
Sketch-Based Screening for Cognitive Impairment Detection: A Human Centered Approach

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Abstract

Early detection of cognitive impairment can prevent or delay the progress of cognitive dysfunction. In the field of neurology, the Clock Drawing Test (CDT) is one of the most popular instruments for detecting cognitive impairment in the elderly. In this paper, we present our preliminary study in developing the ClockReader System, a computerized sketch-based screening tool, based on the human centered design approach. The ultimate goal of the ClockReader Project is to develop an automated recording and analysis of the Clock Drawing Test. We developed two different versions of the ClockReader system. One version is written in C# running on Tablet PC and the other version is MATLAB using image processing to recognize characters. In order to understand the feasibility of the computerized CDT, we are conducting a usability comparison study of computerized CDT running on Tablet PC vs. Pen-and-Paper based CDT.

Keywords

Clock Drawing Test, Sketch recognition, Human Centered Design, Usability, Patient Centered Design

ACM Classification Keywords

H5.m. Information interfaces and presentation

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Introduction

The elderly population has been dramatically increasing. A prominent public health challenge caused by aging is cognitive dysfunction, which is poor mental functioning associated with confusion, forgetfulness, and difficulty 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. Therefore, in order to properly treat cognitive dysfunction, it is critical to identify the early process of cognitive impairment. [2, 3]

The Clock Drawing Test (CDT) is one of the simplest, but most commonly used screening tools to detect cognitive impairment in the elderly. Our collaborators at Emory Alzheimer's Disease Research Center recently developed and validated a screening test capable of identifying individuals with mild cognitive impairment (MCI) and undiagnosed dementia with a sensitivity of 89% and a specificity of 90%, with a positive predictive value of 95% [3]. The screening test combines a brief cognitive screening instrument (Mini-Cog) with a functional scale (Functional Activities Questionnaire; FAQ). The CDT is the main parts of Mini-Cog together with the 3-item recall task [3].

Current practice of the CDT is administered with traditional analog media. Patients are asked to draw a clock by using a pencil on a given sheet of paper. After then clinicians such as neuropsychologists or neurologists would need to spend hours analyzing and scoring the tests. The process is long and tedious.

Furthermore, different administrators of the test may have different scoring criteria. To reduce the tedious efforts of human scoring, and to facilitate a consistent scoring practice and analysis, we develop a computerized system to conduct this screening process. Our ClockReader project investigates the automated recording and analysis of the Clock Drawing Test. Our design and development process follows the human centered design methodologies. Specifically, we take a patient-centered approach in our system development. For example, who are they? How will they interact with the system? What are the differences between using the computerized system and the traditional paper-and-pencil method? In order to determine what might be the best platform for the ClockReader System, we have developed two different sketching recognition systems: (1) Tablet PC using C# and (2) Imaging processing using MATLAB to recognize characters. By conducting formative usability testing, we will understand our users better, decide on the best interface for the computerized Clock Drawing Test, and develop design implementation for making better systems, such as feedback design or handling recognition errors.

Understanding Users

When we design and develop a system, especially in clinical settings, there are always challenging factors. One challenge in developing the ClockReader System is that we should take into consideration two different target users. Our main users are patients who need to take the Clock Drawing Test, and clinicians who administer the test and examine the results. Figure 1 shows the diagram of the two different users of the system. As designers, our expectations in system usage considerations for patients and clinical staff are

different. From a patient’s perspective, the goal is to offer the affordance of a paper-and-pen environment. Using a stylus on the surface of a Tablet PC is similar in form to using a pen on a piece of paper. From a clinician’s perspective, the goal is to offer a well-organized data collection tool, as well as an automated analysis of the results. With a computerized system, doctors or clinical staff may gain easier access and more accurate information about the progress of patients’ cognitive impairment. The computerized clock-drawing tests could be performed frequently without requiring the presence of a test administer. Another benefit of a computerized system is to provide a consistent yet customizable scoring for a more general analysis with high inter-rater reliability. Unlike the simple interface designed for patients, the interface for doctors should involve data representation and information visualization to meet a wide variety of needs.

