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TheraSense

IT 497: Graduation Project Report
Product Release-2

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المحتويات

TheraSense

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Abstract (English): Nowadays, physical therapists mainly use patient surveys and self-reported measures to assess patient adherence to prescribed physical activity. However, studies have demonstrated the wide variability between self-reported and actual performed physical activities, which can impact rehabilitation progress. Consequently, it is crucial to adopt more reliable methods for detecting these activities. This project aims to develop an activity recognition system, consisting of an android mobile application and a single wearable sensor placed on the wrist. The app and the sensor will be used to recognize and monitor upper limbs physical activities. The ML model performed with an accuracy of 0.95%, and the application has satisfied all the agreed requirements on time.

Abstract (Arabic): عادة ما يعتمد المعالج الطبيعي بشكل رئيسي على استبيانات المريض وإجابات المريض نفسه لتقييم مدى التزامه بممارسة التمارين البدنية الموصوفة لهم. ومع ذلك، أظهرت الدراسات التباين الواسع بين ما يُبلغ به المرضى بأنفسهم وبين التمارين البدنية الفعلية المنجزة، مما يمكن أن يؤثر على تقدم عملية إعادة التأهيل. وبالتالي، من الضروري اعتماد طرق أكثر موثوقية لمراقبة هذه التمارين. يهدف هذا المشروع إلى تطوير نظام للتعرف على التمارين البدنية ويتكون من تطبيق على نظام الأندرويد وحساس قابل للارتداء على اليد. سيتم استخدام التطبيق والحساس للتعرف على الأنشطة البدنية للأطراف العلوية ورصدها. أدى النموذج الذكاء الاصطناعي إلى نسبة دقة بلغت 0.95%، وقد لبى التطبيق جميع المتطلبات المتفق عليها في الوقت المحدد.

Keywords: SPI, In-home Rehabilitation, Physical Therapy, Therapist, Activity Recognition System, Sensor.

1 Introduction

Rehabilitation is crucial for individuals experiencing restricted mobility caused by conditions like Spinal Cord Injuries (SCI) to avoid associated symptoms such as obesity and low muscular strength. Various approaches are utilized for the rehabilitation of patients including in-home physiotherapy. Nowadays, therapists mainly use patient surveys and self-reported measures to assess patient adherence to prescribed physical activity. However, studies have demonstrated the wide variability between self-reported and actual performed physical activities, which can impact rehabilitation progress. Consequently, it is crucial to adopt more reliable methods for detecting these activities.

Due to the rapid innovations in information technology, combined with advancement in wearable sensors, the field of activity recognition is attracting more attention, particularly in healthcare applications. These applications include activity recognition systems, can provide quality of life, and support independent living for patients without intruding on their privacy.

1.1 Problem

According to the Ministry of Health (MOH), Saudi Arabia has recorded one of the highest rates of SCI in the world with 62 people injured per 1 million, mostly resulting from traffic accidents [1]. Individuals with such an injury who rely on wheelchairs typically experience associated symptoms, such as obesity and low muscular strength. These symptoms may eventually lead to secondary complications, including diabetes and cardiovascular diseases. Rehabilitation processes, such as in- home strength exercises and telerehabilitation, play an essential role in avoiding such symptoms and redeveloping the required motor skills to perform daily activities and promote quality of life.

Currently, therapists rely on patient surveys to measure their adherence to these activities. However, studies indicate wide variability between self-reported and actual performed physical activity, since questionnaires might feature errors due to human intervention [2]. Consequently, the therapist cannot accurately evaluate the prescribed program, which can undermine rehabilitation progress. In such cases, especially when degradation is noticed in a patient's physical status, it is hard to know whether this degradation is a result of an incomplete application or an unsuitable program. Nevertheless, with rapid technological innovation, emerging physical activity recognition systems show greater reliability in detecting these activities [3].

For instance, once the patients have completed the rehabilitation program. They are required to complete surveys that show their commitment to the program. Due to the difficulty of remembering their performance during a long-term program, the patient reported estimated answers. Eventually, therapists became confused about how to assess the patient's performance. This resulted in inappropriate decisions that have a negative impact on the rehabilitation progress.

This project focuses on the evaluation part of the rehabilitation process, which needs a reliable method for data collection to improve the quality of patient rehabilitation experience.

