A Web Based Decision Support System for Status Assessment in Advanced Parkinson

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Master Thesis
Computer Engineering
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# DEGREE PROJECT

## Computer Engineering

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<td>Farrukh Mohsin</td>
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<th>Supervisor</th>
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<td>Mr. Jerker Westin</td>
<td>Professor Mark Dougherty</td>
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<tr>
<th>Company/Department</th>
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<td>Solvay Pharmaceuticals</td>
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## Abstract

The purpose of this work is to develop a web based decision support system, based on fuzzy logic, to assess the motor state of Parkinson patients on their performance in on-screen motor tests in a test battery on a hand computer. A set of well defined rules, based on an expert’s knowledge, were made to diagnose the current state of the patient. At the end of a period, an overall score is calculated which represents the overall state of the patient during the period. Acceptability of the rules is based on the absolute difference between patient’s own assessment of his condition and the diagnosed state. Any inconsistency can be tracked by highlighted as an alert in the system. Graphical presentation of data aims at enhanced analysis of patient’s state and performance monitoring by the clinic staff. In general, the system is beneficial for the clinic staff, patients, project managers and researchers.
Contents

1 Introduction
  1.1 Background
  1.2 Problem Definition
  1.3 Fuzzy Inference Systems
  1.4 Goals
  1.5 Questions for Investigation

2 Data Analysis
  2.1 E-diary Data
  2.2 Motor Test Data
    2.2.1 Tapping Data
      2.2.1.1 Speed
      2.2.1.2 Percentage Correct
      2.2.1.3 Failure Time
  2.3 Spiral Data

3 Design
  3.1 Database Design
  3.2 Decision Support System Design
    3.2.1 Architecture of FIS
      3.2.1.1 Inputs
      3.2.1.2 Fuzzification
      3.2.1.3 Fuzzy Rule Base
      3.2.1.4 FIS Inference Engine
      3.2.1.5 Defuzzification
      3.2.1.6 Output
    3.2.2 FIS Design Class Diagram
  3.3 Web Application Design

4 Implementation and Testing
  4.1 Business Logic
    4.1.1 Invalid Test
    4.1.2 Compliance Calculation
    4.1.3 Alert
    4.1.4 Period Summary
      4.1.4.1 Ability To Walk
      4.1.4.2 Painful Cramps
      4.1.4.3 Pleased With Function
      4.1.4.4 Normalization
      4.1.4.5 Present Condition
      4.1.4.6 State Last 4 Hours
      4.1.4.7 Motor Test State
      4.1.4.8 Overall Patient State
    4.1.5 Testing
Acknowledgement

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List of Figures

Figure 1: System overview [3]........................................................................................................ 2
Figure 2: Speed - Right hand ........................................................................................................ 7
Figure 3: Speed - Left hand ........................................................................................................ 7
Figure 4: Increasing speed - Failure time .................................................................................... 7
Figure 5: Speed - Random chase ................................................................................................ 7
Figure 6: Avg. taps for question 8 and 9 ..................................................................................... 7
Figure 7: Percentage correct - Right hand .................................................................................. 8
Figure 8: Percentage correct - Left hand .................................................................................... 8
Figure 9: Percentage correct - Failure time ................................................................................ 8
Figure 10: Percentage correct – Random Chase ......................................................................... 8
Figure 11: Percentage correct - Avg. of Q. no. 8 and 9 ................................................................. 8
Figure 12: Failure time (4 miss in a row) ................................................................................... 9
Figure 13: Failure time (3 miss in a row) ................................................................................... 9
Figure 14: Spiral test – Sd1 ........................................................................................................ 10
Figure 15: Spiral test - Sd2 .......................................................................................................... 10
Figure 16: Spiral test – Score ....................................................................................................... 10
Figure 17: Overall design of the system .................................................................................... 11
Figure 18: Database design .......................................................................................................... 12
Figure 19: Fuzzy inference system architecture ......................................................................... 13
Figure 20: General rule for defining fuzzy sets ........................................................................ 14
Figure 21: Input variable - Speed................................................................................................ 16
Figure 22: Input variable - Percentage correct ......................................................................... 16
Figure 23: Input variable - Speed-LR ........................................................................................ 16
Figure 24: Input variable - Percentage correct-LR ................................................................... 16
Figure 25: Input variable - Failure time ..................................................................................... 17
Figure 26: Input variable - Spiral score ..................................................................................... 17
Figure 27: Input variable - Sd1 ................................................................................................... 17
Figure 28: Input variable - Sd2 ................................................................................................... 17
Figure 29: Input variable - Present condition ............................................................................ 17
Figure 30: Fuzzy inference engine [14] ..................................................................................... 22
Figure 31: Fuzzy inference system class diagram ..................................................................... 24
Figure 32: Class diagram for graphs .......................................................................................... 25
Figure 33: Classes relating to patient data .................................................................................. 25
Figure 34: Class diagram relating to administrative tasks .......................................................... 26
Figure 35: Flowchart for verifying a valid test .......................................................................... 27
Figure 36: Compliance flow chart ............................................................................................. 28
Figure 37: Flow chart for identifying alert ............................................................................... 29
Figure 38: Testing membership function for present condition .............................................. 33
Figure 39: Absolute difference between FIS diagnosed condition and patient’s own assessment .......................................................................................................................... 34
Figure 40: Graph at period comparison screen ....................................................................... 35
## List of Tables

Table 1: Diary test options and database values ................................................................. 5  
Table 2: FIS membership functions .................................................................................. 16  
Table 3: FIS rules .............................................................................................................. 21  
Table 4: FIS output ........................................................................................................... 23  
Table 5: Results from the FIS at various stages of development ...................................... 34  
Table 6: Hardware requirements ....................................................................................... 50  
Table 7: Statistical data related to tapping test variable - Speed ...................................... 57  
Table 8: Statistical data related to tapping test variable - Percentage correct ................. 59  
Table 9: Data related to tapping test variable - Failure time .......................................... 60  
Table 10: Statistical data related to spiral drawings .......................................................... 61  
Table 11: Black box testing - Test cases ......................................................................... 65  
Table 12: White box testing - Test cases ......................................................................... 66  
Table 13: Problems identified ......................................................................................... 67
1 Introduction

Parkinson is a slowly progressive neurological disease. It occurs due to loss of dopamine. Dopamine allows control of the body’s muscles and movement. When 80% of the dopamine producing cells is damaged, the symptoms of Parkinson disease appear [1].

No cure for the disease is present; however, there are some treatments available which focus on the relief of symptoms. The key symptoms are

- Shaking (Tremor)
- Stiffness (Rigidity)
- Slow movement and reflexes
- Difficulty with balance

Parkinson patients can also have other problems like depression, tiredness, difficulty in writing, eating and swallowing [2].

The disease can affect both men and women. Mostly the disease is developed after the age of 65, but in some people under age 50 can also have the disease. Diagnosis of the disease is a quite difficult as there is no test available. Diagnosis can be done only after thorough examination of the patient.

A number of medicines are available for the treatment of the disease. The medicine helps to ease the symptoms. As most symptoms are caused by the lack of dopamine, the medicines either replace or mimic dopamine.

1.1 Background

Solvay Pharmaceuticals is involved in research on duodenal infusion of a levodopa/carbidopa gel (Duodopa®) in patients with advanced Parkinson’s disease. The purpose of an ongoing study (DAPHNE) is to evaluate long-term effects and costs of Duodopa® treatment on these patients.

This application is planned to be implemented in DAPHNE. In measuring the health effects, a hand computer-based test battery with diary questions and motor tests is used four times per day during a total of ten periods of one week each.

The existing system consists of PDAs (Personal Digital Assistants) with a program which presents an interface for patients to enter diary data and perform motor tests and transmit this data to a database server via a mobile net. It also consists of a server program which receives the data messages from the PDA program, for further processing and storage in a database, to be displayed on demand from various users [3, 4, 5].

An existing system parse the data from xml files, inserts the data into a database as raw data and distributes the data into different tables [3]. This work involves calculating summaries.
from raw data and storing these in the database. This work aims to diagnose patient’s state based on the test results, summarize the test results and present them in graphical form to the clinical staff.