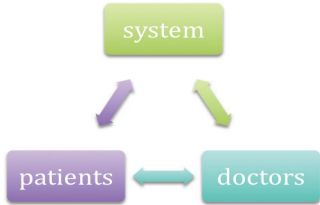


figure 1. Interaction diagram of the ClockReader System

ClockReader System: Computerized Clock Drawing Test

The purpose of the ClockReader System is to allow patients to take the Clock Drawing Test without the presence of a human evaluator. The system consists of three main components: (1) data collection, (2) sketch recognition, and (3) data analysis. First, the system

should record and recognize a patient’s freehand drawing data. Then based on the scoring criteria, the system should automatically analyze the drawing and report the score. For our initial implementation, we adopt the grading system proposed by Joshua Shua-Haim [1]. As shown in Table 1, Clock Drawing Task Evaluation consists of three different criteria: (1) numbers, (2) depiction of time, and (3) center. Please see the Table 1 for more detailed information about the evaluation criteria. Several example results (no dementia or Alzheimer disease) of the Clock Drawing Test are shown in Figure 2.

Table 1. Clock Drawing Task (adapted from Freedman et al., 1994)

Clock Drawing Task Evaluation Criteria	
Numbers	
1.	Only numbers 1 – 12 are present (without adding extra numbers or omitting any)
2.	Only Arabic numbers are used (no spelling, e.g., “one, two”, no roman numerals)
3.	Numbers are in the correct order (regardless of how many numbers there are)
4.	Numbers are drawn without rotating the paper
5.	Numbers are in the correct position (fairly close to their quadrants & within the pre-drawn circle)
6.	Numbers are all inside the circle
Depiction of Time	
7.	Two hands are present (can be wedges or straight lines; Only 2 are present)
8.	The hour target number is indicated (somehow indicated, either by hands, arrows, lines, etc)
9.	The minute target number is indicated (somehow indicated, either by hands, arrows, lines, etc)
10.	The hands are in correct proportion (if subject indicates which one is which after “finishing”, have them fix the proportion until they feel they are correct)
11.	There are no superfluous markings (extra numbers or errors on the clock that were corrected, but not completely erased, are not superfluous markings)
12.	The hands are relatively joined (within 12mm; this does not need to happen in the middle of the circle)
Center	
13.	A Center (of the pre-drawn circle) is present (drawn or inferred) at the joining of the hands

