Certificate

We accept the work contained in the report titled Automated Scoring of the Mini-Cog Psychological Test"', written by Fatima AKhlaq AND Warda Azhar as a confirmation to the required standard for the partial fulfillment of the degree of Bachelor of Science in Computer Science.

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Abstract

Neuropsychological test are used to identify the presence of brain injuries or any associated function deficits. These tests evaluate functioning in a number of areas which include intelligence, attention, memory and language etc. Psychologists generally conduct these tests with a single person in an office environment that is free from distractions and disturbances. Drawing tasks have achieved a central location in neuropsychological assessment and contains information about the presence of neurological disorders. Drawing tests have been long used by doctors and researchers for early detection of psychological and neurological disorders. Mini-Cog test is a combination of the Recall test and Clock Drawing Test and the combined scoring of these tests identifies whether the person is demented or not. This test is divided into three different steps. Firstly, the patient is shown three different words. Furthermore, the patient has to draw digits on a piece of paper where a clock circle is already drawn. In the last phase, patient is asked to recall the words which were shown in the first step. This test is currently scored and interpreted manually which increases the work load of practitioners and also consumes a significant amount of time. The purpose of the proposed project is to develop an efficient, reliable and accurate diagnostic tool which will reduce the work load of psychologists by automatically screening the subjects using the Mini-Cog test. This study proposes the application of image analysis techniques to automatically score a subset of hand drawn clock images in the test. The developed system evaluated on a number of hand-drawn clocks realized promising results.

Acknowledgments

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Acronyms and Abbreviations

CDT	Clock Drawing Test
KNN	K Nearest Neighbor Classifier

Chapter 1

Introduction

1.1 Overview

Neuropsychological test have been long used to identify the presence of brain injuries or any associated function deficits. These tests evaluate functioning in a number of areas which include intelligence, executive functions, attention, memory and language etc. Psychologists generally conduct these tests with a single person in an office environment that is free from distractions and disturbances. Though neuro-imaging can be employed to localize the area of brain affected by any disorder, the neuropsychological tests demonstrate the mechanism of functioning of the affected part of the brain.

Neuropsychological batteries consist of multiple tests and common examples include the Human Figure Draw Test (HFDT), the House, Person, Tree Test (HPTT), the Bender-Gestalt Test (BGT), the Clock Drawing Test (CDT) and the Recall Test (RT). Among these tests, the focus of our study lies on the Clock Draw Test and the Recall Test. Both of these can be combined in a single test, generally known as the Mini-Cog test which is employed to detect dementia at an early stage. The test itself is a component of several widely used neuropsychological assessment batteries; the 7-Minute Screen, the Cambridge Cognitive Examination (CAMCOG), and the Spatial-Quantitative Battery in the Boston Diagnostic Aphasia Examination [8]. Poor performance on the test can be identified by a variety of errors like missing numbers, additional numbers, omitting left side of clock, indicating the time incorrectly or placing the numbers incorrectly with respect to position and order. The score is then used to directly map the specific cognitive impairments.

Dementia represents a common category of brain diseases. It has various symptoms of cognitive-decline such as forgetfulness. It has many causes like Alzheimer's disease(AD), Mild-Cognitive Impairment (MCI), front temporal dementia(FTD), dementia with Lewy bodies(DLB), and corticobasal degeneration, Parkinson and Vascular Dementia(VaD). AD and VaD are the most common causes of dementia. Patients suffering from this type of dementia mostly have difficulty in performing their everyday activites and suffer from memory loss. Such patients have problems in executive cognitive functioning. DLB is a special form of dementia in which subjects face problems in concentration and language skills and they have memory impairment [1].

The Mini-Cog clinical test, which is a combination of the CDT and RT, can be effectively used to detect dementia. The Clock drawing test part of the Mini-Cog test allows psychologists to discover different cognitive domains like cognitive function, memory, language comprehension, motor-programming, visual-spatial ability, and executive function etc [4]. Clock drawing test can also be used to show visual neglect. Example as shown in Figure 1.1 detects the visual neglect in stroke patient.

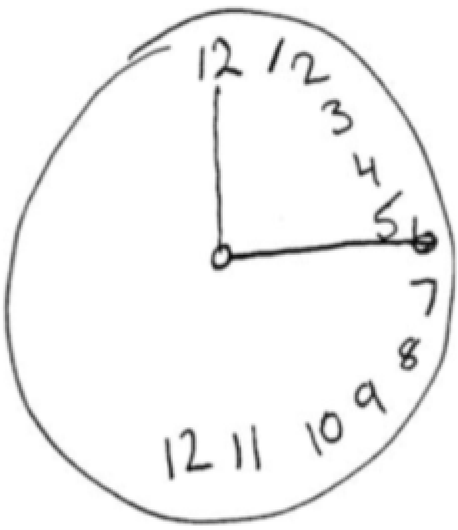


Figure 1.1: Clock drawing from a patient with hemi-spatial neglect [8]

It can be seen from Figure 1.1 that the subject forgets to draw digits on the left side of circle. Patient was able to express verbally that the clock had a left side but he was not able to draw it. This indicates that the person has the specific impairment in the right hemisphere of the brain [8]. Although CDT task seems to be easy but it is surely a complex task because it requires concentration from different brain region and from a wide range of neurological functions. Four different clock drawing images from patients by different types of dementia are shown in Figure 1.2.

Cognition is the set of mental abilities such as knowledge, attention, memory and decision making etc. Recall test is a test of memory in which patients are given to remember

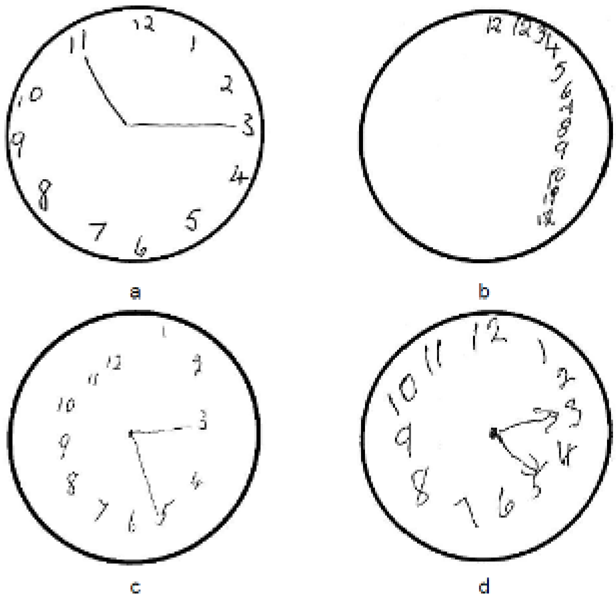


Figure 1.2: Clock drawings from patients with: (a) No dementia, (b) Alzheimer's disease, (c) Mild Dementia and (d) Vascular Dementia [1]

a list of words. Scoring of recall test helps to identify the memory performance of the patient. A number of studies have revealed that the Mini-Cog test which is combination of cognition and recall, is one of the most accurate tests to screen dementia. This test was compared to Mini Mental State Exam (MMSE) and Cognitive Abilities Screening Instrument (CASI) tests. The results revealed that this test had the highest sensitivity (99 percent) and requires less training. Therefore, it can be used by the less educated people effectively since CASI was influenced by people who were less educated [2].

This project proposes to aid the psychologists by automating the scoring and interpretation of Mini-Cog test. This test is currently scored and interpreted manually which increases the work load of practitioners and also consumes a significant amount of time. Therefore, we propose an automated system which will take scanned images of hand drawn clocks of patients and compute the errors using Freedman's Scoring system. This scoring criteria will help to check that whether the clock drawn is normal or abnormal. The results of the CDT and recall test will be combined so that the system can decide whether the person is demented or not.

1.2 Problem Description

The proposed project aims to provide an automated instant screening test of dementia in elderly through Mini-Cog evaluation. As discussed earlier, this test is a combination of two different neuropsychological screening tests i.e. Recall Test and Clock Draw Test (CDT).

This test is divided into three different steps. Firstly, the patient is asked to remember three words. Furthermore, the patient will have to draw digits on a piece of paper where circle is already drawn. After the digits are drawn, patient should be given a task to draw hands for minutes and hours to show a given time. In the last phase, patient is asked to recall the words which were shown in the first step. The psychologist then combines the results of RT and CDT which are calculated using the standard scoring system. By obtaining these results, a psychologist is able to tell that whether the patient is suffering from dementia or not. The psychologist is also able to interpret the stage of dementia of the patient who is labeled to have dementia according to the clock draw test. This process involves planning, requires time and efforts. Developing an automated version of the Mini-Cog test, will allow an instant screening of patients and only suspected cases can be referred to the clinical psychologists for an expert examination.

1.3 Project Objectives

While the Mini-Cog test has been long used by practitioners for early detection of dementia, very few efforts have been made to computerize this test to facilitate the experts. The objective of this project is to automate parts of the scoring of Mini-Cog test using image analysis and pattern classification techniques eventually assisting the practitioners in screening of patients.

1.4 Project Scope

The scope of this study is limited to digitized (offline) images of clock drawing only. There are different steps to carry out clock drawing task. Every task has its own significance to identify the specific portion of brain which is affected. Experts have listed three different ways of taking clock drawing test as mentioned in the following.

1. Free-hand CDT: The patient is asked to draw the face of the clock on a blank sheet of paper [1].

2. Pre-drawn CDT: The patient is given a sheet of paper with a pre-drawn circle of the clock and the subject is asked to complete the clock [1].

3. Examiner clock: The patient is provided with a clock drawing with all the numbers written on it and the subject is asked to set the hands to a specific time [1].

We will be working on pre-drawn clock drawing test. Free-hand CDT technique has been criticized since a poorly drawn circle can compromise the rest of the task and limit interpretation [7] while requiring the subject to only set the hands of the clock to a specific time does not reveal many important aspects of the visual spatial ability of the patient. The most commonly used time setting is 10 past 11 and has found to be the most sensitive to neuro-cognitive dysfunctions. Moreover, there are certain scoring criteria which are fairly simple to quantify manually for a trained person but becomes very difficult for a machine to quantify using computer algorithms. Among the different scoring attributes, to focus of our study lies on the presence or absence of digits in the clock and their correct positioning. The setting of clock arms to a sepcific time is beyond the scope of our study.

1.5 Organization of Document

This report is organized as follows. In the next chapter we present an overview of the significant contributions towards the automation of the Mini-Cog test. Chapter 3 presents the requirement specifications of our project followed by system design in Chapter 4. Chapter 5 details the system implementation while Chapter 6 summarizes the testing and evaluation of the system. Finally, we conclude the report in Chapterchap:conclusions.

Chapter 2

Literature Review

2.1 Introduction

Significant research work has been carried out on Clock Drawing test and different authors have proposed varying scoring criteria to detect dementia. In addition to manual analysis, few machine learning algorithms have also been proposed to develop to automate the CDT. As discussed earlier, Mini-cog test is a combination of two different neuropsychological screening tests i.e. Recall Test and Clock Draw Test (CDT).This test is divided into three different steps. Firstly, the patient is asked to remember three words. Furthermore, the patient has to draw digits on a piece of paper where circle is already drawn. After the digits are drawn, patient should be given a task to draw hands for minutes and hours to show a given time. This step is called CDT. In the last phase, patient is asked to recall the words which were shown in the first step. The psychologist then combines the results of RT and CDT which are calculated using the standard scoring system. By obtaining these results, a psychologist is able to tell that whether the patient is suffering from dementia or not.

2.2 Scoring Criteria For Mini-Cog test

The most important module of our system is to check automatically that whether the clock drawn represents a normal or an abnormal clock. Different scoring criteria have been proposed by different authors. Significant of these include Freedman et al. [5], Lessig et al. [9], Lin et al [10], Manos and Wu [11], Mendez et al [12], Rouleau et al [14], Tuokko et al. [18], Sunderland et al. [17], Watson et al. [19] and Wolf-Klein et al. [20]. Among these, the 30 point scoring criteria proposed by Tuokko et al. [18]is one of the most widely used systems. This test, however, is time consuming and is for free-hand drawing (clock circle is not pre-drawn) [7].

