Using Pen-Based Computing in Technology for Health

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Abstract. Advanced technologies open more possibilities to interact with computers in various different ways. Especially, pen-based computing provides people with an intuitive way to use a computer. In this paper, we present our research on developing pen-based neuropsychological assessment tools for older adults with cognitive impairment. First, we explain the background information and motivation to design technology for the aging population. Then, we describe our two applications: ClockReader and TrailMaker. We then discuss technological affordances to support medical assessment tasks and conclude that pen-based computing could contribute to increase the efficacy of a computer-based assessment tool.

Keywords: Pen-based Computing, Computerized Cognitive Assessments, Senior-Friendly Design, Health-Related Technology, Sketch Recognition, Human-Centered Design, Usability Clock Drawing Test, Trail Making Test.

1 Introduction

Recent advances in pattern recognition technologies and human-computer interaction push more possibilities of designing applications in pen-based computing [1]. Tablet PCs, a representative platform in pen-based computing, provide users with a natural way to interact with a computer [2]. Similar to using a pencil to write on paper, one can use a stylus to draw on top of the tablet screen. Pen-based interaction is easily accessible to people with little or no experience with computers [3]. They can leverage their previous writing experience without having to learn how to manipulate the keyboard and mouse. Despite this potential, there are only few applications utilize the unique features of pen-based interaction [1].

To leverage the opportunities of pen-based input for medical applications, we have investigated developing computerized neuropsychological assessment tools. The current practice of neurological examinations is still administered the same way as it was decades ago. Patients are asked to perform a series of assessment tasks such as diagram drawing, memory testing, or puzzle solving activities by using a pencil on a given sheet of paper. Medical practitioners such as neuropsychologists or neurologists would then spend hours analyzing and scoring the tests. The process is long and tedious. Furthermore, different administrators of the test may have different scoring criteria. By making a computer-based test, we can reduce the tedious efforts of human scoring and facilitate a consistent scoring practice and analysis [4].

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Furthermore, the system would provide a closer doctor-patient relationship, connecting the two more easily through telemedicine. The overarching purposes of our approach are (1) to investigate how pen-based computing technologies can play a critical role in enhancing our knowledge and understanding of the brain-behavior relationship caused by aging-related cognitive impairment; (2) to empower medical practitioners to make evidence-based decision-making; and ultimately (3) to enable transformative research in the field of neurological assessment.

In this paper, we first provide background knowledge, an overview of technology use for seniors, one of the most common diseases in the aging population, and the current use of pen-based computing in healthcare. Then, we describe the purposes of the two application developments: ClockReader and TrailMaker. Lastly, we conclude by discussing the potential of psychometric analysis with respect to pen-based computing in neuropsychological assessment.

2 Related Work

2.1 Gerontechnology

Technology has influenced the quality of our everyday lives. People have connected to one another through the Internet, mobile phones, and virtual reality systems. At the same time, the senior population has been dramatically increasing. However, studies on the design, development, and use of technology have been mostly limited to young adults, particularly aged 20-40 years old [5]. We see a need for guidelines and studies that consider the aging population when designing technology. Physical and cognitive decline of the elders require different methodologies and design considerations.

With the strong need for research on aging and technology, gerontechnology has been established as an interdisciplinary field [6]. Gerontechnology combines gerontology and technology. This approach comes from a deep understanding of the underlying characteristics of aging human beings in their social context to develop technological innovations [6]. How can technology improve the quality of everyday lives for older adults? Fisk et al. have investigated designing technology based on cognitive aging principles [5]. They argue that cognitive aging is a critical issue to be addressed. Because aging can influence task performance in several areas, technology designers should be truly aware of older adults' abilities.

Much research in gerontechnology involves health-related applications. Aiding memory, monitoring health conditions, and supporting communications with distant family members are exemplary applications to support the quality of life for older adults [6]. Indeed, health is one of the most demanding issues for older adults. In order to prevent the progression of cognitive dysfunction, older adults are encouraged to take several screening tests. In the process of developing a computerized screening tool, senior-friendly computer interaction principles should be considered in the initial stage of technology development.