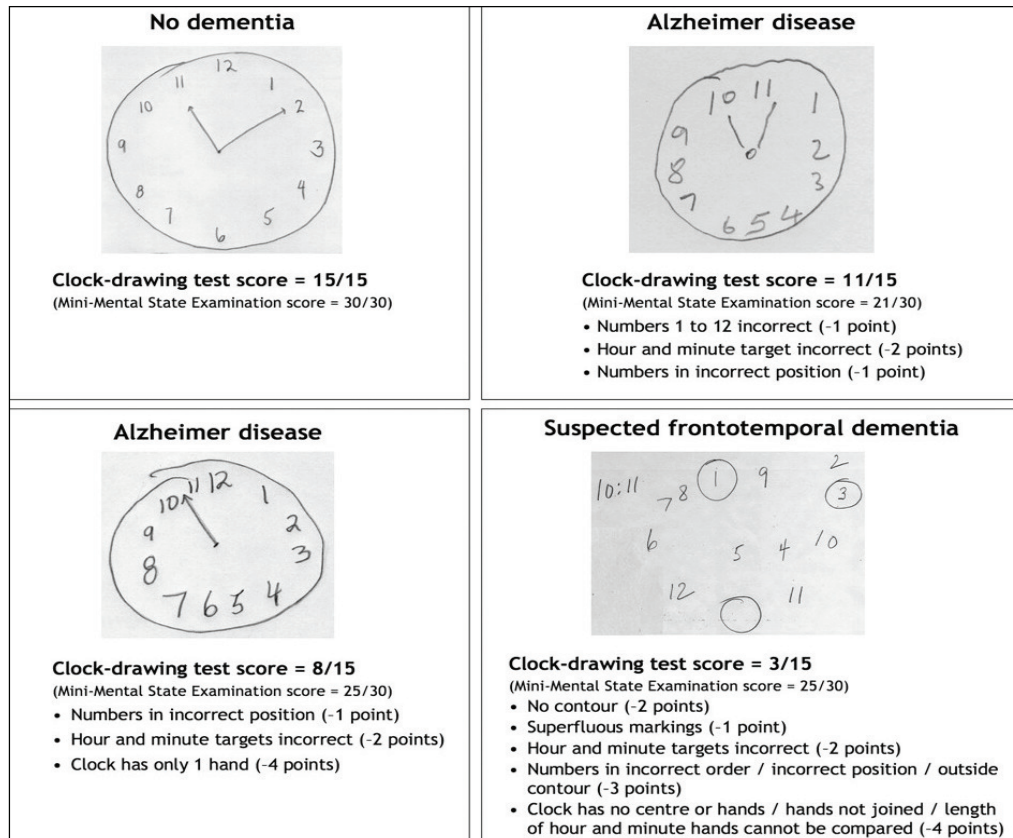


figure 2. Several example results of the Clock Drawing Test

We developed two different versions of the ClockReader system. One version is written in C# running on Tablet PC and the other version is written in MATLAB using image processing to recognize characters.

The version 1 of the ClockReader system is developed in C# programming language and is supported by

"Microsoft Windows XP Tablet PC Edition Software Development Kit 1.7" and "Microsoft Visual Studio 2008." 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 cusps and intersections of each stroke (even if it represents a character) will be stored in the memory. Then the processor will capture a rectangle-shape dynamic recognition region for each stroke, except for two hands in the middle of the clock, and will recognize it to the best-matched character. After the recognition process, the program then analyzes the relative position between each number and scores it under the given criteria. Figure 3 shows a screen shot of our ClockReader system.

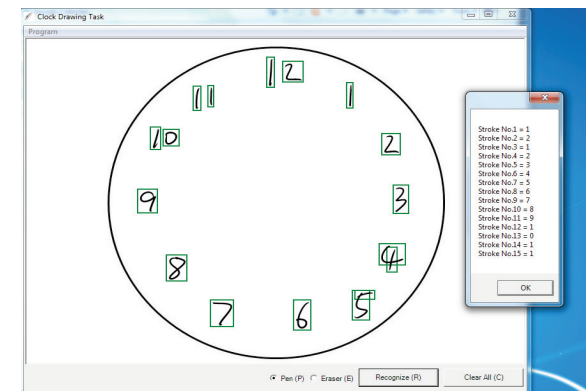


figure 3. A screen shot of the ClockReader system

Another approach using MATLAB is to first recognize handwritten digits and then recognize the clock hands. We utilized machine learning techniques to recognize

handwritten numbers. The algorithm first identifies where the blobs in the figure are and then if those blobs are digits, the system then processes and recognizes each digit. The development process consists of three stages: image pre-processing, digit recognition, and post processing.

At the stage 1, the image-pre-processing, we ran the MATLAB program with the scanned patients' clock face data. The MATLAB program we designed works with the following rules.

- Clean the image and polarize it by converting every bit to a '1' or '0' based on a threshold
- If the blobs have nearly similar maximal and minimal width, draw square bounding boxes and store each as an image.
- If the blobs have much greater length to negligible width, assuming that they are meant to depict the clock hands, skeletonize the hands, identify their elevation with respect to the horizontal, and store the hands as separate images
- Take the digit blobs and resize and clean them again.

Figure 4 left shows a scanned image of a bunch of random sized digits. Figure 4 right shows the results of the extraction program. With the successful extraction, the program cleans up the output and resizes each digit.