1.2 Objectives

Upon completion of the development of this application, we will have achieved the following objectives.

- Product (customer focus-value):

This application will be developed to help therapists make informed decisions regarding the rehabilitation program of a SCI patient. This is to overcome the current practice of verifying the patient’s adherence to the prescribed rehabilitation program, which might be prone to error due to the use of questionnaires. Therapists will benefit from this application, as they will be able to do the following features:

  - Search for a patient.
  - Generate reports.

- Add a rehab program.

  Therapists can add a rehab program prescription on any patient page. This includes specifying program duration, the required physical activities and their frequencies.

- Update rehab program

  After the therapists added the rehab program prescription. Then, they can update the program prescription details according to the patient's status. This means that both extend and delete actions for any of the program details considered under update action.

- Patient performance ranking

  After the reports are generated, therapists can rank the patients' reports by filtering them based on the commitment percentage, which is calculated according to the number of performed activities. The higher the percentage, the higher the performance. This feature facilitates the evaluation process. Therefore, it helps therapists to identify which patients require more care and attention. Hence, therapists can update the patient's program without the need for patient attendance.

- Contact patients

  Therapists can use this feature to contact patients via email, SMS, or WhatsApp. This can be used to send the generated report or to send any other important information. Hence, being able to reach the patient whenever needed. It is important to note that only the therapist can contact patients, and not the other way around. This application is exclusively used by therapists, which means there are no interfaces available for the patients.

- Chatbot

  Chatbot can assist therapists by answering the frequently asked questions (FAQs) related to the application. Hence, increase therapist productivity. In addition, a quiz game feature is embedded within the Chatbot to provide MCQs about SCI Rehab. This helps the therapists to refresh his information.

- Therapists' community

  A shared space allows therapists to read any article related to their field written by a college, a specialist, or any other therapist. Therapists can search these articles using keywords related to these articles. Additionally, therapists can publish their own articles, allowing them to share their experiences with others. This could help other therapists to learn from these experiences.

- Project (solution focus-plan):

In order to accomplish the project, it is essential to follow a list of predetermined steps as follows:

- Domain analysis and requirement engineering.
- Design the application and system architecture.
- Implement the application interface incrementally.
- Data preprocessing and segmentation.
- Feature extraction and selection.
- Model training.
- Model testing.
- Model integration.
- Test the product.
- Release the product.

Furthermore, there will be a need for specific tools: Flutter, Google Colab, Git, GitHub, and Jira.

- Learning (student focus):

Through this project, we will have the opportunity to learn about how to create an AI based product while following the Agile methodology and the process behind it. In addition, we will learn how to develop a classification model and build a mobile application that meets the user's needs. By the end of this project, we will be able to learn the following skills:

- How to perform data preprocessing, feature extraction, model training and testing using python programming language.
- How to deal with raw sensor data for classification including automatic segmentation.
- Explore different packages and libraries that are needed for this project.
- How to implement a user-friendly mobile interface using Flutter framework.
- How to integrate the model with the mobile application.
- How to work on a synced shared platform to facilitate the cumulative work.

1.3 Product Vision Statement

For a therapist who needs a reliable way to detect the physical activity performed during the rehabilitation process of SCI patients. TheraSense is a mobile application with an activity recognition system that helps therapists to conduct a more accurate evaluation of the rehabilitation program, in order to make informed decisions regarding the program. Unlike other rehabilitation applications, our application focuses on SCI patients using wearable sensors to facilitate data collection of physical activity.

1.4 Solution

An activity recognition system, consisting of a mobile application and a single wearable sensor placed on the wrist. This will be used to recognize and monitor upper limbs physical activities. These activities are performed by rehabilitation patients during in-home rehabilitation.

To illustrate the process, consider the following scenario:

First, the therapist specifies a suitable rehabilitation program for the patient based on their physical condition. Next, data will be collected using a sensor similar to the one shown in Figure 1. This sensor captures the sequence of movements during physical activities. A machine learning algorithm-based classifier model will then be employed to classify these activities. A dataset containing sensor data (continuously recorded during physical activities specifically created for rehabilitation purposes) will be utilized to develop the classification model.