2.2 Alzheimer's Disease and Related Disorders (ADRD)

A prominent public health challenge caused by aging is cognitive dysfunction, which is poor mental functioning associated with confusion, forgetfulness, and difficulty in concentrating. Alzheimer's disease is one of the representative disorders. Unlike other diseases that are physically visible, early detection of cognitive dysfunction is rarely easy. In fact, fewer than 50% of Alzheimer's cases are diagnosed, and only approximately 25% are treated, even after several years of progressive cognitive decline [7]. Unfortunately, there are no known treatments for curing Alzheimer's disease [8]. Therefore, in order to properly treat cognitive dysfunction, it is critical to identify the early process of cognitive impairment.

In 2003, the Alzheimer's Foundation of America established the third Tuesday of November as National Memory Screening Day [9]. The goal of this initiation is to promote the early detection of Alzheimer's disease and related disorders (ADRD) and to encourage timely intervention and treatment of them. It is often difficult to detect cognitive impairment because (1) it is hard to differentiate cognitive impairment from normal cognitive degeneration due to aging; (2) there is limited opportunity for seniors to meet with specialists, such as neurologists or neuropsychologists, unless they have serious observable symptoms; and (3) the disease is usually progressively developed, so it is hard to capture the appropriate moment, which normally requires continuous monitoring through everyday activities.

Therefore, our society needs a novel, quick-and-easy screening system for cognitive impairment, as well as preventing the onset of aging cognition. The significant amount of research currently being conducted regarding phone- or computer-based dementia screening indicates that dementia screening should no longer be limited to clinicians' offices [7].

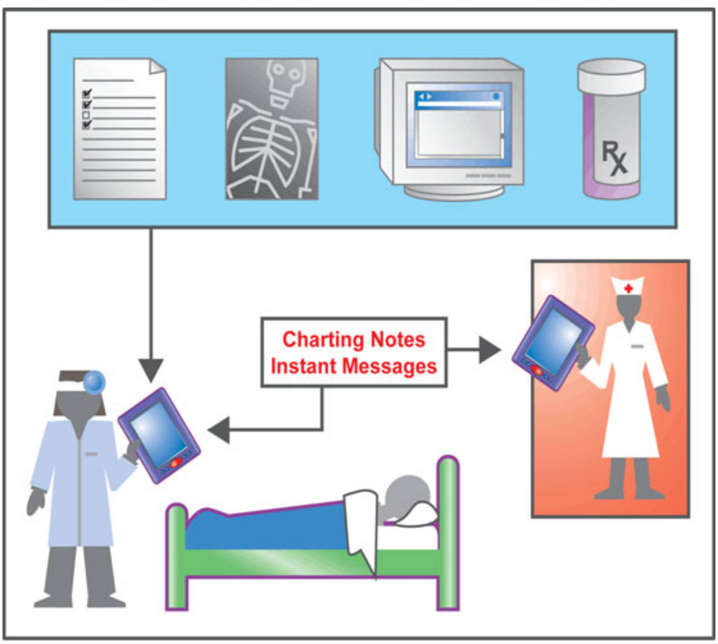

Fig. 1. Diagram showing a doctor and nurse stay connected with the Tablet PC (adopted by Microsoft White Paper 2004 [10])

2.3 The Use of the Tablet PC in Health Care

According to the white paper on the *Business Case for Tablet PC* (2004), Microsoft emphasizes that when implementing the electronic medical record system, the Tablet PC would provide great value to healthcare workers with flexible access to patient information at the point of care in the hospital, and outside of the office, such as home care [10]. They pointed out that the electronic data in the Tablet PC can help reduce medical errors, increase doctor and nurse efficiency, and shorten the duration of patient visits. Figure 1 below shows a visualization of how the Tablet PC's unique form factor and the capability to write directly on the screen would provide more effective ways to facilitate communication in patient care. We also see the potential of the use of tablets in increasing the effectiveness of administrative workflow in complex hospital environments.

3 Applications in Pen-Based Computing

The purpose of our proposed applications in pen-based computing is to develop a quick-and-easy neuropsychological assessment tool for people with age-related cognitive impairment. Based on the literature review on identification of neuropsychological issues, we decided to develop the Clock Drawing Test (CDT) and the Trail Making Test (TMT) into computerized systems.

The applications are developed in C# programming language using "Microsoft Windows XP Tablet PC Edition Software Development Kit 1.7" and "Microsoft Visual Studio 2010." For the first release, the running environment of the program is limited to the Microsoft Windows platform, equivalent to or better than "Windows 2000 Service Pack 4" with "Microsoft.Net Framework 3.5 Service Pack 1." Every coordinate of the cusps and intersections of each stroke (even if it represents a character) are stored in the memory. In this section, we introduce two applications we have developed: the ClockReader and the TrailMaker Systems.