In one of the early studies on this problem, Shulman et al. [16] proposed an effective scoring criteria for CDT. The authors asked patients to draw digits on a pre-drawn circle and to set the time at three o'clock. The proposed scoring system used a 6-point scoring criteria where 1 depicted that person was not demented whereas 6 indicated that the person's mental abilities were highly impaired. Royall et al. [15] developed a 15 point scoring criteria for the CDT. The time setting that they have used is 45 past 11. Likewise, Watson et al. [19] proposed a scoring criteria between the range of 0 to 7. The technique focused on the number placement errors in the fourth-quadrant of the clock. The developed scoring system, however, has been questioned by many researchers.

In another study [20], the authors suggested a scoring criteria in which patients were asked to draw digits in the pre-drawn circle and were not asked to set a specific time. Therefore, this scoring criteria only focused on number placement and had a score range form 1-10, 1 being indicative of the fact that the person is severely impaired and 10 indicating normal condition.

Freedman et al. [5] mentioned two different scoring criteria, a 15 point scoring criteria for CDT in which the clock is not pre-drawn and a 13 point scoring criteria for a pre-drawn clock. Freedman scoring system is the most commonly used one (Table 2.1) and sub-set of this scoring system is also employed in our study [8].

Table 2.1: Freedman's scoring for CDT Scoring [8].

Numbers	
Criterion 1:	Only numbers 1 – 12 are present (without adding extra numbers or omitting any)
Criterion 2:	Numbers are in the correct order (regardless of how many numbers there are)
Criterion 3:	Numbers are in the correct position (fairly close to their quadrants and within the pre-drawn circle
Criterion 4:	Two hands are present (can be wedges or straight lines; Only 2 are present)
Depiction of time	
Criterion 5:	Two hands are present
Criterion 6:	The hour target number is indicated (somehow indicated, either by hands, arrows, lines, etc.)
Criterion 7:	The minute target number is indicated (somehow indicated, either by hands, arrows, lines, etc.)
Criterion 8:	The hands are in correct proportions (if the subject indicates which one is which after "finishing," have him/her fix the proportions until he/she feels they are correct).
Center	
Criterion 9:	A Center (of the pre-drawn circle) is present (drawn or inferred) at the joining of the hands.

Different timing criteria are used in CDT. In some scoring criteria, patients have to set one specific time where as some authors do not consider any time settings. The most commonly used time settings which are mentioned by Freedman include '10 past 11', '20 past 8' and, '3 O'clock'. The most sensitive time setting to neuro-cognitive dysfunctions is '10 past 11' [7].

2.3 Automated CDT

Image analysis and pattern classification techniques have also been employed to automate some aspects of the CDT. In a well-known study [6], authors employ a set of spatial and temporal features to segment the CDT drawings into digits and clock hands using Support Vector Machine (SVM). The proposed algorithm is applied on two data sets. The first set includes 65 drawings made by healthy people and the second set includes 100 drawings made by dementia patients. Authors demonstrate the superiority of the proposed method in segmenting the components of CDT drawings over other methods.

In another study [1], authors employ a series of image processing steps (Figure 2.1) followed by a number of supervised machine learning methods for implementing clock drawing test. These include decision trees, neural networks, cascade classification, random forests, support vector machine and KNN. The system successfully discriminates between normal and abnormal cases with an accuracy of around 89%.

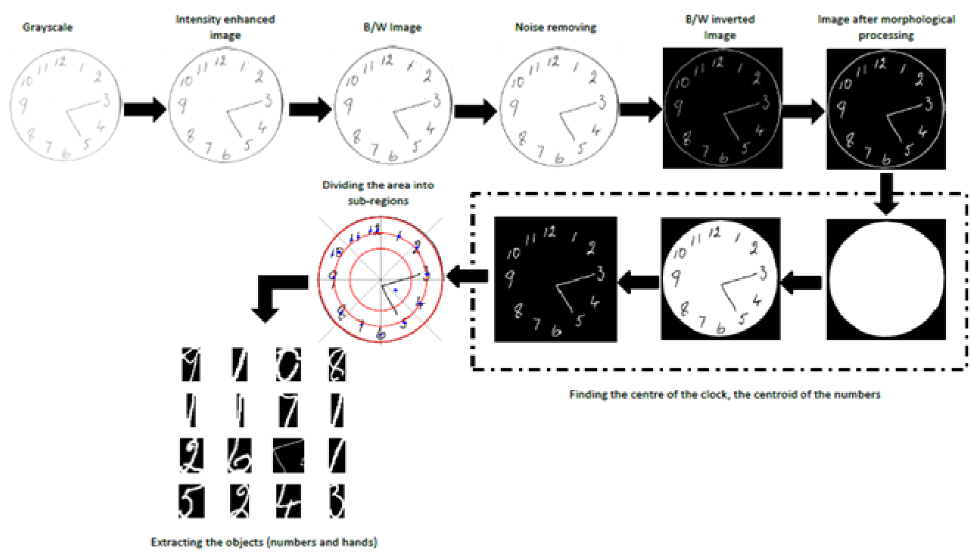


Figure 2.1: Steps for image enchancement and prepration for feature extraction [1]

Mostly authors have focused on offline hand drawings for the CDT test. In [13], however, the authors have developed a mobile application for the online Mini-Cog test. The developed application has been trained on more than 1,000 touch drawn clocks. Scoring is based on three steps listed in the following.

1. Associating a digit to a specific hour mark.

2. Recognizing the digit.
3. Identifying hands

The authors report a correct performance of over 99% for the developed application.

Another notable work on this problem is reported in [8] where the authors carried out a study to investigate that whether online or offline recognition of clock drawing test is better. The authors concluded that while there was no significant difference between the two media, the subjects were more comfortable in drawing shapes on a tablet. In online handwriting recognition, the subjects are asked to draw clock using stylus on the tablet and the results will be stored in database. The key steps of the system include the following.

1. Image binarization
2. Segmentation of digits
3. Identication of angle between hands
4. Recognition of digits and time

For classification, the authors employed nearest neighbor (K-NN) classification as well as an artificial neural network (ANN). While the ANN performed better than KNN, it was relatively slower. Since the application was developed for a mobile platform, KNN was preferred due its efficiency. Figure 2.2 shows the detected centroids of each digit (left) and clock hands (right) in this study. Clock hands are identified by their geometrical features while the angles of the hands with respect to horizontal axis identify the pointing directions of the hands on the clock. The results are generated using the 13-point scoring criteria using Freedman scoring system. [8].

Our study will primarily focus on presence or absence of digits and their positioning. The results of the CDT will be combined with those of the Recall Test to arrive at a tentative decision about the subject (demented or not). The decision criterion is illustrated in Figure 2.3.

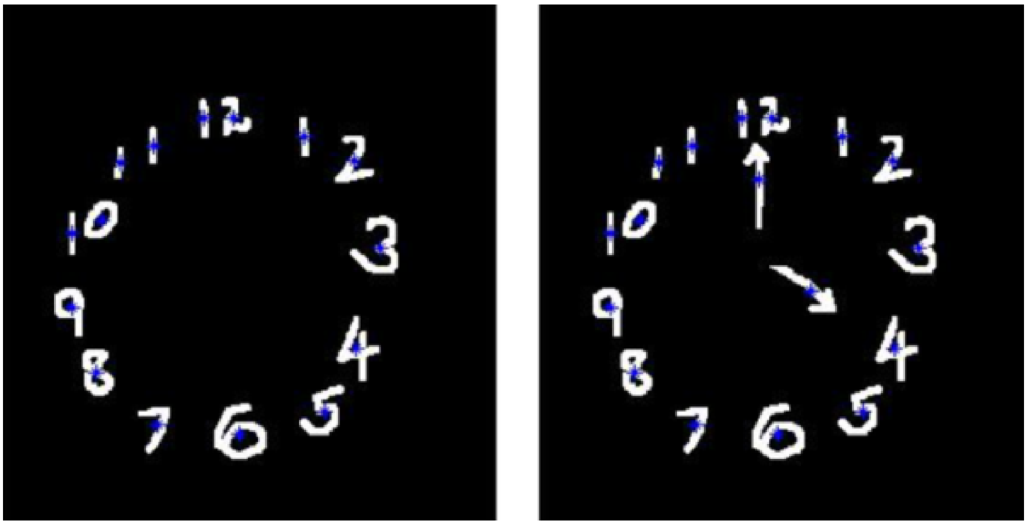


Figure 2.2: Clock drawing showing the detected centroids of each digit(left) and clock hands(right) [8]

Screening Criteria.png Screening Criteria.png

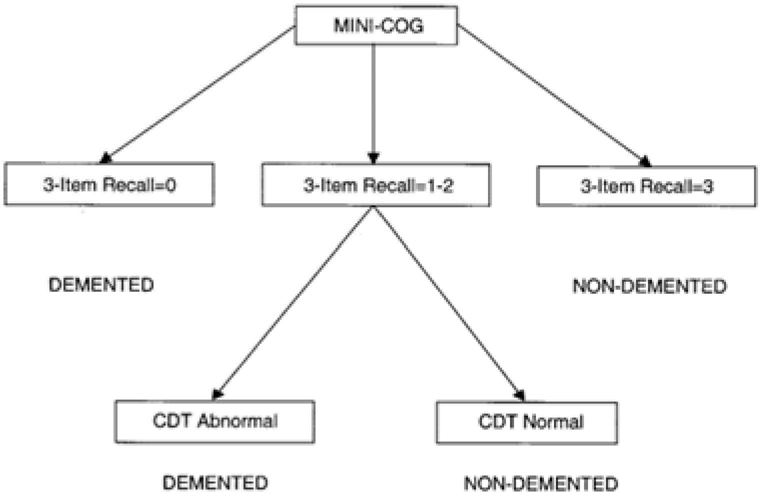


Figure 2.3: Mini-Cog Screening criteria [2]

Chapter 3

Requirement Specifications

This chapter details the requirement specifications of the project. The proposed project aims to provide an automated instant screening test of dementia in elderly people through Mini-Cog evaluation. A subject will be shown three words on the screen to remember and will be required to draw a clock on a sheet of paper with a pre-drawn circle on it. Once the clock has been drawn, it will be digitized and will be analyzed by a computer program. The system will then prompt the subject to reproduce the three words shown earlier. Finally, a combined score of the clock draw test and the recall test will be produced by the system.

The proposed project is a desktop application. The purpose of the proposed project is to develop an efficient, reliable and accurate diagnostic tool which will reduce the work load of psychologists by automating the test. The intended automated system will help the practitioners in an efficient screening of dementia patients. Non-medical personnel can be trained to use the system and provide details of scoring to the experts for further assessment enabling them to keep their focus on the patients and treatment instead of scoring and report formulation. Developing an automated version of the Mini-Cog test, will allow an instant screening of patients and only suspected cases can be referred to the clinical psychologists for an expert examination.

3.0.1 Limitations

Two different approaches can be used to implement this system which are online and offline clock drawing. The scope of this study is limited to digitized (offline) images of clock drawing only. The online clock draw test has the advantage of additional information in terms of the time stamp of the writing stroke coordinates and pressure etc. However, it requires specialized hardware to caputre online handwriting. We, therefore, focus on the scanned images of clocks drawn by subjects on paper sheets. As discussed earlier, the scoring of the developed system will be based on the presence or absence of digits in the clock and their positioning. Analysis of the time settings is beyond the scope of our study.

3.1 Requirement Specifications

We now formally present the requirement specifications of the system in terms of functional and non-functional requirements.

3.1.1 Functional Requirements

The functional requirements from the perspective of subject (patient) and the expert (psyhchologist) are presented in the following.

3.1.1.1 User Requirements: Patients

The system should allow patients to:

- Start the application
- View the list of three words displayed on the screen.
- Move to the next task of clock drawing test.
- Draw digits and set time on piece of paper with pre-drawn circle.
- Move on to the last task.
- Type in three words which were shown in the first task.
- View the score of recall test.
- View the score of clock drawing test.
- View the combined result of recall test and clock drawing test also known as mini-cog scoring criteria.
- Close the application.

3.1.1.2 User Requirements: Psychologists

The system should allow psychologists to:

- Start the application.
- View the three words displayed on the screen to the subject.
- Move to the next task of clock drawing test.
- View the scanned clock.
- Move on to the last task.

- View the three words which the patients have typed in.
- View the score of recall test.
- View the score of clock drawing test.
- View the combined result of recall test and clock drawing test also known as mini-cog scoring criteria.
- Close the application.