**Figure 1: System overview [3]**

### 1.2 Problem Definition

The existing system collects the data regarding the tests performed by the patients, but there is no mechanism which can analyze the results and diagnose patient’s state based on the performance in the test. Moreover, the system is also required to keep the history of the patient in electronic form, so that it can assist in reviewing the patient’s history and the time and cost can be saved in keeping the tracks in paper form. The system is not limited to a particular place (clinic). In fact, it can be accessed from anywhere using a web browser. Fuzzy logic is used for diagnosing patient’s current state based on the test results. The performance of the fuzzy system is measured based on the difference between the patient’s own analysis of his present condition and the diagnosed state by the system. For the overall period state of the patient, different weights are assigned to the parameters based on an expert’s opinion.

### 1.3 Fuzzy Inference Systems

Fuzzy logic is a powerful tool to make intelligent systems to solve many complex problems, such as an expert system. Some medical expert systems are also being developed using fuzzy set theory [6]. Some examples of using fuzzy logic in application development includes
microprocessors, washing machines, fuzzy camera and camcorders that map image data to lens and fuzzy voice commands such as “up”, “down”, “land” to control helicopters[7].

In the medical field, most medical concepts are fuzzy. The fuzzy nature of concepts and their relationships are the basis of using fuzzy logic in medical field. Similarly as in other medical systems [6], fuzzy logic is used for diagnosing the patient’s current condition based on their performance in the test.

To develop a rule based fuzzy system, experts often describe their statements in terms of if-else rules.

A statement like, if x is A, and y is B then z is C.

For examples, the rate at which intravenous fluids are administered to a patient in the ICU is determined by the physician. However, if we describe a physician statement in terms of if-else rule, it will be, if arterial blood pressure is high and hourly urine output is high then intravenous fluid rate needs to be reduced [8].

Here:
x is arterial blood pressure, A is “high”
y describes hourly urine output, B is “high”
z is the intravenous fluid rate, C is “reduced”

Each input variable is defined by a fuzzy set and each fuzzy set is defined by a linguistic value. The linguistic values are associated with the rules and are evaluated to find the membership values. These membership values define the degree of membership. The degree can be in the range of 0 to 1. The variables are represented by a fuzzy set and needs to be fuzzified before passing to the FIS. This leads to a calculation of membership values for every possible value of the input variable.

The output from the FIS is in the form of probability. Every time, input is given to the system, some rules are fired and the results are produced with an indicator of likelihood. For achieving this task an expert’s knowledge is required to define simplified but realistic rules.

1.4 Goals

The scope of the thesis is to develop a prototype web application that provides feedback based on the available raw data regarding the patient’s tests. A detailed description regarding the user requirements can be found in appendix I. The main features of the application are:

- Calculate Motor Test State (MTS) of patient using Fuzzy Inference System (FIS), based on e-diary questions and motor test.
- Generate Period Summary (PS) based on the available test data within a specific period.
- Highlight alerts during a period in case of bad state, large fluctuations, extreme states (off, dyskinetic) and inconsistency between state variables.
- Graphical presentation of patient’s data during a period.
1.5 Questions for Investigation

The validity of this report depends upon the extent to which the following questions have been possibly answered:

- Are the rules significant enough to represent the actual patient’s state?
- What factors can affect the overall patient’s score?
- How the overall score can be verified?
- How any inconsistency in the result can be tracked?
- What factors are responsible for an unexpected result?

- Rectify any error in the stored data.
- Export data into text files to be used for analysis.
2 Data Analysis

The data available for the system is from an existing database which is used for storing the information regarding the tests performed by the patients. This data contains information about the e-diary and motor test. For the analysis, a sample of more than 300 sample tests, including 12 patients with period “Month 0” and 1 patient with Baseline period was used.

2.1 E-diary Data

For the e-diary there are seven questions (1 to 7) need to be answered by the patients. Out of these seven, question 2 (State last 4 hours) is in percentage of time, where as all other are from 1 to 5 except for “Present Condition” (question 7) which is from 1 to 7. The data relating to question 7 is rescaled from -3 to +3, where -3 represents extremely off state, +3 represents extremely dyskinetic state and 0 represents the good state. Rescaling is done as the outputs from the Fuzzy Inference System (FIS) will also be available at the scale of -3 to +3.

<table>
<thead>
<tr>
<th>Database Values</th>
<th>Difficulty to walk</th>
<th>Painful cramps</th>
<th>Pleased with function</th>
<th>Present condition</th>
<th>Diagnosed condition MTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Very off</td>
<td>Very off</td>
</tr>
<tr>
<td>-2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Moderate off</td>
<td>Moderate off</td>
</tr>
<tr>
<td>-1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Slightly off</td>
<td>Slightly off</td>
</tr>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>1</td>
<td>Cannot</td>
<td>All the time</td>
<td>Not at all</td>
<td>Slightly dyskinetic</td>
<td>Slightly dyskinetic</td>
</tr>
<tr>
<td>2</td>
<td>Very difficult</td>
<td>Most of the time</td>
<td>Slightly pleased</td>
<td>Moderate dyskinetic</td>
<td>Moderate dyskinetic</td>
</tr>
<tr>
<td>3</td>
<td>With difficulty</td>
<td>Half of the time</td>
<td>Moderate pleased</td>
<td>Very dyskinetic</td>
<td>Very dyskinetic</td>
</tr>
<tr>
<td>4</td>
<td>Rather good</td>
<td>Small part of time</td>
<td>Rather pleased</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Very good</td>
<td>Not at all</td>
<td>Very pleased</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Diary test options and database values

For the questions relating to ability to walk (question 1), painful cramps (question 5) and pleased with function (question 6), the data is normalized on the scale from 0 to 3 to comply with the motor test state. The normalized data will be used only for the calculation of overall score of the patient during the period. Normalization is done using the following formula.

\[
\text{Normalized value} = \frac{3 \times (x - 5)}{4}
\]
2.2 Motor Test Data
For the motor test, there were two main test-types in it.

- Tapping tests
- Spiral drawings

The data available is in raw format and needs to be converted into some meaningful manner. Details can be found in appendix III.

2.2.1 Tapping Data
There are four types of tests available in the tapping test. From the tapping test, speed, percentage correct, failure time is determined for all the questions. These are

2.2.1.1 Speed
Speed is the number of taps per 20 seconds. As there are four tests available in this category, so the speed is determined as follow:
2.2.1.2 Percentage Correct

For percentage correct, same analysis is done as for speed. The speed is valueless, if the percentage correct is low.

Figure 7: Percentage correct - Right hand
Figure 8: Percentage correct - Left hand
Figure 9: Percentage correct - Failure time
Figure 10: Percentage correct – Random Chase
Figure 11: Percentage correct - Avg. of Q. no. 8 and 9
2.2.1.3 Failure Time

For failure time, a special test question 10 (Increasing speed) is considered.

Two types of statistics are calculated three and four miss in a row. Based on the above statistics, it is observed that most of the times, the patient doesn’t fail in case of 4 miss in a row. So for the FIS, three miss in a row is a better option.
2.3 Spiral Data

There are three spirals to be drawn for each test. A spiral can either be valid or invalid. The validity, score and Standard deviation is determined using a specialized program made by Mr. Xiao Hu [9]. The results from the sample data for the spirals are as follow:

- **Figure 14: Spiral test – Sd1**
- **Figure 15: Spiral test - Sd2**
- **Figure 16: Spiral test – Score**
3 Design

After data analysis, the next phase is to design the FIS. As the system includes a web application, so the application has client-server architecture. All the data relating to the tests and any calculations regarding the data were made at the server end. All the calculations were triggered four times a day and all the uncalculated data was compiled in some meaningful manner and saved in the database. Later on, this data was used to be shown at the client end upon request using a web browser. The overall design of the system is as follow:

![Overall design of the system](image)

The whole system can be divided into three sub modules namely,

1. Database Design
2. Fuzzy Inference System Design
3. Web Application Design

3.1 Database Design
The database available in the system contains the information about the tests performed by the patients, but there were no tables available to store the results of the tests. As the new application is integrated with an existing system, so the same database with some enhancement is being used for this product. The design regarding the database is as follow.
There are four tables added in the existing database and one table is modified namely,

1. Tap Data Summary
2. Spiral Data Summary
3. Motor Test State
4. Period Summary
5. Log (modified table)

3.2 Decision Support System Design

A library (FuzzyJ) provided by National Research Council of Canada (NRC) [10, 11] is used for the development of the system.
3.2.1 Architecture of FIS

The architecture of the system is as follows:

1. Input
2. Fuzzification
3. Fuzzy Rules
4. Fuzzy Inference Engine
5. Defuzzification
6. Output

![Fuzzy Inference System Architecture](image)

**Figure 19: Fuzzy inference system architecture**

3.2.1.1 Inputs

For the diagnosis of condition, the following inputs are given to the FIS.