3.1 The Clock Drawing Test (CDT)

Prior to explaining the ClockReader System, what it is and how it is used, let's first explain the Clock Drawing Test (CDT). The CDT has been used for decades as a neuropsychological screening test [11, 12]. The CDT is usually part of the 7-Minute Screen, CAMCOG (Cambridge Cognitive Examination), and Spatial-Quantitative Battery in the Boston Diagnostic Aphasia Examination [13]. The CDT focuses on visual-spatial, constructional, and higher-order cognitive abilities, including executive aspects [12]. The CDT accesses human cognitive domains from comprehension, planning, visual memory, visual-spatial ability, motor programming and execution, abstraction, concentration, and response inhibition [11, 14, 15]. The major value for clinicians to conduct this test is that the CDT can capture cognitive dysfunction and provide concrete visual references of the patients.

The Clock Drawing Test (CDT) is one of the simplest, but most commonly used screening tools to detect cognitive impairment in seniors [11]. By simply asking people to draw a clock, it easily identifies people with dementia [13]. Figure 2 shows three different clock drawings from three patients [11]. The drawings clearly show degradation of the patient's cognition. A salient pattern is that patient could not use the space of the clock evenly. Clock drawings from people with cognitive impairment frequently show missing or extra numbers, or misplaced clock hands [11, 14].

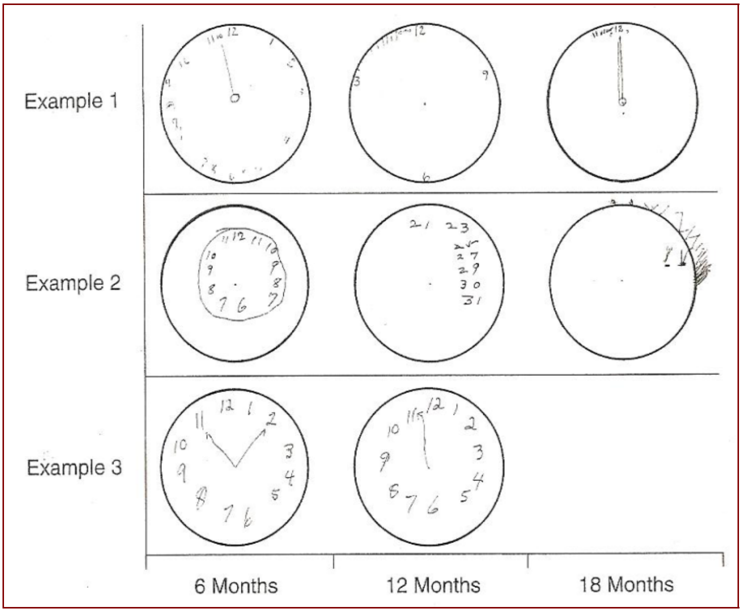

Fig. 2. Three examples of clock drawings showing deterioration in dementia [11]

There are two variations of the test. One test asks the patients to draw a clock in a pre-drawn circle. This test focuses on the spatial distribution of the numbers, as well as the hands of the clock. The other test does not provide any pre-drawn circle. Patients are asked to draw a freehand circle on the paper. In some cases, patients are shown a picture of a clock drawing and are asked to copy that onto the paper. Patients are then asked to set different times for the clock, such as 11:10, 1:45 or 3:00 [11-13].

Numerous scoring systems are also available. Each of the scoring systems places differing emphases on visual-spatial, executive, quantitative, and qualitative issues [15]. Qualitative errors can provide more valuable information to understand different patterns of drawings due to the progression of dementia. For example, clocks drawn by patients with right frontal lesions show difficulty with number position. Clocks drawn by patients with left frontal damage show reversal of the minute and hour hand proportion [11]. Overall, the CDT is accepted as the ideal cognitive screening test, based on widespread clinical use [13]. Among published studies, the CDT achieves a mean sensitivity of 85% and a specificity of 85% [16, 17].

3.2 The ClockReader System

The purpose of the ClockReader System is to enable patients to take the Clock Drawing Test without the presence of a human evaluator. The system consists of three main components: data collection, sketch recognition, and data analysis. First, the system would record and recognize a patient's freehand drawing and collect the data. Then, based on the scoring criteria, the system would automatically analyze the drawing and report the score.