3.1.2 Non-Functional Requirements

The non-functional requirements of the system are presented in the following.

- **Reliability:** The application should reliably segment and recognize the clock hands and the digits. The position of digits with respect to the clock circle as well as with respect to one another should also be reliably computed so that the overall score of the test reflect a true picture of the subject's mental state.
- **Security:** The system does not have any specific security requirements. The personal information of the subjects is not archived.
- **Performance:** The system should be efficient and perform the scoring without any noticeable delay by the users.
- **Maintainability:**The maintenance of the application will be carried out by the developers, if required.
- **State Maintenance:** Backup copies of different versions of the system should be kept to avoid any accidental loss of data.
- **Availability:** The system does not require any Internet connectivity and will be available once the application has been installed on a device.

3.1.3 User Categories

Three user cateogries are identified for this project as illustrated in Figure 3.1. These include the subject, the psyhchologist and an optional monitor to observe the session.

3.1.4 Use Cases

Use cases provide a picture of the boundary of a system and describe the interaction of the users with the system. The use cases in the developed system are presented in the following.

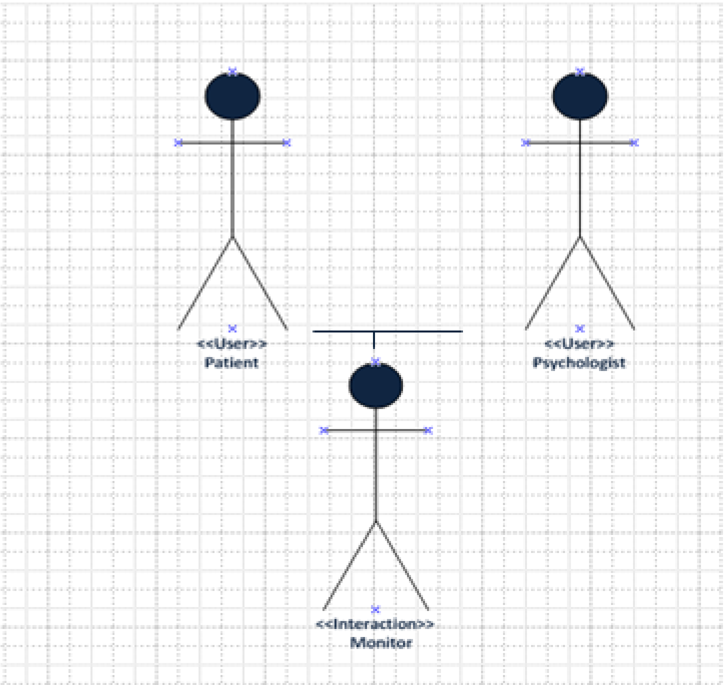


Figure 3.1: User Categories

3.1.4.1 UC1: Startup Page

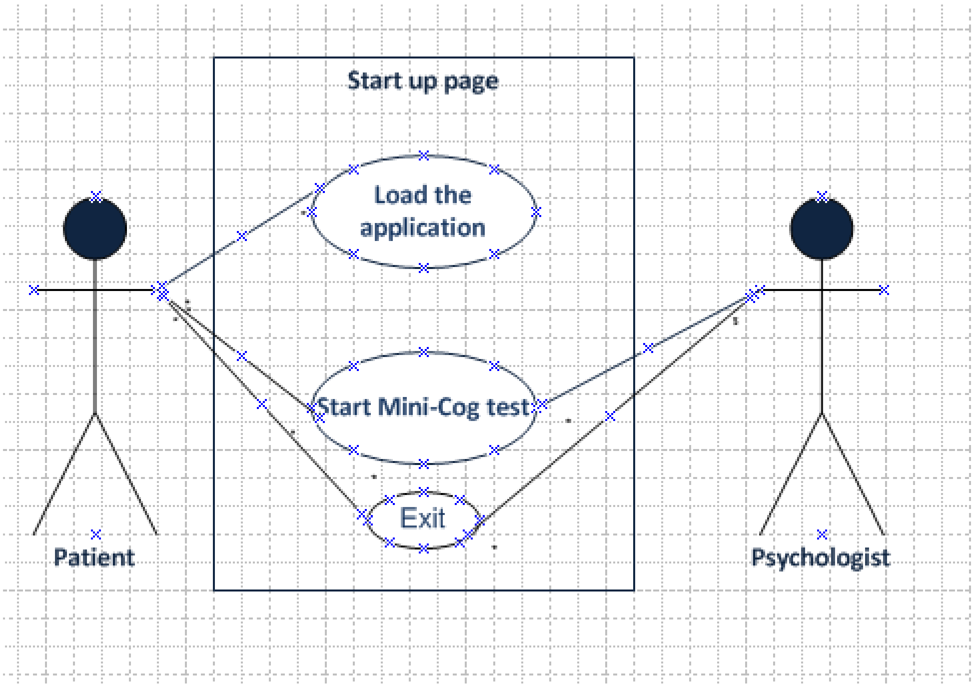


Figure 3.2: Use cases at the system start-up page

Table 3.1: Startup page

Title	Startup page
Actors	Patient and Psychologist
Roles	Patient and Psychologist must load the application and can then start the test or exit the system
Description	Patient can start the test
Pre-conditions	System should be running
Post-conditions	Starting the application should take users to the next screen

3.1.4.2 UC2: Display Words

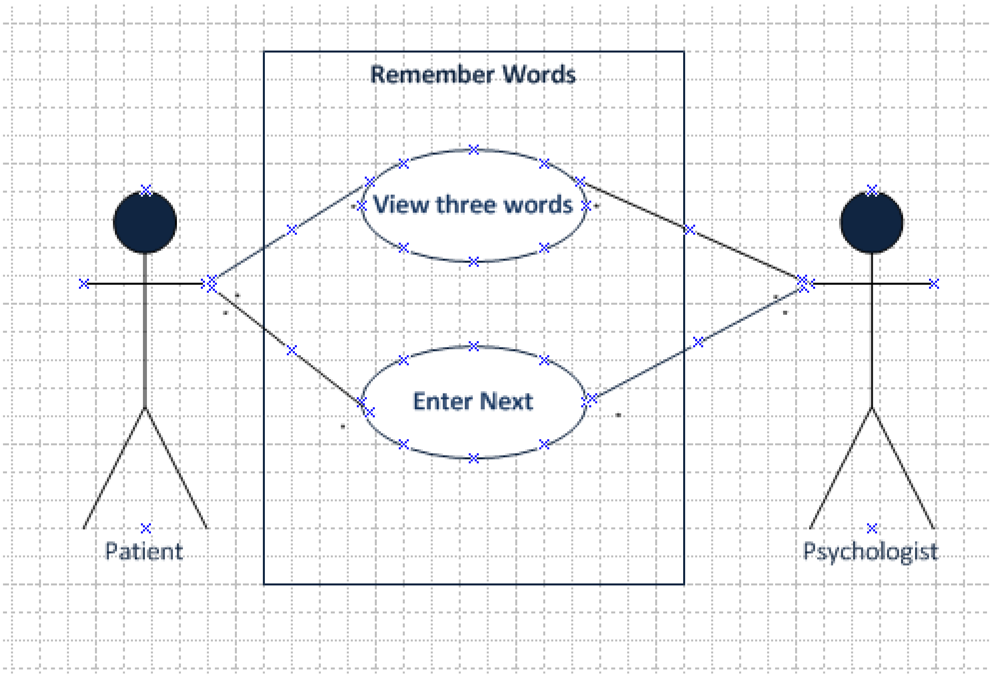


Figure 3.3: Display Words

Table 3.2: Words displayed to the subject

Title	Display Words
Actors	Patient and Psychologist
Roles	Patient and Psychologist must load the application and can then view the words displayed on screen.
Description	Three words are displayed on the screen
Pre-conditions	System should be running
Post-conditions	Subject can view words and move to the next step

3.1.4.3 UC3: Clock Drawing Test

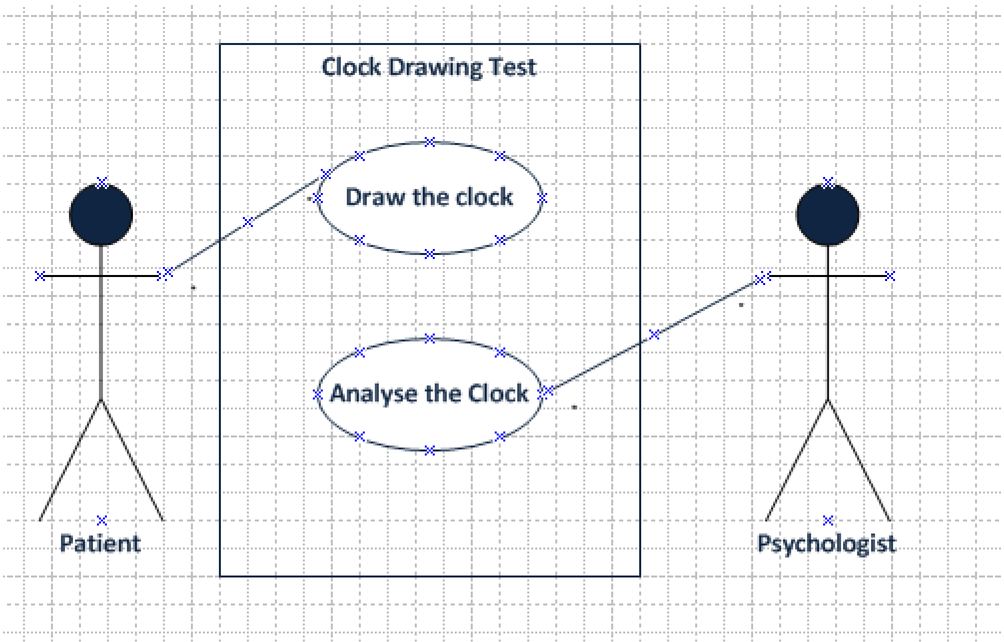


Figure 3.4: CDT

Table 3.3: Clock Drawing Test

Title	Clock Drawing Test
Actors	Patient
Roles	Patient should draw the clock on sheet of paper with predefined circle
Description	Use case to allow clock drawing
Pre-conditions	System should be running and clock should be drawn
Post-conditions	Recall words screen should be displayed

3.1.4.4 UC4: Write Words

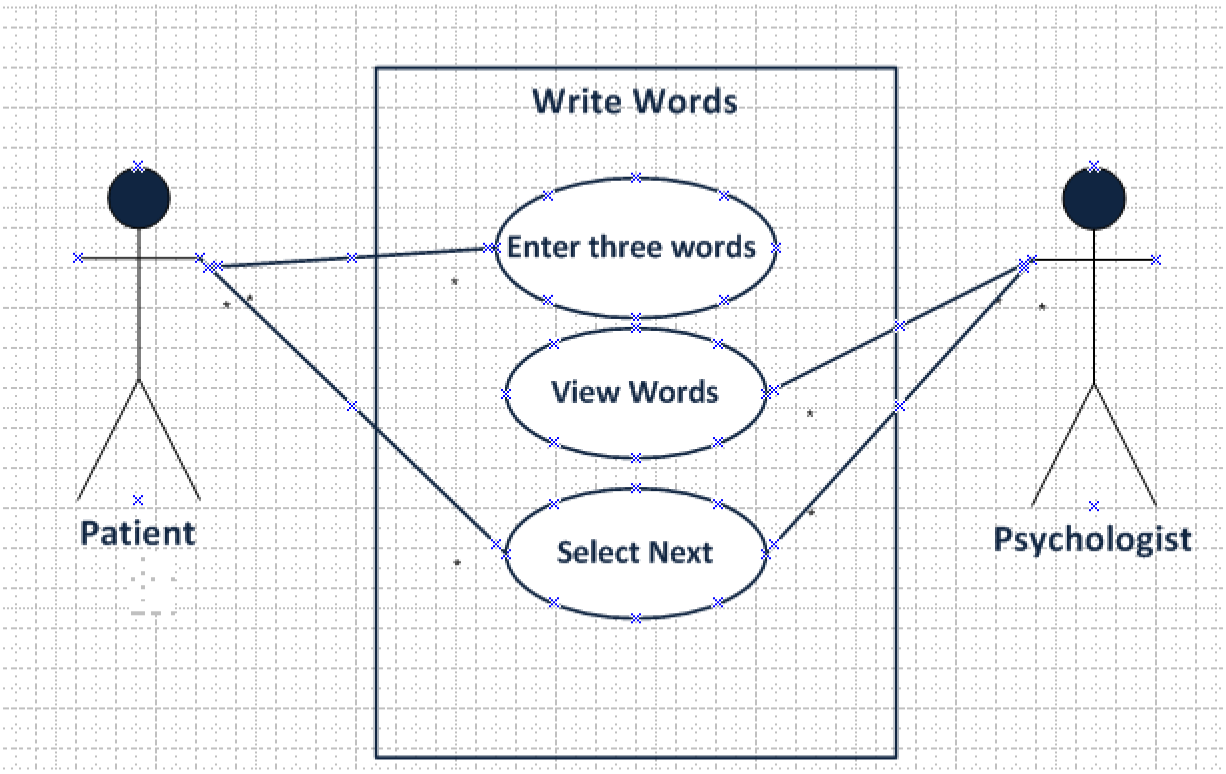


Figure 3.5: Recall Words

Table 3.4: Write Words

Title	Write Words
Actors	Patient
Roles	Patient recalls words and types them while the psychologist views the recalled words
Description	This use case represents the recall test
Pre-conditions	System should be running and page should be open where the words will be written.
Post-conditions	Scoring screen is displayed