1. Speed (question 11 of tapping test)
2. Speed – LR (mean value of question 8 and 9 of tapping test)
3. Percentage Correct (question 11 of tapping test)
4. Percentage Correct – LR (mean value of question 8 and 9 of tapping test)
5. Failure Time – Increasing speed (question 10 of tapping test)
6. Spiral Score (question 13, 14, 15 of spiral drawings)
7. Sd1 (question 13, 14, 15 of spiral drawings)
8. Sd2 (question 13, 14, 15 of spiral drawings)
9. Present Condition (question 7 of E-diary)

*Speed* – Speed is the number of taps per tapping question

*Speed (LR)* – average number of taps for question 8 and 9

*Percentage Correct* – number of correct clicks / speed

*Percentage Correct (LR)* – average number of correct clicks / average speed

*Failure Time* – 3 consecutive wrong taps during question number 10 of tapping test

*Spiral Score* – average score of valid spirals from question 13, 14 and 15.

*Sd1* – average score of valid spirals from question 13, 14 and 15. It is the standard deviation of dyskinetic movement’s component of a spiral.

*Sd2* – average score of valid spirals from question 13, 14 and 15. It is the standard deviation of tremor component of a spiral.

*Present Condition* – as defined by the patient in diary test, question 7.

### 3.2.1.2 Fuzzification

The Fuzzification operator has the effect of transforming crisp data into fuzzy sets [12]. Membership function is used to associate a grade to each linguistic term [13].

From the statistics of sample data, rules are made. For each variable, the tendency of results is observed and the fuzzy sets are defined based on these results. In the sample data, it was found that there exists a sequence. A very low score is in the range of up to 30% of the values. A rather low score is in the range from 10% to 50% of the values. Similarly, a low score is observed in the range from 30% to 70% of the sample data and a high score is above 50% of the results. So as a general rule the ranges are defined as follow:

![General Rule for Defining Fuzzy Sets](image)

**Figure 20: General rule for defining fuzzy sets**

In case of spiral score, sd1 and sd2, the rules are the same, except for the fuzzy terms. These terms are replaced as very low is replaced by low, low is replaced by rather high, rather low is replaced by high and high is replaced by very high.
<table>
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<th>Based on</th>
<th>Range</th>
<th>Fuzzy Terms</th>
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<td>Min</td>
<td>Max</td>
<td>Min</td>
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<td>Q. No. 11</td>
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<td>50</td>
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<td></td>
<td>Rather Low:</td>
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<td></td>
<td>High:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not Very Low:</td>
</tr>
<tr>
<td>Speed Left / Right Hand</td>
<td>Q. No. 8 and 9</td>
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<td>100</td>
<td>Very Low:</td>
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**Table 2: FIS membership functions**

Graphical presentation of these membership functions are as follow.

**Figure 21: Input variable - Speed**

**Figure 22: Input variable - Percentage correct**

**Figure 23: Input variable - Speed-LR**

**Figure 24: Input variable - Percentage correct-LR**
Figure 25: Input variable - Failure time

Figure 26: Input variable - Spiral score

Figure 27: Input variable - Sd1

Figure 28: Input variable - Sd2

Figure 29: Input variable - Present condition
3.2.1.3 Fuzzy Rule Base

Fuzzy rules are defined in terms of “if-then” statements. The rules are the transformation of an expert’s knowledge into the system. For the application under consideration a number of rules are defined based on input variables.

Initially, some basic rules with speed, percentage correct, failure time were introduced and their outputs were observed. The problem at this level was the diagnosed state and the rules were limited to Very off (-3), moderate off (-2), very dyskinetic (+3) and moderate dyskinetic (+2) states. Later on, some more rules were introduced to cover the slightly off (-1) and slightly dyskinetic (+1) states.

At this stage only random chase (question 11) of motor test was considered for calculating the speed and percentage correct, and for failure time (question 10) the standards were based on 4 misses in a row. The results observed were not so impressive, so motor test question 8 (right hand test) and 9 (left hand test) and failure time rule was modified to 3 miss in a row were also introduced in the FIS. As there were no means of determining if a patient is right handed or left handed, so an average of both the tests were taken for defining the rules. Later on rather high and rather low rules were also introduced regarding the left hand and right hand rules.

Now it was the time for the spirals to contribute to the FIS. By the help of Mr. Xiao Hu [9] the results regarding the spirals analysis were available for the FIS. The results were improving by the introduction of new rules in the FIS.

Analyzing the results concluded that if a patient diagnosis his present condition as “good”, the FIS always diagnoses the state as “good”. So, FIS needs some rules regarding the “good” state. So rules were introduced in the system for it and the results were satisfactory at this stage. Development of the FIS was complete now. The rules are as follow:
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<td>-</td>
<td>-</td>
<td>-</td>
<td>high</td>
<td>good</td>
<td>-2</td>
</tr>
<tr>
<td>54</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rather high</td>
<td>good</td>
<td>-1</td>
</tr>
<tr>
<td>55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Very high</td>
<td>Not Very high</td>
<td>3</td>
</tr>
<tr>
<td>56</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>high</td>
<td>Not Very high</td>
<td>2</td>
</tr>
<tr>
<td>57</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rather high</td>
<td>Not Very high</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3: FIS rules
3.2.1.4 FIS Inference Engine

Fuzzy Inference Engine (FIE) is responsible for firing of the rules. The rules are fired only if they are matched. Mamdani fuzzy inference is used for the development of the system. The inference engine checks for the appropriate matching of rules from the rule based, and also the degree to which the rule is matched. The FIE performs the following steps to obtain a fuzzy output as a combination of all the matched rules.

1. Firing level of each matched rule
2. Output of each fired rule
3. Aggregation of each rule output to obtain overall output of the system

Mamdani model is used for the execution of the rules. After a rule is fired, a fuzzy sum of the current value and the previous value is generated. When all the rules have been checked or executed, defuzzification is done to get the crisp output.

![Fuzzy inference engine](image)

3.2.1.5 Defuzzification

Defuzzification is the process of translating the fuzzy set output values into crisp output. Weighted average approach is used for defuzzification of the fuzzy set.

3.2.1.6 Output

The crisp output of the system is the patient’s diagnosed condition which can be in the range of -3 to +3. The diagnosed outputs and the patient’s condition are mapped as follow.
<table>
<thead>
<tr>
<th>Crisp Output</th>
<th>Diagnosed Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>Very Off</td>
</tr>
<tr>
<td>-2</td>
<td>Moderate Off</td>
</tr>
<tr>
<td>-1</td>
<td>Slightly Off</td>
</tr>
<tr>
<td>0</td>
<td>Good</td>
</tr>
<tr>
<td>1</td>
<td>Slightly Dyskinetic</td>
</tr>
<tr>
<td>2</td>
<td>Moderate Dyskinetic</td>
</tr>
<tr>
<td>3</td>
<td>Very Dyskinetic</td>
</tr>
</tbody>
</table>

Table 4: FIS output

3.2.2 FIS Design Class Diagram

The FIS layer lies in between the web application and the database, the results of tests are passed to the FIS which diagnose the patient’s condition on the basis of answers. FIS module is scheduled to be executed four times in a day (morning, afternoon, evening and night) and all the uncalculated tests will be analyzed for diagnosis.

The validity of a test is based on the “Random Chase” (question 11) of the motor test. If there is an entry in the database regarding a particular test in the “tapdata” table for question 11 of the motor test, the test is considered as valid. Otherwise, no diagnosis is made regarding that test as it is considered as incomplete.

The class diagram of FIS is as follow.
3.3 Web Application Design

In the web part of the system, the application provides a number of features which are explained in appendix I and II. However, all the interaction between the web and the database is interconnected by the middle layer (Fuzzy Inference System). There are a number of classes which are involved for displaying the results to the users.

For better understanding, the class diagram has been divided into three modules as stated below.

Figure 31: Fuzzy inference system class diagram
Figure 32: Class diagram for graphs

Figure 33: Classes relating to patient data
Figure 34: Class diagram relating to administrative tasks
4 Implementation and Testing

The system is implemented using MySql Server 5.0, FuzzyJ by NRC [11], jdk 1.4, JSP and Fusion Charts 2.3 [15]. The site is hosted using Apache Tomcat 4.1 server. The backup data from DAPHNE is loaded in the MySql, and is then accessed using java. Communication between java and MySql is done by using mysql-connector-java version 3.0.17. The implementation is done using the sample dataset of 300 tests and later on tested with the test data.