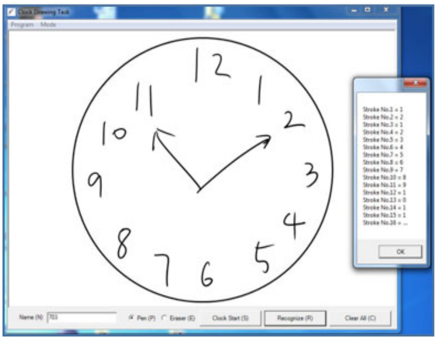

Fig. 3. A Screen shot of the ClockReader System

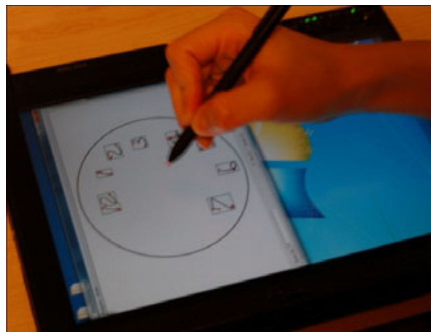

Fig. 4. A picture showing how a patient uses the ClockReader System

Figure 3 shows a screen shot of our ClockReader system. The small window on the right shows the results of the digit recognition. Figure 4 shows a patient drawing a clock in the ClockReader system using a stylus on a tablet PC.

Let us briefly explain how the ClockReader recognizes handwriting. The ClockReader system is developed based on the Microsoft Tablet PC recognizer. The current Tablet PC SDK provides character recognition through the stroke level. However, rather than capturing each character based on a stroke, we modified it to capture the character level. Some Arabic numbers include more than two strokes For example, the number 4 is often written with two strokes. Therefore, the recognition process of the ClockReader System starts from setting a rectangular area per character, passing the data from the rectangular area to the Microsoft SDK handwriting recognition engine, and then finally saving the recognized results as a string. We also implemented a simple machine learning technique, a Context-Bounded Refinement Filter Algorithm, to improve the recognizer accuracy [4]. After the recognition process, the program then analyzes the relative position between each number and scores the complete clock drawing with the given criteria.

3.3 The Trail Making Test (TMT)

The Trail Making Test (TMT) is also frequently used to assess psychomotor speed, complex attention, and executive functions for people with cognitive impairment [12]. Historically part of the Army Individual Test of General Ability, the Trail Making

Test assesses general intelligence [18]. There are two different versions of the TMT: Part A and Part B. Both versions ask a subject to connect the dots of 25 consecutive targets on a sheet of paper. In Part A, the TMT includes only numbers as a target (such as 1, 2, to 25). Part B of the TMT includes both numbers and letters as targets (such as from 1, A; 2, B; to 13, L). Due to the complexity of the test, Part B of the TMT is more frequently used to access prefrontal dysfunction, which is observable by performance in flexible shift response sets [19]. The goal of the TMT is to measure how quickly the subject completes the test without errors. Usually, people with aphasia or detectable neglect show latency in completing TMT Part B [18].

3.4 The TrailMaker System

The TrailMaker System enables patients to take the Trail Making "Part B" Test without the presence of a human evaluator. Compared to the ClockReader System, the TrailMaker System includes a very simple scoring criterion, such as whether the dots are connected with the appropriate sequences (such as 1-A-2-B-3-C). First, when a user draws a line to connect each big circle dot, the evaluation algorithm initiates to detect the correctness. Then, based on the amount of correctness, the system would automatically analyze the connecting-the-dots result and report the score. The system provides the user with an erase-all function to delete all the lines they drew and restart the test. Thus, users can restart as many times as they like. However, the number of trials will be recorded together with the total scoring results and the completion time. Figure 5 below shows a screen shot of our TrailMaker system.