3.1.4.5 UC5: View Score

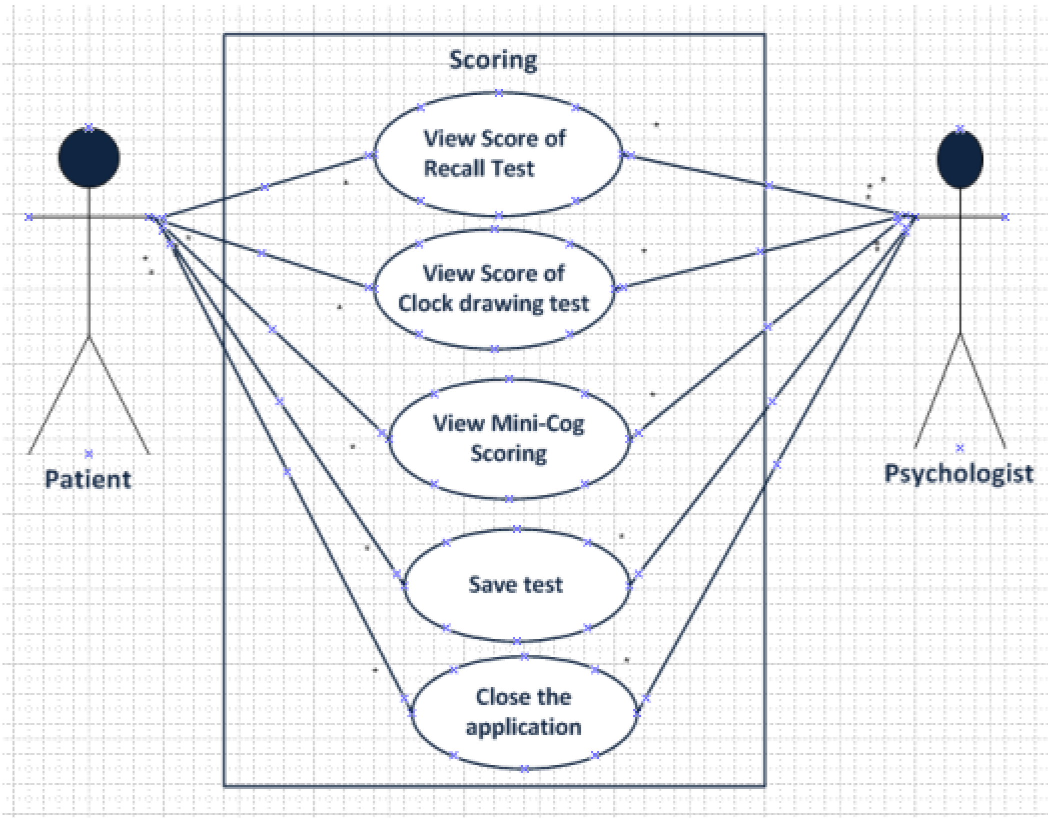


Figure 3.6: Usecase to view scores

Table 3.5: Result of Mini-Cog Test

Title	Score
Actors	Patient and Psychologist
Roles	Patient and Psychologists should be able to view the score of CDT,Recall Test and Mini-Cog test results.
Description	This is a use case for viewing the results of test
Pre-conditions	System should be running and score page should be open.
Post-conditions	Exit

Chapter 4

Design

This chapter details the different design aspects of our system.

4.1 System Architecture

The basic interaction of the application with other modules and hardware devices includes the following.

- Scanner for taking the clock images.
- Memory for retrieving the previously saved image as an input.
- Processor for executing the algorithms.

The interaction between different components within the application includes the AForge.Net library which processes the images to extract digits and these digits are then classified using KNN classification algorithm.

4.2 Design Methodology

An overview of the intended system with major modules is presented in Figure 4.1. The proposed system mainly relies on image analysis and pattern recognition techniques to generate a complete score from an image of the hand-drawn clock. The implementation of recall test is fairly trivial and only requires to be integrated with the clock draw test. The most important module of our system is to check automatically that whether the clock drawn represents a normal or an abnormal clock. The decision will be based on a series of steps as summarized in Figure 4.1. The first step, pre-processing, will be carried out to binarize the images. Once binarized, a segmentation module will be developed to segment the different components of the drawn clock including digits. The digits will be matched against a training database for recognition. The scoring will be based on the Freedman scoring system where the drawn shape is analyzed against a set of scoring criteria. Finally, the system will provide its decision on whether the clock is normal or not.

A database of 21 sample clocks has been collected. The hand-drawn clocks are scanned and stored as grayscale 8-bit images. The grayscale images are binarized and the circle of the clock is identified and eliminated using blob filtering. The digits in the image are then segmented and recognized by matching them with digits in the training database using a nearest neighbor classification. The positing and order of digits is also checked according to the Freedman's scoring guidelines.

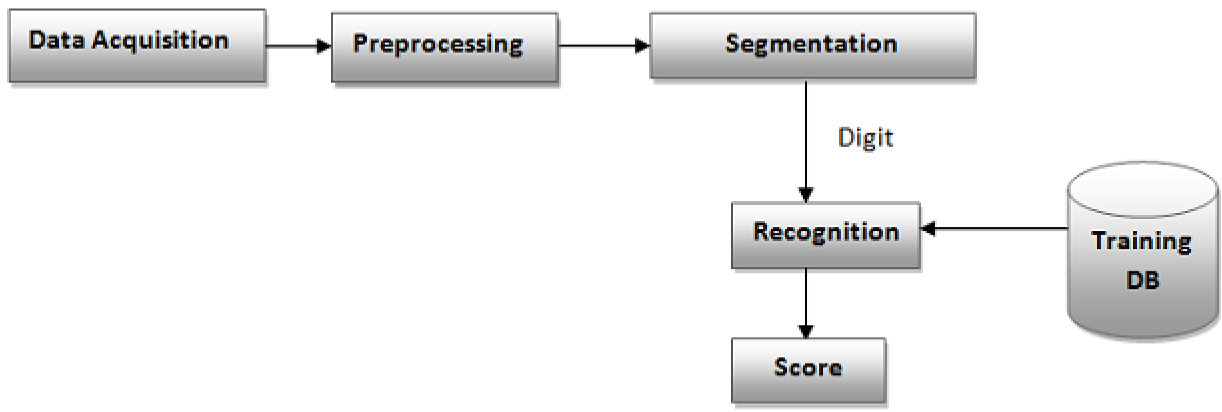


Figure 4.1: Methodology

4.3 High Level Design

This section presents the high level design of the system including logical design and process design.

4.3.1 Conceptual/Logical Design

An overview of the logical or conceptual design of the system in terms of component (package) diagram is presented in Figure 4.2.

4.3.2 Process Design

The process interaction in the system is summarized in Figure 5.3 given detail about process interaction of the system while Figure 4.4to 4.8 illustrate the sequence diagrams of the system.