4.1 Business Logic

4.1.1 Invalid Test

Before diagnosing the state of a patient, a test needs to be verified to be a valid test. There might be scenario, when a test has been started, but not completed by the time. The criteria for verifying a test to be valid or invalid is based on question 11 of the tapping test.

![Flowchart for verifying a valid test](image)

Figure 35: Flowchart for verifying a valid test

4.1.2 Compliance Calculation

To analyse the progress of patient during a period in terms of number of tests performed by him is done using compliance. Compliance is calculated based on number of valid tests in the system from the first test to a maximum time of 28th test time slot. If the patient has
performed more tests, all the tests after the deadline will not be considered for calculating the compliance.

![Compliance flow chart]

**Figure 36: Compliance flow chart**

### 4.1.3 Alert

Sometimes there are occasions when the results are unusual. This should be noted as an alert. For this reason warnings are generated for consideration by the clinical staff. The alerts are related to worst conditions of e-diary answers and diagnosed motor test state. There might be some inconsistency between the patient’s statement about his condition and the diagnosed state of the patient. This inconsistency is also notified. There are five specific conditions under which warning are generated. These are,

- Bad occasions (e.g. unable to walk)
- Extremely off
- Extremely dyskinetic
- Large fluctuations (e.g. jump of 3 units or more in case of scale 1-7)
- Inconsistencies (e.g. Motor test shows good result, but perceived current state displays bad)
4.1.4 Period Summary

Period summary is calculated bases on the test results during the period. There are number of variables which are calculated before calculating the overall score of the patient. These variables are mentioned in the database design table “Period Summary”. The formulas used to calculate these values are
### 4.1.4.1 Ability To Walk
- Ability to Walk (AW, Best two) = \( \frac{x}{N} \times 100 \)
- MSD Ability To Walk (MSD_AW) = \( \sum \frac{(X)^2}{N} \) (Normalized)

### 4.1.4.2 Painful Cramps
- Painful Cramps (PC, Worst three) = \( \frac{x}{N} \times 100 \)
- MSD Painful Cramps (MSD_PC) = \( \sum \frac{(X)^2}{N} \) (Normalized)

### 4.1.4.3 Pleased With Function
- Pleased With Function (PWF, Best Two) = \( \frac{x}{N} \times 100 \)
- MSD Pleased With Function (MSD_PWF) = \( \sum \frac{(X)^2}{N} \) (Normalized)

### 4.1.4.4 Normalization
The following formula is used for normalization of all the above mentioned values: \( \frac{3 \times (x - 5)}{4} \)

### 4.1.4.5 Present Condition
- Present Condition Good Time (PCond) = \( \frac{x}{N} \times 100 \) (slightly off, good, slightly Dyskinetic)
- MSD Present Condition (MSD_PCond) = \( \sum \frac{(X - 4)^2}{N} \)
- Present Condition Off Time (PCond_OT) = \( \frac{x}{N} \times 100 \) (moderate off, Very off)
- Present Condition Dyskinetic Time (PCond_DT) = \( \frac{x}{N} \times 100 \) (moderate Dyskinetic, Very Dyskinetic)
4.1.4.6 State Last 4 Hours

- Percentage of Good Time (PGT) = \[ \frac{\sum_{i=1}^{N} X_i}{N} \]
  where \( X_i \) is the percentage of good time from Q2

- Percentage of Off Time (POT) = \[ \frac{\sum_{i=1}^{N} X_i}{N} \]
  where \( X_i \) is the percentage of good time from Q2

- Percentage of Dyskinetic Time (PDT) = \[ \frac{\sum_{i=1}^{N} X_i}{N} \]
  where \( X_i \) is the percentage of good time from Q2

4.1.4.7 Motor Test State

- MTS Percentage of Good time (MTS) = \[ \frac{x}{N} \times 100 \]
  where \( x \) is the count of “good time” (-1, 0, 1) from MTS

- MSD MTS Good time (MSD\_MTS) = \[ \frac{\sum(X - 0)^2}{N} \]

- MTS Percentage of Off time (MTSOT) = \[ \frac{x}{N} \times 100 \]
  where \( x \) is the count of “off time” (-2, -3) from MTS

- MTS Percentage of Dyskinetic time (MTSDT) = \[ \frac{x}{N} \times 100 \]
  where \( x \) is the count of “dyskinetic time” (2, 3) from MTS
4.1.4.8 Overall Patient State

- **Overall Score**

\[
\frac{W_1 \cdot (MSD\_MTS) + W_2 \cdot (MSD\_AW) + W_3 \cdot (MSD\_PWF) + W_4 \cdot (MSD\_PCond) + W_5 \cdot (MSD\_PC)}{W_1 + W_2 + W_3 + W_4 + W_5}
\]

\[W_1 = 0.4; W_2 = 0.5; W_3 = 0.15; W_4 = 0.2; W_5 = -0.25\]

- **Overall Patient Off Time:**

\[
\frac{W_1 \cdot (MTSOT) + W_4 \cdot (PCond\_OT)}{W_1 + W_4}
\]

- **Overall Patient Dyskinetic Time:**

\[
\frac{W_1 \cdot (MTSDT) + W_4 \cdot (PCond\_DT)}{W_1 + W_4}
\]

\[W_1 = 0.4; W_4 = 0.6 \text{ (For Overall Patient Off and Dyskinetic Time)}\]
4.2 Testing

The purpose of testing is to identify maximum number of bugs in less time. For this purpose, both black box and white box testing is performed to identify as much bugs as possible. However, there are still chances for some bugs which remain unidentified during the testing phase.

4.2.1 White Box Testing

White Box testing is the detailed testing of the system at a very low level. For the FIS, all the membership functions are tested by plotting them using Fuzzy J to be sure that they are defined properly.

![Diagram of Testing Membership Function for Present Condition]

Figure 38: Testing membership function for present condition

Later on, the firing of the rules is also tested by giving manual inputs to the system and looking at the fired and unfired rules. Similarly, from the statistics and there results, rules are checked to be fired correctly. For example, the system is run using all the rules except for the “Good” state rules of Present Condition and results are saved. Later on, the system is run again including the “Good” rules also. The results are compared in such a way that the diagnosed state for all the tests for which Present Condition is not equal to “good” should not be changed.

4.2.2 Black Box Testing

Black box testing is performed with the help of my colleague Mr. Xiao Hu [9]. Four patients were identified and all the calculations that appear on the web are calculated manually and compared with those on the web. All the formulas are checked and verified. See appendix V for details.
5 Results and Observations

5.1 Fuzzy Inference System

A fuzzy inference system is developed to diagnose the patient’s condition based on the test result. The graph below displays the various stages of development and the absolute difference between the diagnosed state and patient’s own assessment.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Rules</th>
<th>Absolute Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>With Speed, Percentage Correct, Failure time but without rather high and rather low rules</td>
<td>213</td>
</tr>
<tr>
<td>2</td>
<td>Including Speed-LR and Percentage-LR rules</td>
<td>191</td>
</tr>
<tr>
<td>3</td>
<td>Including rather high and rather low rules</td>
<td>182</td>
</tr>
<tr>
<td>4</td>
<td>Including Spiral rules without rather high and rather low rules</td>
<td>179</td>
</tr>
<tr>
<td>5</td>
<td>Including rather high and rather low rules in spirals</td>
<td>180</td>
</tr>
<tr>
<td>6</td>
<td>Introducing Present Condition (Good) rule</td>
<td>186</td>
</tr>
</tbody>
</table>

Table 5: Results from the FIS at various stages of development

![Difference between FIS output and Patient's Statement](image)

Figure 39: Absolute difference between FIS diagnosed condition and patient’s own assessment

The results show that the absolute mean difference at stage 6 is slightly higher than stage 4, but it covers the entire domain. At stage 4, all the scenarios are not covered by the FIS for the evaluation of the patients. For example, at stage 4, FIS was having the same output “good”, if the present condition is “good”, but by the introduction of new rules, the output might differ based on the results of other input variables.
5.2 Web Application
A web application is developed to be used by the clinical staff for the analysis of patient’s progress in the study. The application has the following main screens.

