techniques such as the number of "straight" segments, but those parameterizations depend on the scale of measurement and the definition of "straight." For example, a segment could be deemed to be straight if the maximum perpendicular distance is less than a given threshold.

In order to avoid the necessity of making such assumptions, we developed several metrics that are relatively independent of scale. The first of these is the ratio of the lengths of the trajectory to the distance between the endpoints. This metric measures the deviation from a single straight line. A straight line, however, is not necessarily the most efficient way for a human to move from one point to another because of the kinematic and dynamic constraints of human articulated mechanisms of the arm and hand.

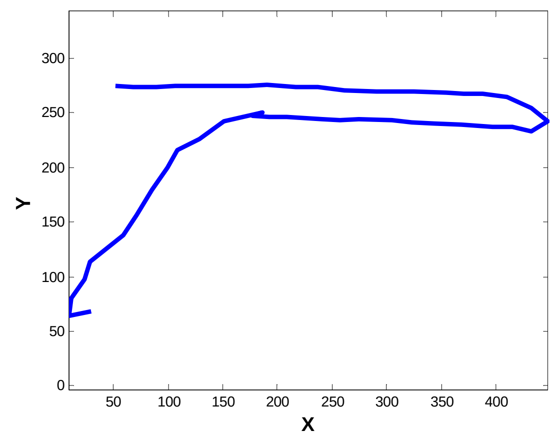

Figure 2. A typical trackball movement during a game of FreeCell.

For that reason we developed a novel approach borrowed from machine vision called Fourier Descriptors [17]. Intuitively, Fourier Descriptors capture the trajectory in terms of harmonic functions that capture the various rates of deviation from the straight line. Formally, if the trajectory is described in terms of the coordinates in a complex plane, then

$$u(t) = x(t) + jy(t) \tag{1}$$

where j designates an imaginary dimension. Given this formulation, it is natural to express the trajectory in terms of its harmonic components using the Fourier representation

$$u(t) = \frac{1}{N}\sum_{k=0}^{N-1} a(k)\exp\left(\frac{j2\pi kt}{N}\right) \tag{2}$$

where the coefficients $a(k)$ are computed

$$a(k) = \sum_{k=0}^{N-1} u(t)\exp\left(\frac{-j2\pi kt}{N}\right) \tag{3}$$

The coefficient corresponding to the k=0 represents the location of the trajectory, and thus we ignore it for the purpose of this analysis. The remaining coefficients represent the trajectory in terms of components that vary with higher frequencies.

For the purpose of the analysis of the pointing device, trajectories were sampled and interpolated so that the sample spacing was approximately 10 pixels along its length. In order to avoid discontinuities, the paths were extended by their mirror images in each coordinate.

A graph of the first 10 components for the trajectory in Figure 2 is shown in Figure 3. It is interesting to note that the global characteristics of each move are represented by the "low frequency" components, while the small deviation, e.g., corresponding to tremor, would be characterized by the higher components. This can be seen by band-limiting the Fourier Descriptor representation to the low-frequency components and reconstructing the move.

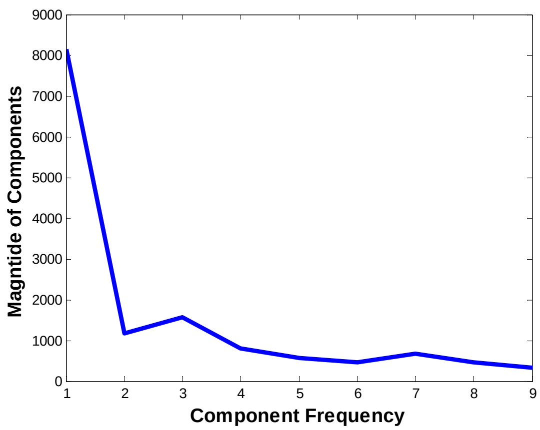

Figure 3: First 9 Fourier Descriptors

For the purpose of the trajectory characterization, we used the total power in the trajectory and in different sub-bands.

V. Conclusions

We have presented a new method for continuous in-home monitoring of sensory-motor function, as a potential indicator of cognitive performance. We analyzed both keyboard and pointing device interactions to develop robust measures of naturally occurring motor effects. The advantage of this approach over conventional cognitive tests is that it is inexpensive and continuous. With trend detection, we are able to use subjects as their own controls and depend less on referring to data from population norms. This is a promising approach for the early detection of cognitive problems, as well as for monitoring cognitive effects of medication management.

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