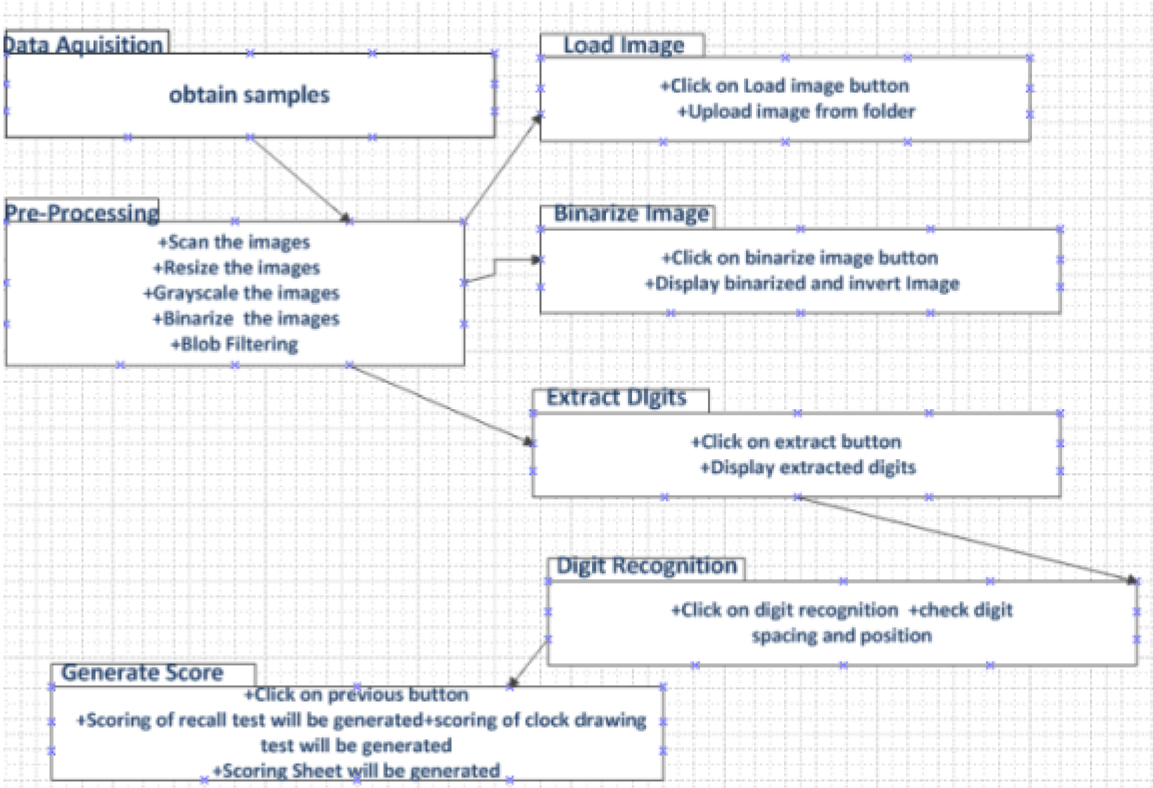


Figure 4.2: Component or Package Diagram

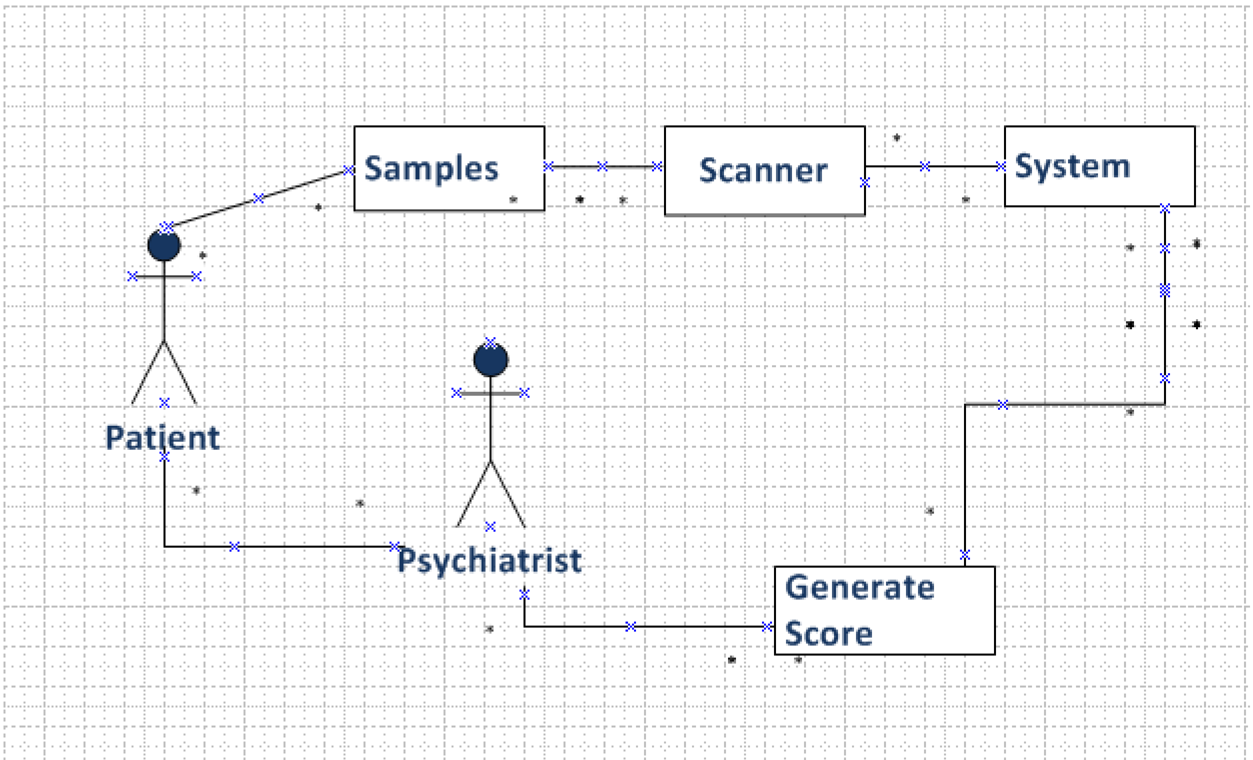


Figure 4.3: Process Interaction

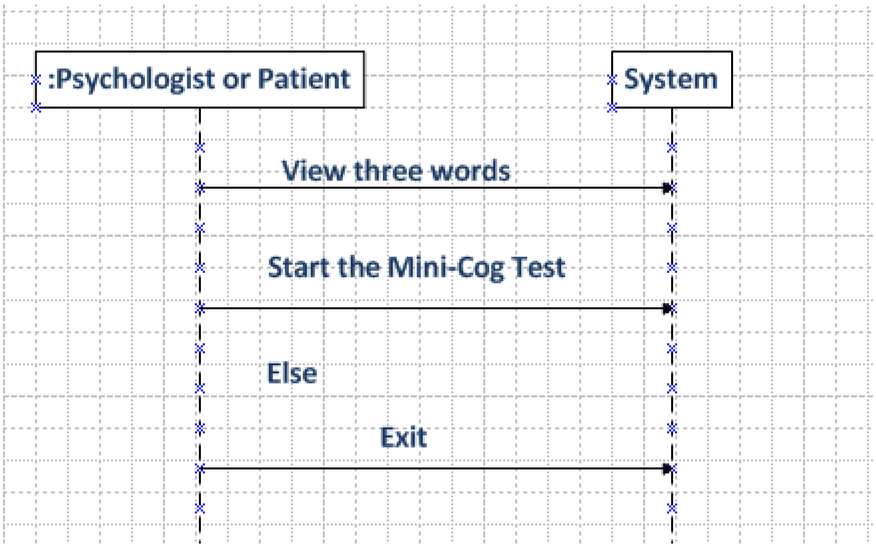


Figure 4.4: Start the application

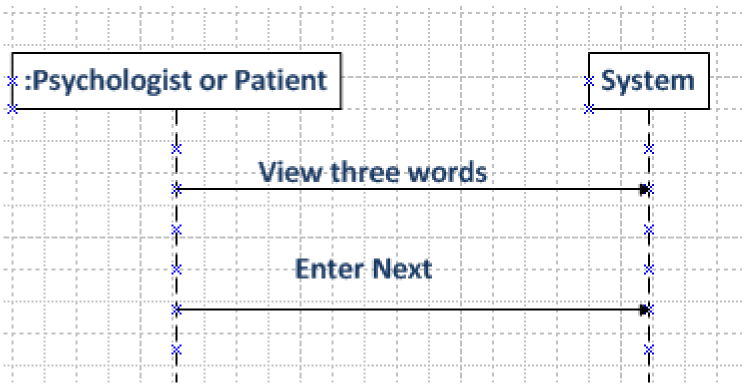


Figure 4.5: Remember Words

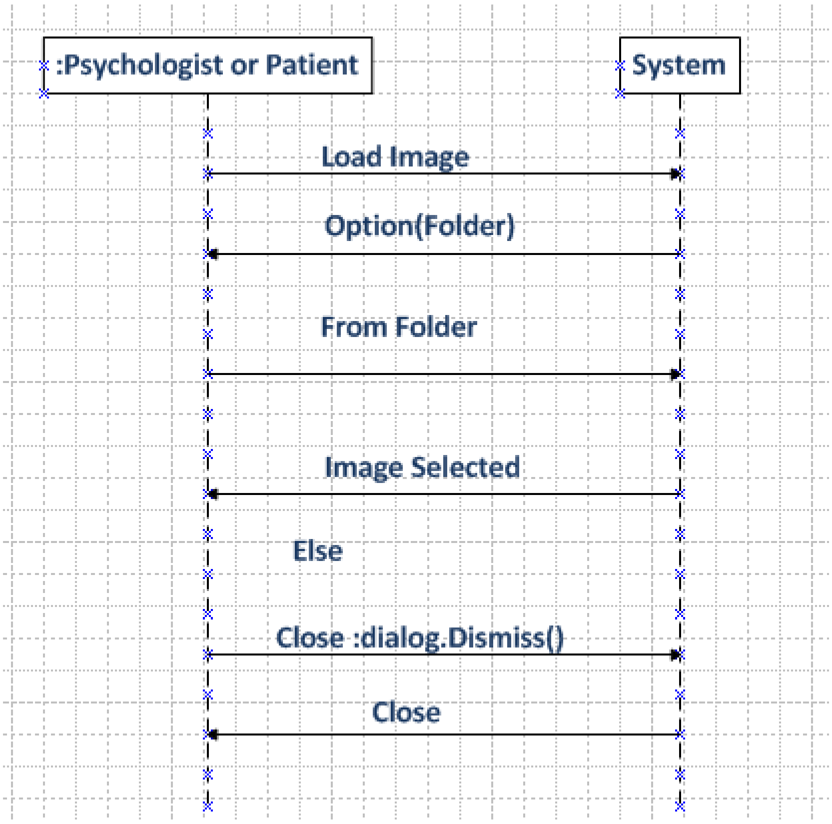


Figure 4.6: CDT

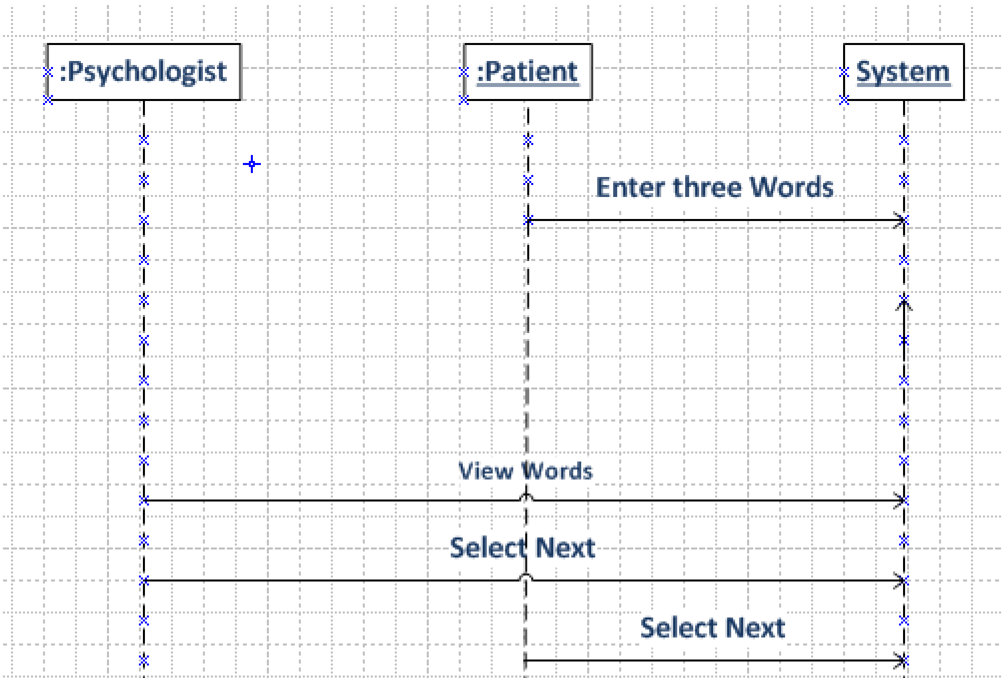


Figure 4.7: Recall Words

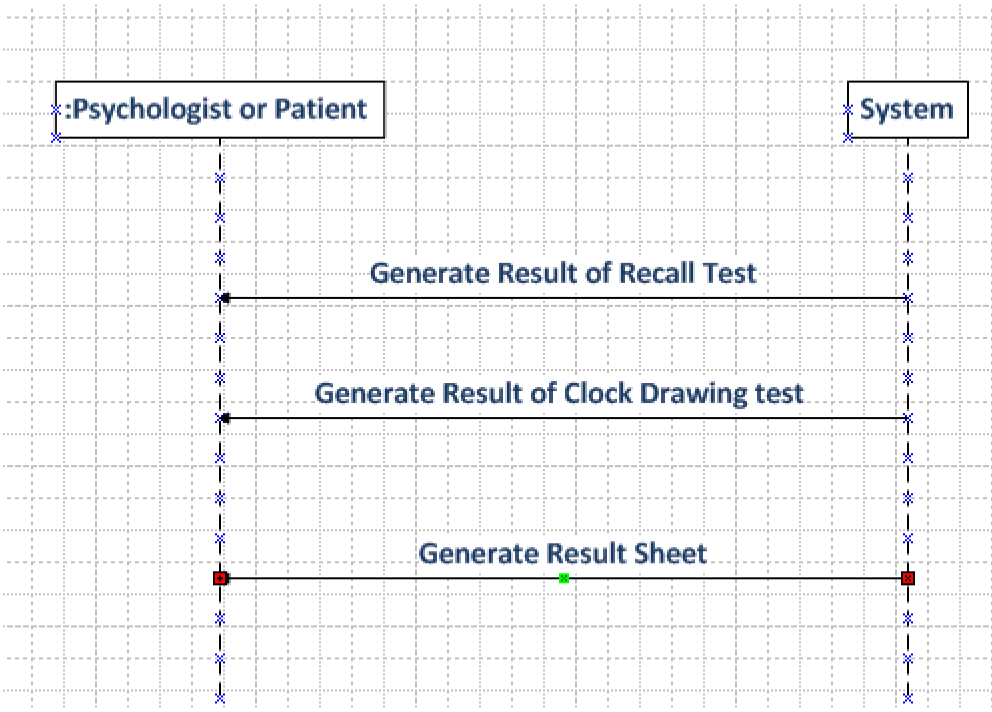


Figure 4.8: Test Results

4.3.3 Security

The system is a desktop application and it should only be used by the psychologist and clinicians. Patients should be only be allowed to use the system under the observation of clinicians as he would have the detail knowledge of the results which will be generated at the end of the test.

4.4 GUI Design

The GUI of a system requires to be simple and user friendly. The designed system will be used by psychologists and patients instead of computer scientist, therefore the GUI had to be simple yet comprehensive. The developed interface does not only produce the final scores but also shows the step-wise analysis process so that the users can see the output at different stages of the processing and verify it.

There are a total of 5 forms in our application. The users are first presented with a start-up page to launch or exit the application as illustrated in Figure 4.9. Once the user starts the test, three words are displayed on the next screen which the subject is required to remember (Figure 4.10). Afterwords, the subject can move to the clock drawing test as shown in Figure4.11.