5.2.1 Period Comparison

Comparison of values for the overall patient state is done on this page. The graph contains the patient’s overall score, group mean and the group standard deviation for a particular period. For the first time, all the patient’s periods are displayed, however, the user can select among the available periods to compare. There are two more links which are available with the period’s name. One is the “Summary” which takes the user to the summary page of that period and the other is the “Alerts” which represents some abnormalities found during that period. Alerts may or may not be present. These will be explained later in detail.
5.2.2 Detailed Comparison

The first graph displays the values related to Period State Variables in terms of patient’s good, off and dyskinetic time along with the Group Mean and Standard Deviation. However, there are some state variables (ability to walk, painful cramps and pleased with function) which only have good time. The bars represent the patient values and the sticks represent the group mean and standard deviation.

The second graph relates to the E-diary and Motor test questions. For a particular period, the first stick displays the patient’s mean and standard deviation and the second stick represents the group mean and standard deviation.

Figure 41: Detailed comparison
5.2.3 Period Summary

After selecting a period from “Period Comparison” or “Detailed Comparison”, the summary of a selected patient’s performance for the specific period will be displayed. The information contained relates to,

- Period state variables, which are displayed in percentage of time, and
- E-diary and motor test results, which contain the median, minimum and maximum values for each type of question or test for the whole period.

Figure 42: Period summary
5.2.4 Alerts

Figure 43: Alerts screen

A brief description related to unusual conditions in terms of date, time, state variable and type of warning will be displayed where necessary. The page is also printable.
5.3 Observations

5.3.1 Compliance
On applying the application on the test data, it was found that the mean compliance for all the periods by all the patients is almost 82 percent with median at 93%.

![Figure 44: Compliance based on test data](image-url)
5.3.2 Relationship between Period State Variables

5.3.2.1 Relationship between Overall Score and other variables

On comparing the plots of “Overall Score” and other period state variables, it can be observed that there is a strong correlation between present condition, ability to walk and overall score. However, the relationship with motor test state, pleased with function and painful cramps is a bit weak with few outliers.
5.3.2.2 Relationship between Motor Test State (MSD) and other variables

Diagnosed motor test state has a bit weak relationship with all the other variables except for overall score (sec 5.3.2.1). This is due to difference in between the patient’s own assessment of their state and their performance in the motor tests.
5.3.2.3 Relationship between Present Condition (MSD) and other variables

Present condition has strong relationship with pleased with function and overall score (sec 5.3.2.1); however, the relationship is bit weak with ability to walk, painful cramps and motor test state (sec 5.3.2.2).
5.3.2.4 Relationship between Ability to Walk (MSD) and other variables

Ability to walk is in good relationship with overall score and a bit weak relationship with other variables, with a few outliers in all the other cases.

5.3.2.5 Relationship between Pleased with Function (MSD) and other variables

Pleased with function has a strong relationship with present condition (sec 5.3.2.3), but not with the other variables in the period summary section. Relationship with painful cramps is very weak.

5.3.2.6 Relationship between Painful Cramps (MSD) and other variables

Painful cramps have no strong relationship with any of the other variables, but have weak relationships with all of them. However, relationship with pleased with function is very weak.
5.3.3 Patient’s Results from Month 0 and Month 3

At present there are 17 patients who have completed their Month 0 and are now either in Month 3 of the study or above it. An analysis of their progress from one month to another is observed as follow.

The correlation between the variables is quite good. Sometimes, the deviations are quite large. This is due to mean square deviation used for calculating the period state variables. The overall score is the most stable among the period state variables.
5.4 Result Analysis

Based on the results mentioned above in this chapter, it can be concluded that:

- The rules formed cover the whole domain of the tests parameters.
- The finalized rules give optimal results with an acceptable error rate.
- The web application can be quite helpful for the doctors in order to review a patient’s records.
- Increased stability is observed for the “Overall Patient State” from Month 0 to Month 3.

5.5 Limitations

Although the rules are made by the help of an expert, but the reliability of the FIS is based on patient’s own assessment of the present condition. A better way to determine the reliability of the FIS is to compare its results with the results of an expert. Unified Parkinson Disease Rating Scale (UPDRS) [1] is a standard way to determine the condition of the patient. The UPDRS values regarding the patients in the study are not available at this stage. Both the FIS parameters and weights for calculating overall score need further optimization.
6 Conclusion

Application of fuzzy logic is increasing in the field of medicine. Medical concepts like high, low, very low etc are very well covered by the fuzzy logic. The developed system is cost benefit for the clinic staff, patients, project managers and researchers. Due to online availability of patient’s data and results immediate consultation can be provided within no time. The rules for diagnosing the current patient state were made with consultation of medical experts and are analyzed in depth, so that only affective rules are involved in the decision making process. Similarly, the graphical presentation of the results can also help in evaluating the patient’s condition. As the tests are performed after every three months by the patients, the medical staff can work on the patient during the period and can observe the results of the treatment given to the patient by observing their performance in the test.

Most of the time, in off or dyskinetic state, the patient is unable to walk which might be due to improper balance, stiffness or shaking. So, the overall patient state is highly affected by patient’s ability to walk. This factor is given the highest weight for the analysis. It was also observed that most of the times; the Parkinson patients don’t have cramps. So, this factor doesn’t affect their ability to walk.

The scores were verified, by statistical analysis of the results generated. The results were analyzed by looking manually in the system for the values, and any improper results were verified with reasons for non compliance. Any inconsistency can be tracked by highlighted as an alert in the system, which might be due to several reasons. Alerts section can help in focusing on areas which need immediate attention of the medical staff.

A web based Decision Support System is only an advisor and should not be considered as a replacement of the clinical staff. Moreover, some work is still remaining regarding the UPDRS values to make it optimal.

The developed system is in complying with the requirements as agreed upon in the requirements specification. It appears that the overall score is stable between test periods when the same patient keeps the same treatment. Modifications are expected to come during the testing phase by the clinical staff. Later on, the system will be available in real life to be helpful in decision making.

6.1 Future Work

Tuning the system in accordance with the UPDRS values still needs to be done in future. This involves adjusting the fuzzy sets and rules to comply with the UPDRS values. Neuro Fuzzy approach can also be used for tuning the parameters to comply with the UPDRS.

The system has been developed as a prototype and will be used by some users for evaluation purposes. Later on, it will be implemented in the real world at a large scale.
References


Appendix I: User Requirements

1. Purpose
The purpose of this document is to give a detailed description of the basic user and functional requirements of the system, as agreed upon. This documentation will highlight the functionality of the system to be designed to cater for the needs of the users. Any assessment of the completed system will be done keeping in view the system and user requirements mapped out in this document.

2. Intended Audience
The document is intended for thesis students, thesis advisors and system evaluators (Solvay Pharmaceuticals, Hannover, Germany). In the following sections, a detailed description regarding the functional and non-functional requirements along with external interfaces of the system will be described. Moreover, the document will contain system requirements, types of users and other requirements.

3. Overall Description
3.1. User Classes and Characteristics
The system consists of PDAs (Personal Data Assistant) with a program, which presents an interface for patients to enter diary data and perform motor tests and transmit these data to a database server via a mobile net. The web-application is connected to the database server. There are two types of users relating to this application.

1. Clinic Staff (including nurses and doctors)
2. Administrator of the DAPHNE feedback system

The Clinic Staff are allocated the PDAs to be used by the patient’s for performing the tests. The staffs are not limited to a particular place. The staff can be at different locations and can be identified by the PDA.

The administrator is responsible for the proper working of the system. User management, error correction, exporting data, system security, reliability and proper maintenance of the system are also the responsibility of the administrator.

3.2. System Services
The main services of this system can be divided into two parts according to user classes:

3.2.1. Clinic Staff
- View the list of patient’s registered at a particular site, test compliance of the patient’s during the last period and their first and last test entries in that period.
- The graphical comparison of overall state of the patient for a particular period with the mean value of the state of all the patients in the same period and its standard deviation.
• A graphical comparison of the values relating to a selected patient’s Period state variables, E-diary answers and motor test results with the corresponding group mean values and standard deviation.
• Patient’s summary relating to period state variables, E-diary and motor test results for a particular period.
• Highlighted alerts, if exist, for a particular period.
• Time series graphs relating to the E-diary and motor test results for a particular period along with date and time of test.
• Summary relating to the number of patients included in the system at various sites and the period wise distribution of these patients.

3.2.2. Administrator

• Correcting errors in terms of wrongly entered patient id or period id.
• Exporting data in form of text files for further analysis.
• Reset user’s password.

3.3. Fuzzy Inference System (FIS)

Combinations of test variables related to the patient state (per test occasion) are performed by a Fuzzy Inference system (FIS). A library (FuzzyJ) provided by National Research Council of Canada (NRC) will be used for this purpose. A rule-base (If-then-else) are developed utilizing expert knowledge and data. FIS is used to diagnose the patient’s condition based on patient’s answers.