Upon completion of the rehabilitation program, a report will be provided to the therapist, demonstrating the patient's performance. This report will include a list of physical activities performed by the patient and their respective frequencies. The therapist can use the generated report to conduct a more accurate evaluation of the rehabilitation program. This evaluation considers both the patient's current health status and their adherence to the program. Armed with this crucial information, the therapist will be better equipped to decide whether to continue the program or explore alternative options.

This report provides a detailed overview of the TheraSense system development process. Section 1 outlines the project's background and objectives, establishing the foundation for the report. Section 2 covers the background information relevant to the project, setting the context for the subsequent sections. Following this, section 3 presents a literature review, summarizing existing research and frameworks that inform the system's design and development. Section 4 then delves into the system design and development, describing the methodology, system requirements, design processes, data preparation, interface development, and implementation. Next, section 5 evaluates the system's performance, detailing experimental results, user acceptance testing, and quality attributes, and includes a discussion of the findings. Finally, Section 6 provides conclusions and suggests future work based on the project's outcomes. The report is supplemented by acknowledgements in Section 7, references in Section 8, and additional supporting information in the appendix in Section 9.

2 Background

In order to gain a better understanding of TheraSense, this chapter will provide an overview of our domain characteristics. First, we will explain the key terms of rehabilitation domain knowledge, then the use of technology in the rehabilitation field which will help in building TheraSense.

2.1 Domain Knowledge

The knowledge of the rehabilitation domain is very wide and full of terminologies. In this section we will discuss the most important terminologies about our domain, including Spinal Cord, Spinal Cord Injury (SCI) in general, rehabilitation and occupational therapy specifically, and some physical activities for SCI patients.

2.1.1 Spinal Cord

Spinal Cord is a cervical vertebra is a curved structure that runs along the center of the spine, from the brainstem to the lower back. It is a delicate network of nerve fibers and cells that transmit signals between the brain and the rest of the body [11]. The length of the spinal cord in most adults is 18 inches (45 centimeters) long[12].

The spinal cord is protected by 33 vertebrae, each of them arranged in five main regions. Seven Cervical Vertebrae, twelve Thoracic Vertebrae, five Lumbar Vertebrae, five Sacral (fused in adults to form the sacrum) and four Coccygeal Vertebrae (fused to form the coccyx) [12]. Illustrated in Figure 1 below. Additionally, the main functions of the spinal cord are, regulate body functions and movements, report senses to your brain, and manage your reflexes[11].

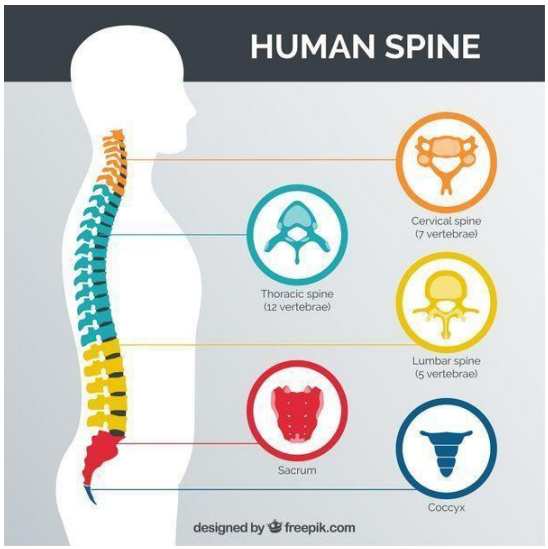


Figure 1: The five main regions in the vertebrae of the spinal cord [12]

2.1.2 Spinal Cord Injury (SCI)

According to the World Health Organization, the majority of spinal cord injuries are caused by traffic crashes, falls or violence. The term Spinal Cord Injury (SCI) is defined as “damage to the spinal cord resulting from trauma (e.g., a car crash) or from disease or degeneration (e.g., cancer)". Furthermore, the symptoms of a spinal cord injury vary according to the severity of the injury and its location on the spinal cord. These symptoms include partial “some” or complete loss of the sensory functions or motor control of the arms, legs, and/or body [13]. SCI often results in permanent alterations in strength, sensory perception, and other body functions that will appear below the level of injury as illustrated in Figure 2 [14].