Once the clock has been drawn and provided to the system, image analysis algorithms are applied to the image resulting in segmentation of digits from rest of the image. Once the digits have been analyzed, the subject may move to the recall test (Figure 4.12) and provide the words shown in the first step. The subject is required to enter the three words and can finally see the scoring of the test as shown in Figure 4.13.

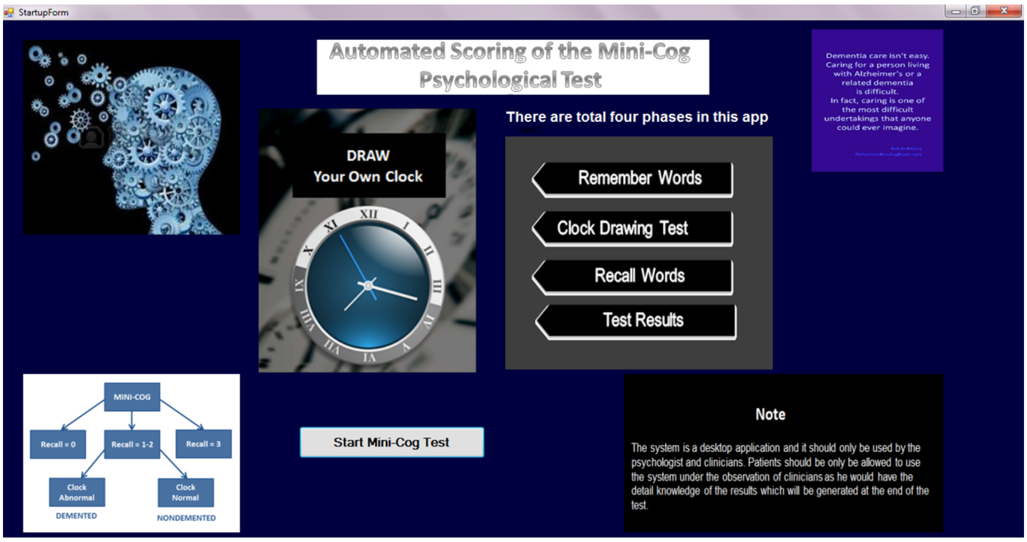


Figure 4.9: Startup Form

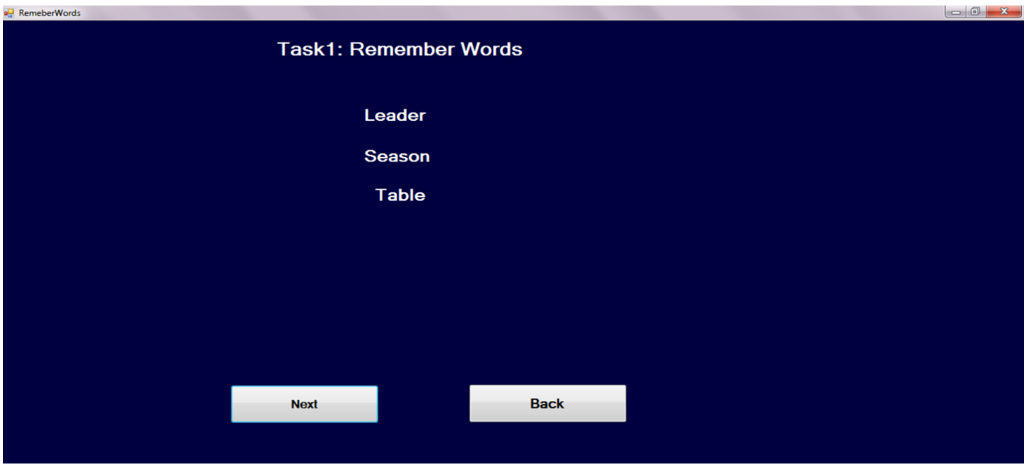


Figure 4.10: Form to display words to be rememberd by the subject

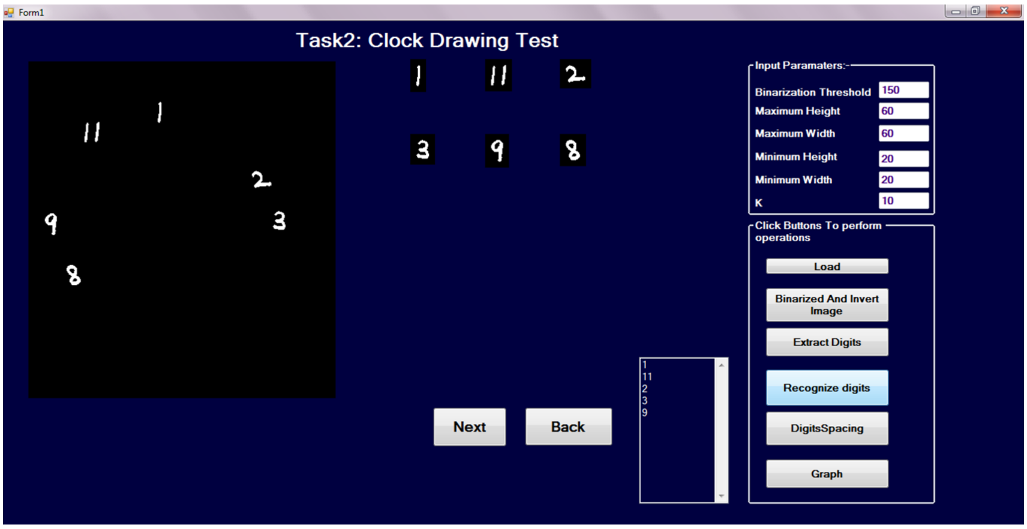


Figure 4.11: Form to show analysis of the user drawn clock

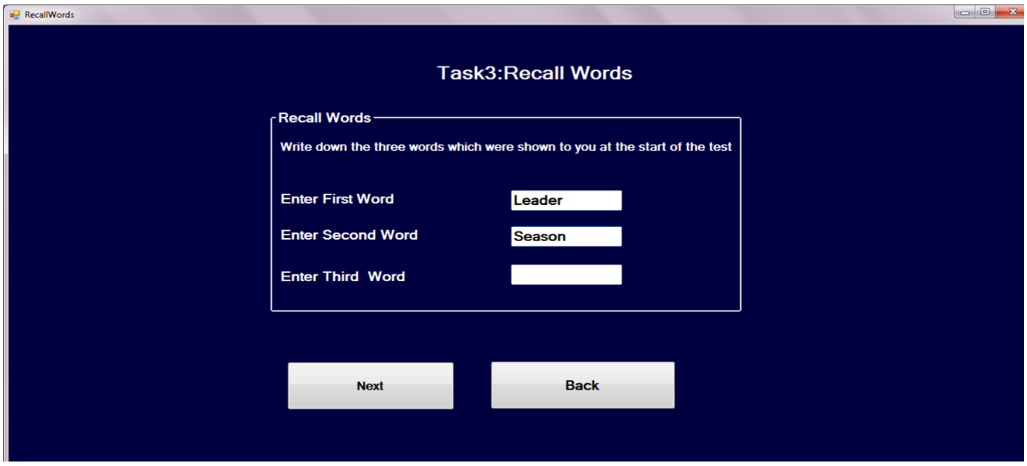


Figure 4.12: Forms to enter words in the recall test

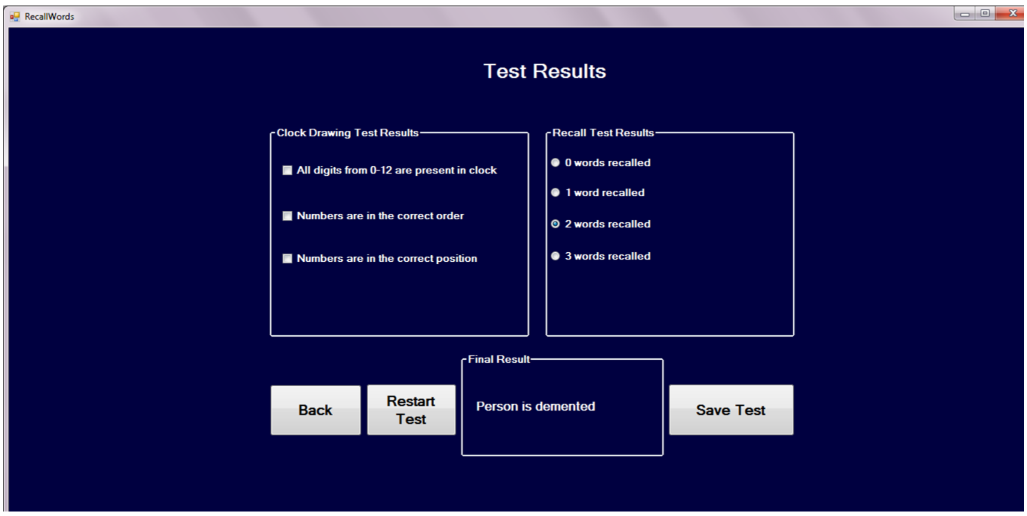


Figure 4.13: Form showing summary of the test results

Chapter 5

System Implementation

This chapter presents the implementaiton details of our system including the tools and technologies employed and the algorithmic details of the system.

5.1 Tools and Technology

Following tools were employed in the development of the automated Mini-Cog scoring system.

5.1.1 Visual Studio 2013

Visual Studio 2013 is an integrated environment of Microsoft to develop software programs. Visual Studio supports multiple language like C plus plus,C sharp etc. The proposed system is developed in C#.

5.1.2 AForge.NET

AForge.NET is a Computer Vision and Artificial Intelligence library originally developed by Andrew Kirill for the dot Net framework. The following libraries are included with the AForge.NET distribution.

- AForge.Imaging - library with image processing routines and filters
- AForge.Vision - computer vision library
- AForge.Video - set of libraries for video processing
- AForge.Neuro - neural networks computation library
- AForge.Genetic - evolutionary programming library
- AForge.Fuzzy - fuzzy computations library

- AForge.Robotics - library providing support of some robotics kits
- AForge.MachineLearning - machine learning library

We have primarily used the AForge.Imaging library in our system.

We now present the algorithmic details of the system in the next section.

5.2 Methodology and Algorithmic Development

The algorithmic details of the developed system are presented in the following.

5.2.1 Grayscale Conversion

The digitized images are mostly 8-bit grayscale images. In some cases, however, 24-bit (3-channel) images may also be provided to the system. Consequently, the first step is to convert the 3 channel images to a single channel 8-bit grayscale image. A grayscale image has 256 colors ranging from 0 (black) to 255 (white).

5.2.2 Binarization

Binarization is the process of converting a grayscale 8-bit image to binary form, i.e. only two colors black (0) and white (1). Effectively, Binarization is a 2 class segmentation problems where one class represents the objects while the other class represents background. Depending upon the images under study, Binarization can be based on global or local thresholding. In global thresholding, a single threshold value computed from the histogram of the gray scale image is used to binarize the image. Local thresholding, on the other hand, comprises sliding a window over the image and computing a threshold for every pixel of the image as a function of its neighboring pixels. Since we deal with scanned images of handwriting, the histogram of the images comprise a bi-modal distribution with two distinct peaks (Figure 5.1), one for the drawn digits and arms and the other for the background. Consequently, we employ global thresholding and binarize the image as follows.

$$g(x,y) = \begin{cases} 1 & \text{if} f(x,y) \geq T \\ 0 & \text{otherwise} \end{cases}$$

Where $f(x,y)$ represents the original gray scale image, $g(x,y)$ is the binarized image and T represents the threshold computed from the image. Figure **??** represents a grayscale clock image and the respective binarized version of the image. The binary image is then inverted to have white objects on black ground before further processing.