3.4. Operating Environment

Below is the description related to the hardware and software requirements on the server. However, the users only need a web browser that supports JSP (Java Server Pages) and a modem with internet connection.

3.4.1. Hardware Requirements

<table>
<thead>
<tr>
<th>Processor</th>
<th>1 G Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAM</td>
<td>512 MB</td>
</tr>
<tr>
<td>Hard disk</td>
<td>20 GB</td>
</tr>
<tr>
<td>Internet Connection</td>
<td>Broadband</td>
</tr>
</tbody>
</table>

Table 6: Hardware requirements

3.4.2. Software Requirements

At the server, the software required for the communication are Java, MySQL and Fusion Charts 2.3. The interface will be provided by the JDBC connector mysql-connector-java (version: 3.1.12). This will act as a bridge for communication between Java and MySQL.

Apache Tomcat (version: 5.5.16) will act as a web-server and will fulfil the queries as requested by the client web browsers

At the client side, the system needs to be HTML (4.0 and later) compatible
3.5. **Functional Requirements**
The following are the main services that the system will provide. Only a brief description is given in this chapter to give the reader an idea about the functionality of the system.

3.5.1 **Login, Logout, Change Password**
These features are available to all the users for protecting the system from unauthorized access.

3.5.2 **View Patient Data**
After login, the user can view the list of all patients belongs to the user of a particular site, their last period (first entry to last entry), compliance with the diary and the last PDA unit used by the patient.

3.5.3 **Calculation of Patient State Values**
For the “Motor Test State” (MTS), a set of if-then rules are defined based on the results from motor tests and one e-diary question (Patient’s present perceived condition). The membership functions defined are linear containing “high” and “low” clauses based on actual data distribution in the study. MTS is defined on the scale [-3, +3] for each test occasion.

For the “ability to walk” and “painful cramps”, the best two outputs are counted, summed together and then divided by total number of observations to get the weekly percentage of good time.

For the “Overall Score” (OS) a weekly weighted average is calculated based on MTS result, “painful cramps”, “ability to walk”, “pleased with function” and “present condition”.

3.5.4 **Period Comparison**
After selecting a patient, the user can inspect the OS of the patient during each period of study along with the group mean and standard deviation.

Overall score is the weighted average means squared deviation of motor test state, ability to walk, painful cramps, pleased with function and present condition. A lower score represents better function. A higher score represents worse function.

An alert link will be highlighted, in case some unusual conditions relating to a period occurs. Cf 3.5.8.

3.5.5 **Detailed Comparison**
Functionality for comparing the patient’s performance during different periods is also provided by the system. In this section two types of graphs are available,

- Graph relating to patient’s period state variables
- Graph relating to e-diary, motor and spiral test results.
The graph relating to Patient Period State variables displays the patient’s values in terms of good, off, and dyskinetic time (where applicable). Group mean and standard deviation are also displayed in the graph. The period state variables include:

- Overall Patient State
- Ability to Walk (only good time)
- Painful Cramps (only good time)
- Pleased with Function (only good time)
- Perceived Current State
- Motor Test State

In the graph relating to e-diary and motor test results, the patient and group means are displayed in the form of bars and their standard deviations are represented by lines. The graph includes:

- Ability to Walk
- Percentage of Good, Off and Dyskinetic Time
- Worst Off
- Worst Dyskinetic
- Painful Cramps
- Pleased with Function
- Present Condition
- Speed (right / left hand / random chase)
- Percentage correct (right / left hand / random chase)
- Failure time (Increasing speed)
- Spiral Score
- Spiral Completion Time
- Motor Test State

3.5.6 Period Summary
There is a summary page which presents the details relating to a particular period. It includes the minimum, maximum and median values related to E-diary and motor test results. It also includes the percentage of good, off and dyskinetic time related to period state variables.

3.5.7 Raw Data Graphs
To have a closer look at the answers given by a patient in the individual tests, a raw data time series graph can be viewed. The graph is related to the specific period which was selected from the “Period Comparison” section. The graph includes the date and time slot of tests along with the categories which are mentioned for the e-diary and motor test questions.

3.5.8 Alerts
Sometimes there are occasions when the results are unusual. This should be noted as an alert. For this reason warnings are generated for consideration by the clinical staff. The alerts are related to worst conditions of e-diary answers and diagnosed motor test state. There might be some inconsistency between the patient’s statement about his condition and the diagnosed
state of the patient. This inconsistency is also notified. There are five specific conditions under which warning are generated. These are,

- Bad occasions (e.g. unable to walk)
- Extremely off
- Extremely dyskinetic
- Large fluctuations (e.g. jump of 3 units or more in case of scale 1-7)
- Inconsistencies (e.g. Motor test shows good result, but perceived current state displays bad)

3.5.9 Prints
The reports (period summary, alerts) can be printed on a standard A4 paper in an appropriate font.

3.5.10 Inclusion
Summary of the systems in terms of number of patients at each site and period can be viewed in the inclusion section of the application. This gives a general idea about the progress of the study and the current condition of a particular site.

3.5.11 Error Correction
After request from responsible staff, the administrator has the right to correct any wrongly entered patient or period IDs on the PDA’s. All changes are logged.

3.5.12 Export Data
Exporting data for statistical analysis (text file) will also be managed from the web-application. The export can be of four types.

- Period Summary - To export the period summary of all the patients and periods into a single text file.
- Raw Data – Data relating to answers for e-diary and summary of motor test results can be exported under this head.
- Detailed Export – This contains the detailed answers for the e-diary and motor test as given by the patient. This data is exported at a detailed level containing all the necessary information at a very low level.
- Log Export – Records related to modifications made in the patient’s data can also be exported in a text file.

3.6. Other Non-Functional Requirements
3.6.1 System Documentation
The system needs to be properly documented. Any change in the requirements should be captured and documented at the appropriate places. Updated versions of documents should be produced whenever necessary.

3.6.2 Security
For the security of the system, any modifications in the database from the application should be logged. Moreover, backups should be taken at regular intervals to recover the system from failure.
3.6.3 Reliability
To make the system reliable, all the calculations done by the system should be accurate and verified during the development phase of the system.

3.6.4 Availability
Twenty four hour availability of the system is necessary for its proper working. However, if the system fails at anytime, it should be able to recover within a limited time period. For this purpose, database backups will be used in case of error.

3.6.5 Scalability
The application works for the initial intended scope of use, but must be completely rewritten when the scope increases. A good design practice is to design for expandability of the system.
Appendix II: User Interfaces

MoDiTrac - DeciDU
Patient List

<table>
<thead>
<tr>
<th>Patient ID</th>
<th>Last Used Unit</th>
<th>Last Period</th>
<th>Compliance (%)</th>
<th>First Entry</th>
<th>Last Entry</th>
<th>Select Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>E0101</td>
<td>2006021</td>
<td>Month 3</td>
<td>96.4 %</td>
<td>2006-06-08</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>E0102</td>
<td>2006020</td>
<td>Month 0</td>
<td>71.4 %</td>
<td>2006-06-30</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>E0103</td>
<td>2006021</td>
<td>Month 3</td>
<td>14.3 %</td>
<td>2006-06-27</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>E0104</td>
<td>2006020</td>
<td>Month 0</td>
<td>100.0 %</td>
<td>2006-06-30</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>E0105</td>
<td>2006022</td>
<td>Month 3</td>
<td>99.3 %</td>
<td>2006-07-19</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>E0106</td>
<td>2006021</td>
<td>Baseline</td>
<td>100.0 %</td>
<td>2006-06-24</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Figure 66: Staff main screen

MoDiTrac - DeciDU
Raw Data

Figure 67: Raw data for motor test state
Figure 68: Raw data for spiral score containing invalid tests

Figure 69: Modify patient's record
Appendix III: Data Analysis

1. Tapping Data
Four types of tests available in the tapping test. These are used to determine speed, percentage correct, failure time is determined for all the questions. These are