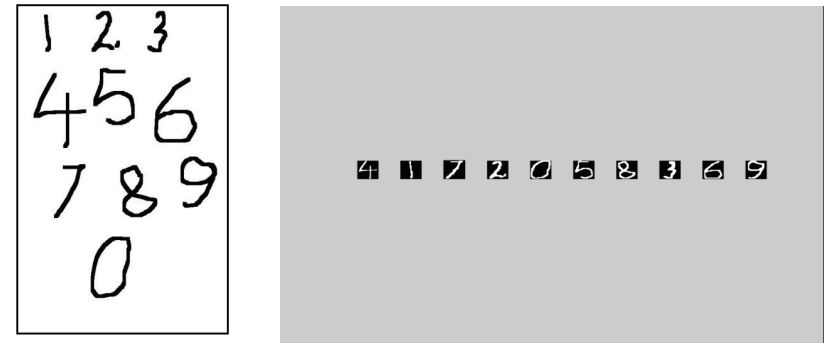


Figure 4. Left: scanned image, Right: Results after running extraction program

At the stage 2, we focused on digit recognition. After the first stage, we know the locations of the digits. So we need to classify the digits by using a machine learning algorithm. From our own experiment with machine learning techniques such as kNN (k Nearest Neighbor), neural networks, and decision trees on the dataset of 10000 digits, we found that the neural networks have the best performance. However, it is incredibly slow to train. Since we need to approximate speed and high accuracy, we have decided that kNN is the best choice. The kNN algorithm has a reasonable success rate (85 ~95%) if a large enough (10,000 instances) data set is used for comparison.

At the stage 3, the post processing, we will implement the other evaluation criteria and design the interface for the outputs of the screening test.

Usability Comparison Study

As mentioned before, we are conducting a usability comparison study. Our two different versions of the ClockReader System enable us to compare the

outcomes using computerized CDT test with the outcomes of Pen-and-Paper version of CDT. Having a Tablet PC version enables us to administer the CDT without requiring a clinician's presence. Another version using MATLAB enables us to process existing data set.

Even though tablet PCs can support handwritten recognition, elderly users may experience difficulties in drawing a clock. Drawing with a stylus can have a different feeling, and drawing on the surface of a tablet PC is also very different from the look and feel of drawing on a piece of paper. Because the drawing quality can influence the screening test results, we are concerned about the possibility of negative effects using Tablet PC. Therefore, we have decided to conduct a usability comparison study.

The study consists of three procedures: (1) the pre-questionnaire, (2) the use of two different ClockReader Systems, and (3) the post-interview. As for the pre-questionnaire, we will ask our users about their demographic information, such as age and gender. We will also ask them about their experience with computers to learn about their familiarity in using technology. More importantly, it is important for us to know their levels of cognitive dysfunction and their experience in using the computerized test.

People who have cognitive impairment can be slower than others when they need to learn and use a new system. After collecting background information, we will conduct a usability study. Our study design is a within-subject experiment. Individuals will use two different systems in the same study session. Then we will examine and compare their drawings. In order to avoid any carryover effect, we will conduct a study with two

different groups: one group will use Tablet PC with a stylus first, then Pen and Paper, and vice-versa. Users' main tasks are: (1) to write down ten numbers on the paper and on the Tablet PC screen; (2) to draw a sun or house; and (3) to draw a clock with hands for 11:10. We would also test the accuracy rate of the system's recognition of hand-written numbers with the currently available data from Emory Alzheimer's Disease Research Center (about 750 patients' drawing) by running the MATLAB program. In order to investigate the quality of drawings based on a different system, we would like to ask users to draw a sun or a house. We expect to learn how users interact with systems by observing the ways in which they draw (process), as well as their final drawings (product). After collecting their drawings, we will ask doctors to evaluate the clock drawing. We will then learn if there is any discrepancy between the drawings produced by the Tablet PC and the Paper-and-Pencil methods. We are now planning to conduct this usability test with the help of our collaborators at Emory University.