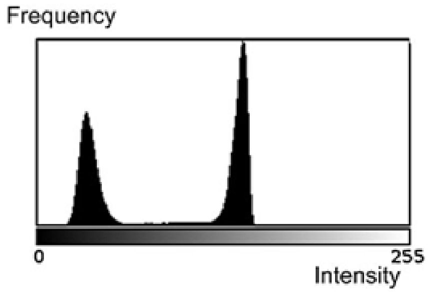
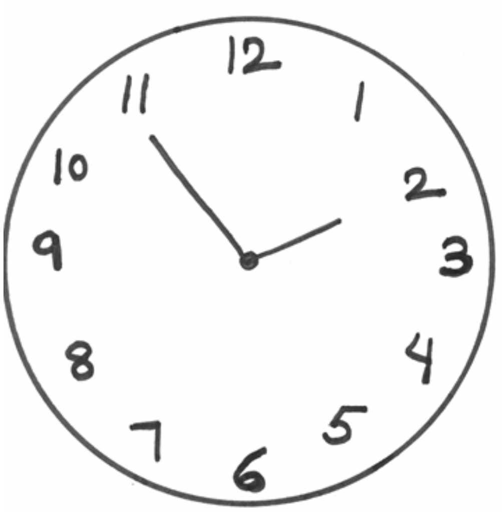
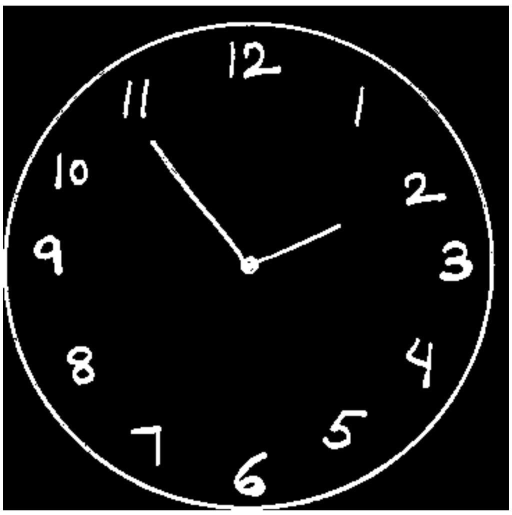


Figure 5.1: Bimodal intensity histogram in handwriting images



(a)

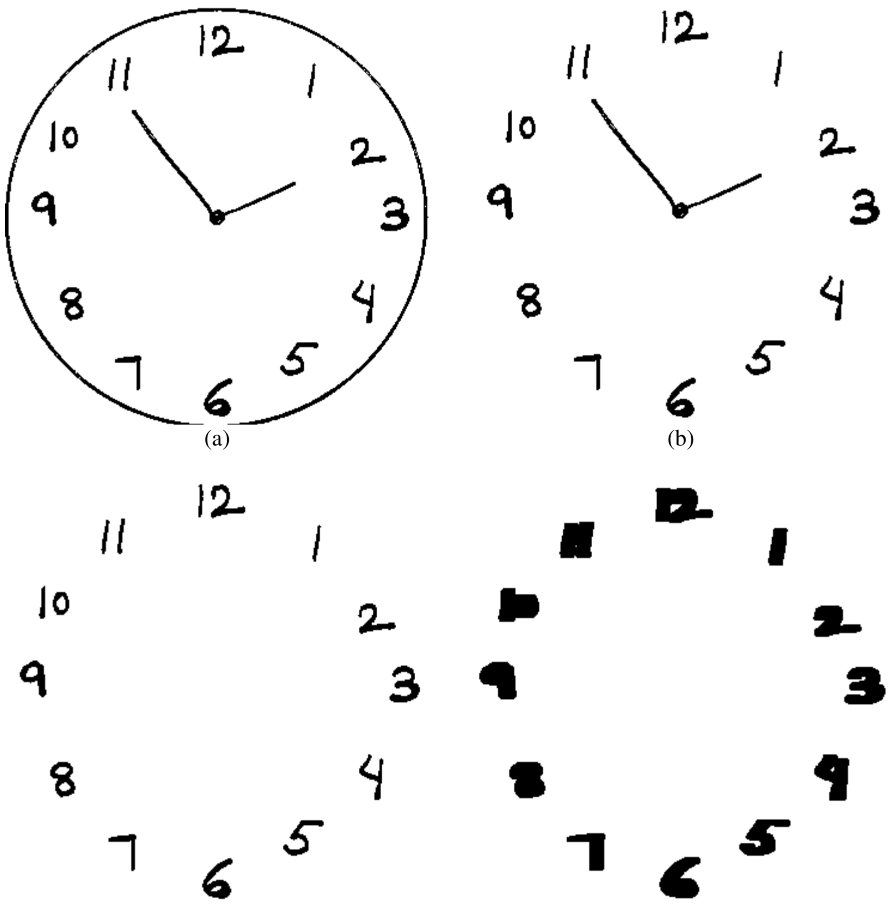


(b)

Figure 5.2: Image of a clock drawn by a subject (a): Grayscale image (b): Binarzied and inverted image

5.3 Segmentation of Digits

To segment the digits for recognition, we perform connected component labeling of the image. Each connected component or blob is extracted from the image along with the location and size of each blob. The pre-drawn circle of the clock is always the largest connected component and is filtered out. Likewise, the average are of the connected components in the image is computed and the arms of the clock have an area which is well-above the average component area in the image. This allows removing the circle and arms of clock and leaving behind digits only. The numbers 1 to 9 are single digit numbers while 10, 11 and 12 represent two digit numbers. To merge the digits of a number together into a single component, we apply morphological dilation with a horizontal structuring element. This merges the neighboring components together resulting in a single blob for each number. These blobs are then extracted from the image and fed to the recognition module. The different steps of segmentation are illustrated in Figure 5.3.



(a) (b) (c) (d)

Figure 5.3: Segmentation of digits (a): Binarized image (b): Circle removed (c): Arms removed (d): Dilated image [Images are shown inverted for printing purposes]

5.3.1 Digit Recognition

Digit recognition is a classical pattern classification problem that involves 10 classes 0-9. A number of digit recognition systems have been proposed over the years which work either directly on pixel values or by first extracting a set of features from the digit images. Classification is carried out either using a nearest neighbor rule or by first training a classifier (like an artificial neural network or a support vector machine). For our system, we have chosen to work on pixel values of the binarized digit images and employ K-nearest neighbor classification using template matching.

We employ a training database of digit images where each digit is resized to a fixed size of 28 pixels. A digit extracted from the hand-drawn clock is scaled to the same size and the resulting vector is compared with the templates in the database using Euclidean distance. Considering each digit to be a point in an 'n' dimensional space (where 'n' is number of pixels in the digit image), the Euclidean distance between two digits 'p' and 'q' is given as follows.

$$d(p,q) = \sqrt{\sum_{i=1}^{n} (p_i - q_i)^2}$$

For training, we use the standard handwritten digit dataset from MNIST database [3]. The training images are stored along with the ground truth label of each image. The images of digits segmented from the clocks are compared with those in the database and the digit it recognized using a majority vote of $K = 5$ neighbors. To recognize the numbers from 10-12, we separately recognize each of the digits and the combine them together. Figure 5.4 illustrates the digits recognized from a sample clock.

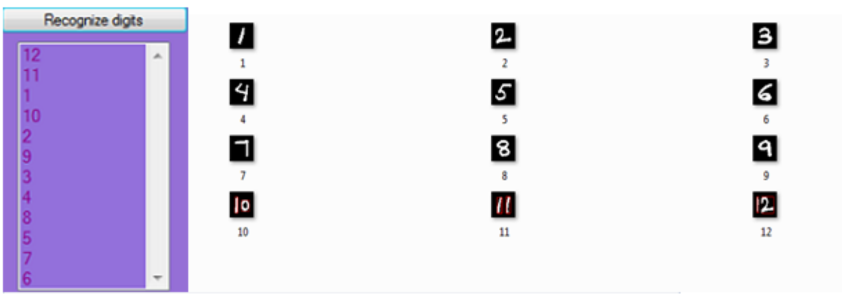


Figure 5.4: Recognized Digits

5.3.2 Scoring

As discussed earlier, scoring is carried out on two aspects, missing digits and misplaced digits. Once the digits have been recognized the identification of missing digits is trivial.

Likewise, the position of each digit in the image with respect to the circle is also known. The clock is divided into four quadrants and the position of (center of gravity of) each digit is analyzed. Numbers 12, 6, 3 and 9 are used for reference purposes. If any of the digits are missing,or are not correctly placed within the circle, the clock is scored accordingly.

5.4 Conclusion

This chapter presented in detail the system implementation along with the algorithmic details of the system including binarization, segmentation and classification. The evaluations carried out to validate the proposed system are presented in the next chapter.

Chapter 6

System Testing and Evaluation

Software testing conforms that whether the developed software results are according to the specified requirements and to check that each and every component of the system works efficiently. Testing plays a vital role to ensure that whether the developed software meets the quality standards or not. We discuss the testing of our system in the following.

6.1 Graphical User Interface Testing

User Interface is one of the most important modules of the project as it is very important to satisfy the users by making the interface simple and interactive. The users in our case are potential patients and psychologists which are not computer science experts. There are a total of five forms in the system and theme has been kept consistent. Five subjects were asked to interact with the system and the feedback was sought after the sessions. The subjects did not have any issues in interacting with the user interface and were satisfied. Figure 6.1 to Figure 6.4 illustrate the different forms of the system.

6.2 Usability Testing

The system is fairly simple to use and the usability guidelines have been followed in the design. As discussed earlier, five subjects were asked to use the system and provide feed back on different aspects of the interface. The users did not report any major issues in the system usability and were able to complete the test within the expected time.

6.3 Software Performance Testing

Software Performance testing is carried out to ensure that the developed application is efficient and reliable. In our case, reliability refers to the reliability of the scores which are dependent upon correct segmentation and recognition of digits. A total of 20 clock images