1.1. Speed
The statistical analysis of sample data is as follow:

<table>
<thead>
<tr>
<th>Question</th>
<th>Question 9</th>
<th>Question 10</th>
<th>Question 11</th>
<th>Avg. of Question 8 and 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>41</td>
<td>36</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.1</td>
<td>24</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.2</td>
<td>30</td>
<td>26</td>
<td>14</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.3</td>
<td>32</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.4</td>
<td>36</td>
<td>33</td>
<td>15</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.5</td>
<td>41</td>
<td>36</td>
<td>16</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.6</td>
<td>43</td>
<td>39</td>
<td>16</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.7</td>
<td>47</td>
<td>42</td>
<td>17</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.8</td>
<td>52</td>
<td>46</td>
<td>17</td>
</tr>
<tr>
<td>Percentile</td>
<td>0.9</td>
<td>64</td>
<td>52</td>
<td>19</td>
</tr>
<tr>
<td>Percentile</td>
<td>1.0</td>
<td>98</td>
<td>95</td>
<td>49</td>
</tr>
</tbody>
</table>

| Quartile     | 0          | 4           | 4           | 3                        | 3                        | 8                        |
| Quartile     | 1 (0.25)   | 31          | 28          | 14                       | 19                       | 30                       |
| Quartile     | 2 (0.50)   | 41          | 36          | 16                       | 22                       | 38                       |
| Quartile     | 3 (0.75)   | 48          | 44          | 17                       | 26                       | 46                       |
| Quartile     | 4 (1.00)   | 98          | 95          | 49                       | 33                       | 89                       |

Table 7: Statistical data related to tapping test variable - Speed
From the above graphs, it can be seen that for question 8, most of the values lie in the range of 30 to 50 taps. Similarly, for question 9, the results lie in the same range as that of question 8. There is no mean to determine from database, whether a patient is left handed or right handed, so an average of the taps is taken for consideration. Increasing speed test is useful for calculating the failure time, so it is not considered for the speed.
1.2. Percentage Correct
For percentage correct, same analysis is done as for speed. The speed is valueless, if the percentage correct is low.

<table>
<thead>
<tr>
<th></th>
<th>Question 8</th>
<th>Question 9</th>
<th>Question 10</th>
<th>Question 11</th>
<th>Avg. of Question 8 and 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>81</td>
<td>67</td>
<td>77</td>
<td>96</td>
<td>73</td>
</tr>
<tr>
<td>Percentile 0.1</td>
<td>56</td>
<td>37</td>
<td>50</td>
<td>83</td>
<td>50</td>
</tr>
<tr>
<td>Percentile 0.2</td>
<td>65</td>
<td>48</td>
<td>58</td>
<td>89</td>
<td>58</td>
</tr>
<tr>
<td>Percentile 0.3</td>
<td>72</td>
<td>55</td>
<td>67</td>
<td>93</td>
<td>63</td>
</tr>
<tr>
<td>Percentile 0.4</td>
<td>78</td>
<td>62</td>
<td>71</td>
<td>95</td>
<td>68</td>
</tr>
<tr>
<td>Percentile 0.5</td>
<td>81</td>
<td>67</td>
<td>77</td>
<td>96</td>
<td>73</td>
</tr>
<tr>
<td>Percentile 0.6</td>
<td>85</td>
<td>71</td>
<td>84</td>
<td>100</td>
<td>77</td>
</tr>
<tr>
<td>Percentile 0.7</td>
<td>89</td>
<td>75</td>
<td>89</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>Percentile 0.8</td>
<td>92</td>
<td>81</td>
<td>94</td>
<td>100</td>
<td>84</td>
</tr>
<tr>
<td>Percentile 0.9</td>
<td>96</td>
<td>88</td>
<td>100</td>
<td>100</td>
<td>88</td>
</tr>
<tr>
<td>Percentile 1.0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>99</td>
</tr>
</tbody>
</table>

| Quartile       | 0          | 19         | 7        | 20        | 0                      |
| Quartile 1 (0.25) | 69        | 52         | 63       | 91        | 61                      |
| Quartile 2 (0.50) | 81        | 67         | 77       | 96        | 73                      |
| Quartile 3 (0.75) | 90        | 78         | 94       | 100       | 83                      |
| Quartile 4 (1.00) | 100       | 100        | 100      | 100       | 99                      |

Table 8: Statistical data related to tapping test variable - Percentage correct

As there is a strong relationship between speed and correct clicks. So, percentage correct is considered for question 11 and average of question 8 and 9 to be used by the FIS.
1.3. Failure Time
For failure time, a special test question 10 (Increasing speed) is considered.

<table>
<thead>
<tr>
<th></th>
<th>3 miss in a row</th>
<th>4 miss in a row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Percentile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>0.2</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>0.3</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>0.4</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>0.5</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>0.6</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>0.7</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>0.8</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>0.9</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>1.0</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Quartile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 (0.25)</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>1 (0.50)</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>2 (0.75)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>3 (1.00)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 9: Data related to tapping test variable - Failure time

For the failure time, two types of statistics are calculated three and four miss in a row. Based on the above statistics, it is observed that most of the times, the patient doesn’t fail in case of 4 miss in a row. So for the FIS, three miss in a row is a better option.
2. Spiral Data
There are three spirals to be drawn for each test. A spiral can either be valid or invalid. The validity, score and Standard deviation is determined using a specialized program made by Mr. Xiao Hu. The results from the sample data for the spirals are as follow:

<table>
<thead>
<tr>
<th></th>
<th>Sd1</th>
<th>Sd2</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>15,61</td>
<td>7,30</td>
<td>29,61</td>
</tr>
<tr>
<td>Percentile 0,1</td>
<td>9,87</td>
<td>4,99</td>
<td>21,08</td>
</tr>
<tr>
<td>Percentile 0,2</td>
<td>11,13</td>
<td>5,72</td>
<td>23,11</td>
</tr>
<tr>
<td>Percentile 0,3</td>
<td>12,66</td>
<td>6,28</td>
<td>25,42</td>
</tr>
<tr>
<td>Percentile 0,4</td>
<td>14,53</td>
<td>6,72</td>
<td>27,66</td>
</tr>
<tr>
<td>Percentile 0,5</td>
<td>15,61</td>
<td>7,30</td>
<td>29,61</td>
</tr>
<tr>
<td>Percentile 0,6</td>
<td>17,45</td>
<td>8,07</td>
<td>32,06</td>
</tr>
<tr>
<td>Percentile 0,7</td>
<td>19,53</td>
<td>8,82</td>
<td>34,45</td>
</tr>
<tr>
<td>Percentile 0,8</td>
<td>22,75</td>
<td>9,85</td>
<td>38,64</td>
</tr>
<tr>
<td>Percentile 0,9</td>
<td>26,30</td>
<td>12,23</td>
<td>44,73</td>
</tr>
<tr>
<td>Percentile 1,0</td>
<td>61,45</td>
<td>70,85</td>
<td>141,84</td>
</tr>
<tr>
<td>Quartile 0</td>
<td>5,59</td>
<td>2,68</td>
<td>15,68</td>
</tr>
<tr>
<td>Quartile 1 (0,25)</td>
<td>11,78</td>
<td>5,97</td>
<td>24,20</td>
</tr>
<tr>
<td>Quartile 2(0,50)</td>
<td>15,61</td>
<td>7,30</td>
<td>29,61</td>
</tr>
<tr>
<td>Quartile 3(0,75)</td>
<td>21,23</td>
<td>9,33</td>
<td>36,48</td>
</tr>
<tr>
<td>Quartile 4(1,00)</td>
<td>61,45</td>
<td>70,85</td>
<td>141,84</td>
</tr>
</tbody>
</table>

Table 10: Statistical data related to spiral drawings
Appendix IV: Database Modification

DROP TABLE IF EXISTS tapDataSummary;
CREATE TABLE tapDataSummary
(
    testdataid int(11) default NULL,
    questionid int(11) default NULL,
    speed int(4) default NULL,
    percentageCorrect float(5,2) default NULL,
    failureTime int(6) default NULL,
    PRIMARY KEY (questionid, testdataid),
    CONSTRAINT FOREIGN KEY (testdataid) REFERENCES testdata (testdataid),
    CONSTRAINT FOREIGN KEY (questionid) REFERENCES question (questionid)
);

DROP TABLE IF EXISTS motorTestState;
CREATE TABLE motorTestState
(
    testdataid int(11) default NULL,
    state int(1) default NULL,
    PRIMARY KEY (testdataid),
    CONSTRAINT FOREIGN KEY (testdataid) REFERENCES testdata (testdataid)
);