In this paper, we present our ClockReader System and our human centered design approach in developing the system. By attending this workshop, we hope to learn from fellow researchers' experiences in designing and developing a sketch recognition system. We also hope to share the results of our usability comparison study.

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About the Authors

Ellen Yi-Luen Do, Ph.D. is Associate Professor in the College of Architecture & College of Computing (School of Interactive Computing), Director of ACME Lab (A Creativity Machine Environment) and Health Space Futures (Healthcare Environment of the Future courses) at Health System Institute, at Georgia Institute of Technology. Professor Do is committed to building better design tools, from understanding the human intelligence involved in the design process and leading to the improvement of the interface with computers. Her research explores new modalities of communication and collaboration in the areas of design, computation, creativity and cognition, as well as the physical and virtual worlds that push the current boundaries of computing environments for design. Professor Do has conducted empirical studies of design drawing and constructed computer software to support creative design and analysis since the early 90s. Her research work includes the development of freehand sketching, gesture and physical objects as an intuitive interface to knowledge based design systems, diagram indexing and retrieval to case-based systems, design cognition and creativity, visual analysis tools, 3D sketching for annotation and performance simulation, and the area of visual and spatial reasoning in education. Her research

efforts have been supported by NASA Space Grant, NSF IIS, CILT and CCLI. Her papers have appeared in peer-reviewed international conferences and journals on computer-aided design in architecture and civil engineering, design studies, computer graphics, artificial intelligence, diagrammatic reasoning, knowledge-based systems, and the human computer interactions.

Hyungsin Kim is a Ph.D. Student in Human Centered Computing Program at School of Interactive Computing at Georgia Institute of Technology. She has been involved in designing and developing the ClockReader System which is an automated recording and analysis of the Clock Drawing Test. She has investigated designing sketch recognition systems based on the Human Centered Design approach. Her research focuses on developing sketch recognition systems for truly positive computer human interaction experiences. She is affiliated with Graphics Visualization and Usability Center (GVU) and Health Systems Institute (HSI) at Georgia Tech. She received a B.A. in Educational Technology from Ewha Women's University in Korea and M.A. in Learning Sciences from Northwestern University.

Anupam Guha is a graduate student pursuing Master of Science in Computer Science in the College of Computing and a Graduate Research Assistant working in the Health System Institute. Mr. Guha's primary area of study is Artificial Intelligence, and he is committed to understand human intelligence and cognition in all their different facets. Currently he is working on using Machine Learning algorithms to classify and recognize sketches, as well as identify extractable features of sketches, in order to build an interface for the Clock

Reader Test. This work has been inspired by his need to understand the treatment of sketches by neuro-atypical human agents and the conclusions one can draw from this about visual representations in reasoning and cognition. Aside from sketch recognition and diagrammatic reasoning, he is interested and working in areas like Narratology, Cognitive Science and Ambient AI.

Young Suk Cho is a Master Student in School of Computer Science at Georgia Institute of Technology. His primary interested area is Sketch and Character Recognition. As a graduate research assistant at Health Systems Institute, he has been involved in developing the ClockReader System. He has been in charge of developing the entire system including all necessary technical supports. He has implemented ClockReader System using Tablet PC SDK. To enhance participant's

hand-written recognition accuracy, he has adopted statistical analysis approach using various kinds of automatically collected data. (E.g. coordinates of end-points and intersected-points of each stroke, time interval records among each stroke, distance and angle between both clock hands, and etc.) In addition, he has put his effort on making the interface as simple as possible by reducing the number of required user inputs. This has resulted users to draw intuitively as they draw the same clock with a pen on a paper without additional learning process. He received a B.S. degree in Computer Science & Electronic Engineering from Handong Global University. He has work experience at Microsoft, Korea as a research intern in Program Management & Localization Testing area and also has experience in Program Management Administration area at Samsung Thales Company.