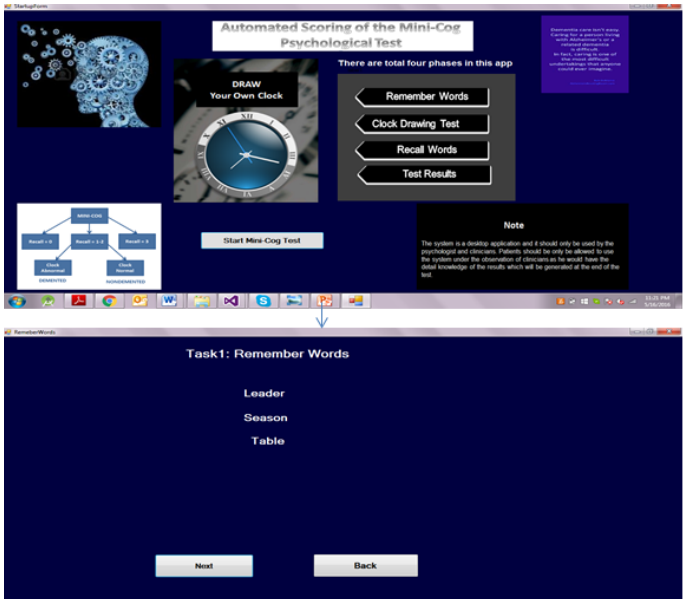


Figure 6.1: StartupPage and the Word List Page

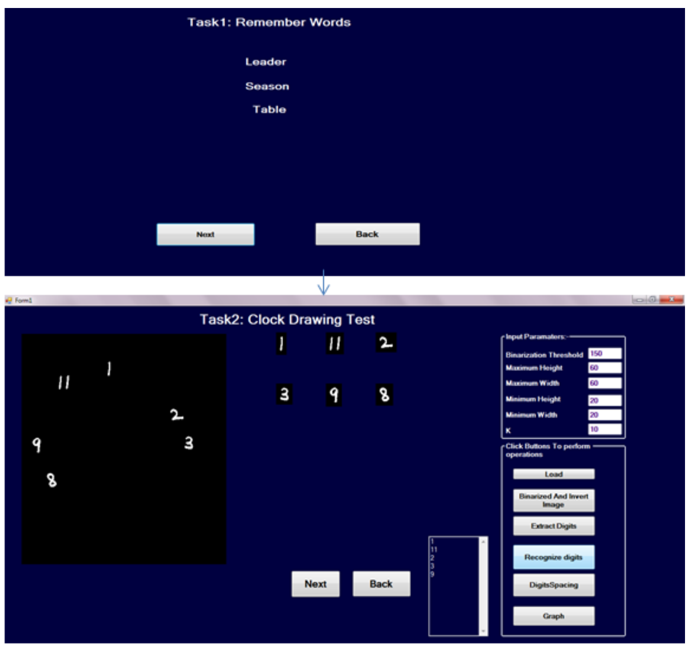


Figure 6.2: Remeber Words Page and CDT

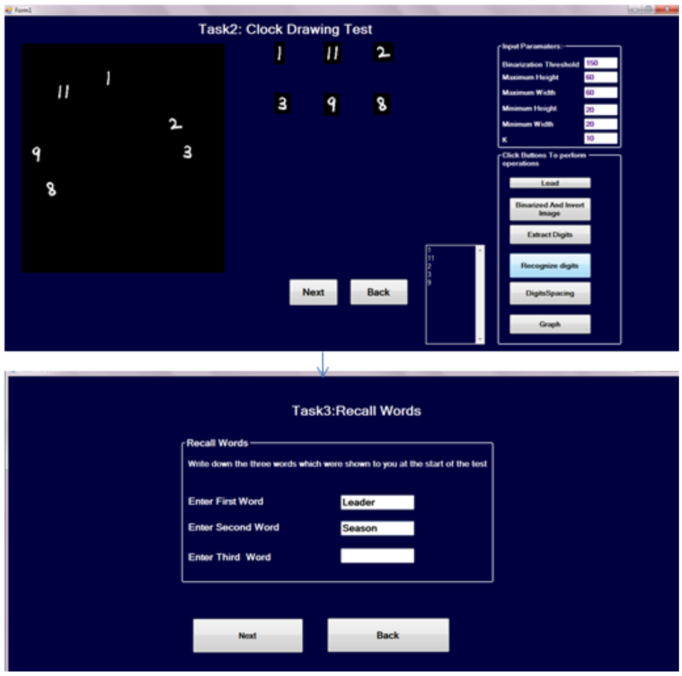


Figure 6.3: CDT and Recall Words

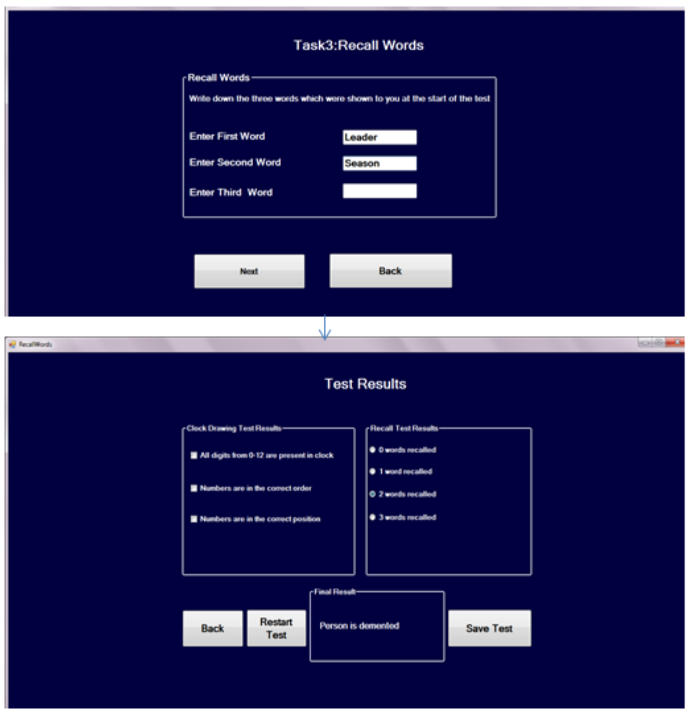


Figure 6.4: Recall Test and Test Results GUI

were loaded in the system. The segmentation and recognition results for each of the clocks are summarized in Table 6.1. The 20 clocks comprised a total of 163 numbers and all of these were correctly segmented. Out of these 128 were correctly recognized reporting a correct classification rate of 79.5% and 16 clocks were correctly scored out 20.

Table 6.1: Segmentation and Recognition Results on 20 Clock Images

Clock Number	Total Digits	Segmented Digits	Recognized Digits	Score
1	12	12	11	Correct
2	12	12	10	Not Correct
3	12	12	7	Not Correct
4	12	12	8	Not Correct
5	10	10	11	Correct
6	9	9	7	Correct
7	9	9	8	Correct
8	8	8	6	Correct
9	8	8	6	Correct
10	8	8	6	Correct
11	7	7	5	Correct
12	7	7	4	Correct
13	7	7	6	Correct
14	7	7	5	Correct
15	7	7	7	Correct
16	7	7	4	Correct
17	6	6	3	Correct
18	6	6	6	Correct
19	5	5	4	Not Correct
20	4	4	4	Correct
Total	**163**	**163**	**128**	**16**

6.4 Compatibility Testing

Compatiblity testing is the process to ensure that the application runs on different platforms. The present application is developed in Visual Studio 2013 and is compatible with different versions of the Windows operating system.

6.5 Exception Handling

The system may generate an exception (Figure 6.5) if the AForge.NET DLLS are not placed in the resource file of the project. The DLLS must therefore be added correctly to avaoid this exception.

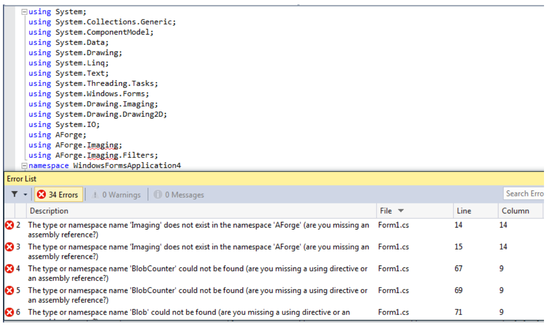


Figure 6.5: Resource File Error

6.6 Load Testing

Load testing is done to check the system behavior at the normal and heavily load conditions.The system can be heavily loaded when the clock image is of very high resolution. In most cases, however, a very high resolution image is not required for this application. The digits can be easily segmented and recognized in the normal resolution images.

6.7 Installation Testing

Installation Testing is the process to ensure that the application is successfully installed on the platform for which it was developed. The application was tested on different platforms of Windows including Windows 7 and Windows 10 and did not offer any problems.

6.8 TestCases

6.8.1 Test Case 1: Load Image

Table 6.2: Test Case 1

Test Case ID:	TC1
Unit of Test:	Test to verify that a clock image is loaded successfully
Steps to be executed	Click on ‘Load’ button and select an image
Expected Result:	Clock image loaded successfully
Actual Result:	Clock image loaded successfully
Status:	Pass

6.8.2 Test Case 2: Binarize And Invert Image

Table 6.3: Test Case 2

Test Case ID:	TC2
Unit of Test:	Test to verify that clock images are binarized and inverted
Steps to be executed:	Click on ‘Binarize & Invert’ button
Expected Result:	Clock images should be binarized and inverted.
Actual Result:	Clock images are binarized and inverted
Status:	Pass

6.8.3 Test Case 3: Segmentation of Digits

Table 6.4: Test Case 3

Test Case ID:	TC3
Unit of Test:	Test to verify if all digits are extracted from the image
Steps to be executed	Click on ‘Extract Digits’ button
Expected Result:	All digits should be extracted from the clock images.
Actual Result:	All digits are extracted from the clock images
Status:	Pass

6.8.4 Test Case 4: Recognition of Digits

Table 6.5: Test Case 4

Test Case ID:	TC4
Unit of Test:	Test to verify if digits are recognized correctly
Steps to be executed	Click on ‘Recognize Digits’ button
Expected Result:	Digits should be correctly recognized
Actual Result:	Approximately 80% of the digits are correctly recognized
Status:	Pass

Chapter 7

Conclusion and Perspectives

7.1 Conclusion

Dementia is a progressively increasing neurological disorder which may eventually result in a number of diseases, Alzheimer being the most common one. A number of screening tests have been proposed by practitioners for early detection of dementia, Mini-Cog being the most effective of these. This study was aimed at automating the Mini-Cog test using computational algorithms of image analysis and pattern recognition as discussed in the previous chapters. The clock images produced on a pre-drawn circle on a sheet of paper are binarized and digits are segmented from rest of the image. The extracted digits are then recognized using a nearest neighbor classifier. Once recognized, the missing digits are identified and the position of the digits with respect to the circle as well as among one another is analyzed. The results of the CDT are then combined with those of the recall test and a final decision is produced by the system. The system evaluated on 20 hand-drawn clock images produced promising results.

7.2 Perspectives

The present version of the system relies on a nearest neighbor classification and realizes promising digit recognition rates of around 80%. These can be further enhanced by using a more sophisticated classifier like a multi-layer artificial neural network or the support vector machine. In addition, we presently work directly on image pixel values. A set of features can be extracted from each digit image which will not only reduce the representation space but will also lead to efficient computations. Moreover, we only consider the absence of digits and the misplaced digits as the errors in drawing the clock. The analysis of the drawn time can also be incorporated in the system. Likewise, in addition to offline digitized images of clocks, the system can be extended to an online version where the subjects can directly produce the clock on a digitizing device without the need of a paper sheet and writing instrument. It is expected that this study will contribute towards the development of a complete diagnostic tool which will reduce the work load of psychologists by automatically screening the subjects. The authors also hope that the system developed during this academic project will be helpful for researchers and developers aiming to automate other similar tests.

Chapter 8

Appendix-A

Sample Clock Images

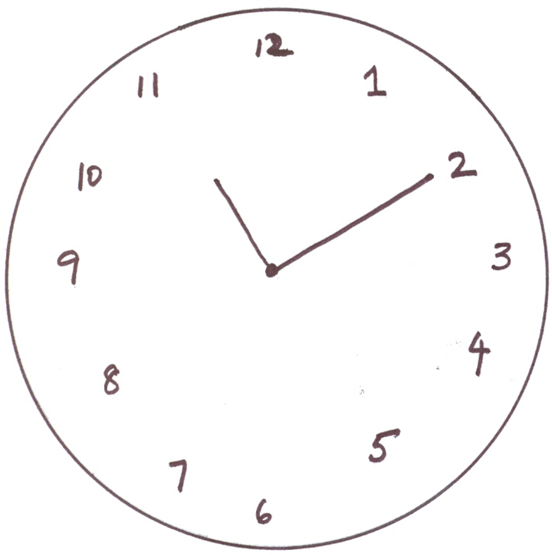


Figure 8.1: Sample Clock Image - Subject 1

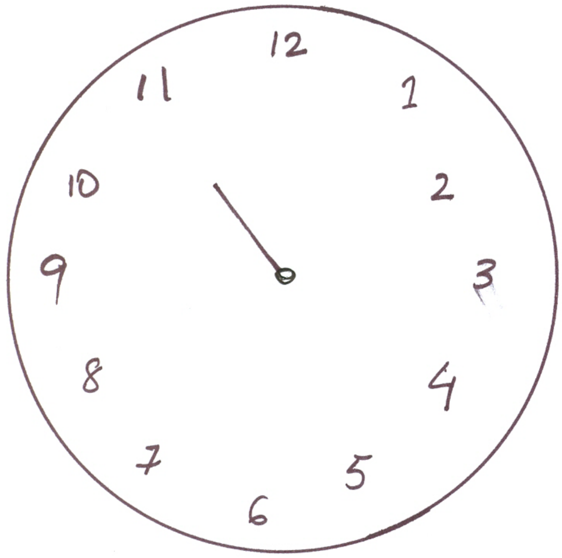


Figure 8.2: Sample Clock Image - Subject 2

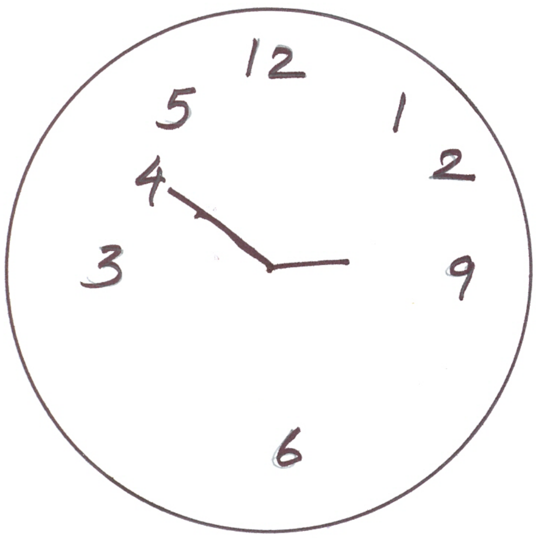


Figure 8.3: Sample Clock Image - Subject 3

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