DROP TABLE IF EXISTS periodsummary;
CREATE TABLE periodsummary
(
    patientid varchar(20) default NULL,
    periodId varchar(250) default NULL,
    status varchar(1) default NULL,
    msd_overallpatientstate_gt float(6,2) default NULL,
    overallpatientstate_gt float(6,2) default NULL,
    overallpatientstate_ot float(6,2) default NULL,
    overallpatientstate_dt float(6,2) default NULL,
    abilitytowalk float(6,2) default NULL,
    abilitytowalk_msd float(6,2) default NULL,
    painfulcramps float(6,2) default NULL,
    painfulcramps_msd float(6,2) default NULL,
    pleasedwithfunction float(6,2) default NULL,
    pleasedwithfunction_msd float(6,2) default NULL,
    presentcondition_gt float(6,2) default NULL,
    presentcondition_msd_gt float(6,2) default NULL,
    presentcondition_ot float(6,2) default NULL,
    presentcondition_dt float(6,2) default NULL,
    stateLast4Hours_gt float(6,2) default NULL,
    PRIMARY KEY (patientid, periodId)
);
stateLast4Hours_ot float(6,2) default NULL,
stateLast4Hours_dt float(6,2) default NULL,
motorteststate_gt float(6,2) default NULL,
motorteststate-msd_gt float(6,2) default NULL,
motorteststate_ot float(6,2) default NULL,
motorteststate_dt float(6,2) default NULL,
percentageofvalidspirals float(6,2) default NULL,
compliance float(6,2) default NULL,
PRIMARY KEY (patientid, periodId),
CONSTRAINT FOREIGN KEY (patientid) REFERENCES patient (patientid),
CONSTRAINT FOREIGN KEY (periodId) REFERENCES period (periodId)
);

DROP TABLE IF EXISTS spiralDataSummary;
CREATE TABLE spiralDataSummary
(
  testdataid int(11) default NULL,
  questionid int(11) default NULL,
  validation int(2) default NULL,
  validinfo char(6) default NULL,
  completime float(8,4) default NULL,
  score float(8,5) default NULL,
  ols float(8,5) default NULL,
  sd1 float(8,5) default NULL,
  sd2 float(8,5) default NULL,
  PRIMARY KEY (questionid, testdataid)
);

DROP TABLE IF EXISTS log;
CREATE TABLE log
(
  logid int(11) NOT NULL auto_increment,
  username varchar(20) default NULL,
  oldPatient varchar(20) default NULL,
  newPatient varchar(20) default NULL,
  oldPeriod varchar(20) default NULL,
  newPeriod varchar(20) default NULL,
  starttime datetime default NULL,
  starttimeslot int(2) default NULL,
  endtime datetime default NULL,
  endtimeslot int(2) default NULL,
  deletePatient varchar(3) default NULL,
  modifytime datetime default NULL,
  PRIMARY KEY (logid)
);
Appendix V: Testing

1. Purpose
The purpose of this report is to detail testing that was performed on the Web based decision support system. The testing is performed throughout the development process of the system. This report describes the results at the completion of the development phase.

2. Scope
The system test efforts are primarily driven by the requirements found in the document titled “User Requirements”. In addition to the tests derived from the requirements, extensive integration testing is also performed to comply with the existing running system.

It should be noted that, even after thorough testing, it is not sure that the system will be free from bugs. Bugs can still be present in the system which might appear later.

3. Test Setup and Defect Reporting
The testing is performed by two test engineers. The testing is divided into three parts

- Black box testing
- White Box testing
- Integration testing

Later on, alpha testing and beta testing will also be included, but at the time of writing this report, these two testing were not performed.

All defects shall be documented in the problem reporting section. At the time a defect is discovered, only minimal efforts will be expanded to ensure it is real and previously unknown.

4. Software Testing
The testing is divided into three modules as described in the above section. A test matrix is presented here for better understanding of the test cases performed. Testing is performed by two test engineers. The test engineers are represented by the following id’s.

- FAR
- XIA

Efforts of Mr. Jerker Westin were also involved during the testing of the system.

For the purpose of testing, four sample patients were picked and the tests cases are performed on these patient’s data.
4.1. Black Box Testing
This domain covers the testing of inputs and outputs of the system, compliance with the user requirement and the graphical user interfaces. The following are the test cases performed during this process.

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Results</th>
<th>Tester</th>
<th>Comments and Problem Reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Initialization</td>
<td>P</td>
<td>FAR</td>
<td>Some errors occur, but later on removed.</td>
</tr>
<tr>
<td>System Login and Password</td>
<td>P</td>
<td>XIA</td>
<td></td>
</tr>
<tr>
<td>GUI Color</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>View Patient Data</td>
<td>P</td>
<td>XIA</td>
<td></td>
</tr>
<tr>
<td>Patient State Values</td>
<td>P</td>
<td>XIA</td>
<td></td>
</tr>
<tr>
<td>Period Comparison</td>
<td>P</td>
<td>XIA,</td>
<td></td>
</tr>
<tr>
<td>Detailed Comparison</td>
<td>P</td>
<td>XIA,</td>
<td></td>
</tr>
<tr>
<td>Period Summary</td>
<td>P</td>
<td>XIA,</td>
<td>Error reported regarding decimal places, later</td>
</tr>
<tr>
<td>Raw Data Graphs</td>
<td>P</td>
<td>XIA,</td>
<td></td>
</tr>
<tr>
<td>Alerts</td>
<td>P</td>
<td>XIA,</td>
<td></td>
</tr>
<tr>
<td>Prints</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Inclusion Summary</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Error Correction</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Export Data</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
</tbody>
</table>

Table 11: Black box testing - Test cases
4.2. White Box Testing

White box testing is detailed testing of the system at the code level. The test cases performed in this category are as follow.

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Results</th>
<th>Tester</th>
<th>Comments and Problem Reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation of tapping results</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Calculation of spiral results</td>
<td>P</td>
<td>XIA</td>
<td></td>
</tr>
<tr>
<td>FIS membership functions</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Compliance calculation</td>
<td>P</td>
<td>FAR</td>
<td>Error occur, later on removed</td>
</tr>
<tr>
<td>Period state variables calculation</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Invalid Tests</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Alerts calculation</td>
<td>P</td>
<td>FAR</td>
<td>Null values generated, later on removed.</td>
</tr>
<tr>
<td>Inclusion</td>
<td>P</td>
<td>FAR</td>
<td>Wrong calculation of baseline patients, later on removed.</td>
</tr>
<tr>
<td>Modify patient record</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Delete patient record</td>
<td>P</td>
<td>FAR</td>
<td></td>
</tr>
<tr>
<td>Export data</td>
<td>P</td>
<td>FAR</td>
<td>Proper data was not exporting for period summary, later on adjusted.</td>
</tr>
</tbody>
</table>

Table 12: White box testing - Test cases

4.3. Integration Testing

The web application needs to be integrated with an existing database and an existing system (DAPHNE). This testing is still needs to be done at the main server. At the developer site, no bug is found in this regard.

The FIS needs to be integrated with the spiral program made using Java and Matlab component. This integration is successfully made at the developer’s site. The system still needs to be tested at the main server.
5. **Defects / Problem Reporting**
All defects have been documented in this section. Below is a full listing of all the defects reported during system testing, and the current state of each at the time of this writing.

<table>
<thead>
<tr>
<th>Problem Number</th>
<th>Description</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRN 001</td>
<td>System Initialization</td>
<td>Fixed</td>
</tr>
<tr>
<td>PRN 002</td>
<td>Period Summary</td>
<td>Fixed</td>
</tr>
<tr>
<td>PRN 003</td>
<td>Compliance calculation</td>
<td>Fixed</td>
</tr>
<tr>
<td>PRN 004</td>
<td>Alerts calculation</td>
<td>Fixed</td>
</tr>
<tr>
<td>PRN 005</td>
<td>Inclusion</td>
<td>Fixed</td>
</tr>
<tr>
<td>PRN 006</td>
<td>Export data</td>
<td>Fixed</td>
</tr>
</tbody>
</table>

Table 13: Problems identified

6. **Requirement Coverage Gap**
There are no gaps in requirements coverage. All system requirements have been thoroughly tested during the course of this testing. No gaps in coverage have been identified.

7. **Lessons Learned**
   - White box testing was feasible but time consuming. Prior to future test cycles, alternate test methods should be investigated.
   - Load and stress testing need to be a part of all future testing. Although during this test cycle, these tests were not fully implemented, but the risk associated with load and stress testing is significant.

8. **Quality Assessment**
Upon completion of testing, all test cases have passing results, and the issues encountered during testing were resolved before the release of the product. All requirements coverage has been carefully considered at various peer reviews, and the test team believes that all aspects of the system requirements have been completely tested.