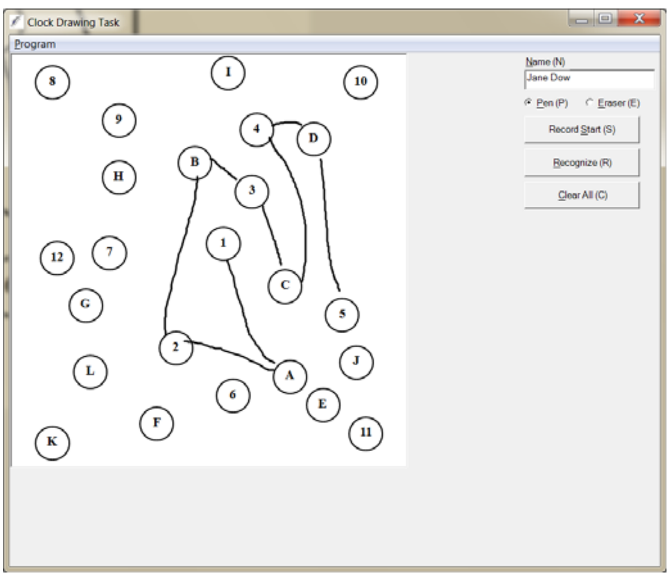

Fig. 5. A Screen Shot of the TrailMaker System

4 Technological Affordances

Researchers advocate that pen-based computing can be the next generation of new interaction techniques for seniors [1]. A recent study shows that older adults have better interaction with a touch screen and digital pen compared to indirect manipulation devices, such as the mouse and keyboard [3]. Unlike WIMP (Windows, Icons, Menus, and Pointers)-based interaction, a pen can provide the seniors with more direct interaction. Users can put the stylus on the tablet screen and see the cursor directly below it. This is contrast to using a relative pointing device such as a mouse, which requires hand-eye coordination (moving the mouse on the desktop while looking at the screen to find the cursor location).

To provide the affordance of a paper-and-pen environment for patients, we implemented the system as a Tablet PC application. Our preliminary usability test results show that using a stylus on the surface of a Tablet PC is similar in form to using a pen on a piece of paper [20]. Many users commented that it is actually easier to draw on the Tablet PC than on a piece of paper. We found that even a 91-year-old grandfather who had never used a computer before succeeded in completing the Clock Drawing Test using our system without any difficulties. However, we believe that the opportunities to leverage pen input can go beyond simple recognition and its physical affordance.

The research focus should shift from what and how to recognize to how to interpret the recognized data for meaningful use. The pen-input enables us to measure more diverse visual spatial factors of human handwriting. More importantly, the computerized screening system will make it possible to gather behavioral data, such as airtime, tendency to pause, patterns of exerting pressure, and sequence of the drawing. Thus, based on our work, we propose applications in pen-based computing to perform in-depth psychometric analysis in terms of **Processing Capturing** and **Airtime Capturing**.

Instead of analyzing the drawing as a final output, Kaplan argues that the process-oriented approach can be the best way to understand a patient's performance, and she later names it as the Boston Process Approach, quantifying the process as a natural evolutionary step [15]. **Processing Capturing** can be useful in interpreting qualitative information rather than simply reporting result scores. For example, the ClockReader provides information to capture a patient's drawing process and records the drawing sequence; therefore, a clinician can play back and interpret the planning strategy of a patient (e.g., 12, 3, 6, 9, or, 1, 2, 3, 4). This provides clinicians with new and useful information that was not previously available from paper-and-pencil tests. Furthermore, it can also be used to make a differential diagnosis on the sub-types of Alzheimer's disease and related disorders by categorizing the different error types.

Both systems collect two types of time capture records: (1) total completion time and (2) airtime. The total completion type is always a good standard measurement in any kind of testing. The **Airtime Capturing** can provide important data for clinicians to understand a patient's cognition. For example, the TrailMaker captures "airtime," which is the time when the patient is not drawing – the time of pausing. When patients connect the dots, at a certain point, they may hesitate to connect, perhaps due to memory problems. None of the existing criteria for the paper-based Trail Making Test take this factor into consideration. However, airtime could be a useful indicator of abnormal and unstable cognition. The airtime graph from a patient can provide time-related patterns of the patient's drawing task. That information can show critical moments when the patient spent time thinking before performing executive behaviors.

5 Conclusion and Future Directions

As the senior population increases, more dementia screening and prevention support will be needed for patients and medical practitioners. In this paper, we discussed two pen-based computing applications to support neuropsychological assessment, especially for seniors with cognitive impairment. For future work, we will first add several modules to enhance the systems. Then, we plan to deploy our systems in community centers or clinics to for longitudinal study. Ultimately, we expect to contribute to the efficacy of a computer-based cognitive screening test by leveraging the potential of pen-based computing. We believe that technology can offer more effective and efficient cognitive impairment screening. Furthermore, we see the potential of extending this research in building neuropsychological assessment systems to identify the early detection of children with developmental disorders.

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