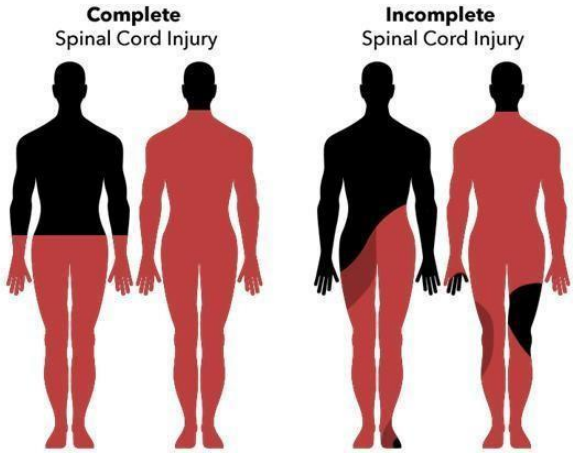


Figure 2: The partial and complete loss of the human body resulting from SCI [15]

2.1.3 Rehabilitation

Globally, millions of people are currently living with a health condition that needs rehabilitation. The World Health Organization defined Rehabilitation as “a set of interventions designed to optimize functioning and reduce disability in individuals with health conditions in interaction with their environment”. It helps minimize the impact of a wide range of health conditions, including diseases, illnesses, or injuries (e.g., SCI). In addition, it complements other health interventions, such as medical and surgical interventions, helping to facilitate recovery and achieve the best possible outcome [16] .

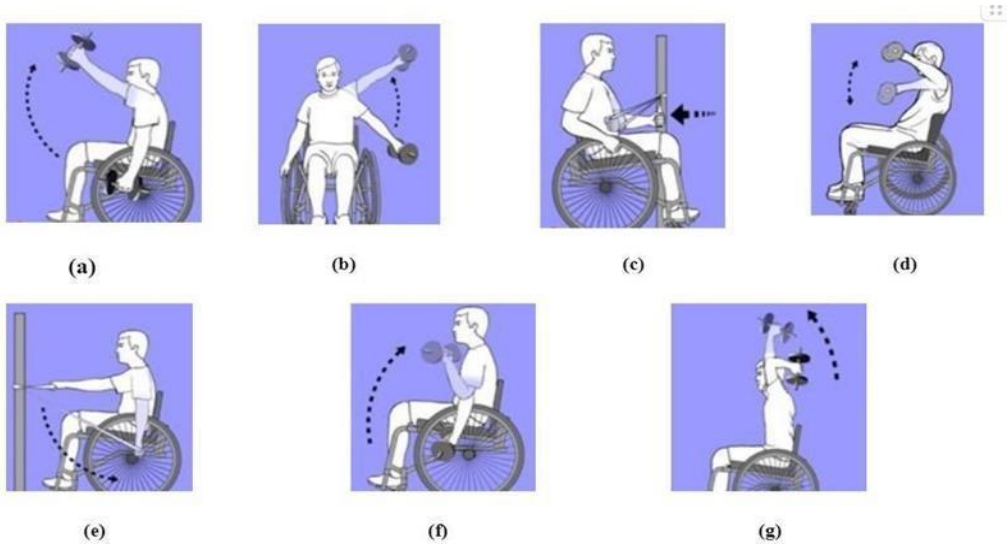
Rehabilitation involves many therapy techniques, for instance, physical therapy which is used to preserve, enhance, or restore movement. Rehabilitation also involves Occupational Therapy, which enables patients to perform daily activities and promotes quality of life despite limitations in physical or mental function. This occurs by specific physical activities designed for rehabilitation [17].

A. Physical Activities

The World Health Organization defines physical activity as" any bodily movement produced by skeletal muscles that requires energy expenditure" [18]. People with SCI are more likely than the general population to have health problems related to weight gain, changes in cholesterol, high blood sugar and at higher risk of cardiovascular disease. However, not being active may contribute largely to these problems. Normally, everyday activities aren't enough to maintain cardiovascular fitness with SCI people. Therefore, specific exercises are needed to reduce the risk of health problems after SCI [19].

Unlike stroke and other neurological disorders, SCI affects the patient's lower limbs. Hence, patients require rehabilitation to avoid associated symptoms such as muscle weakness. Rehabilitation through physical activity is essential for the development of upper limb motor skills. This enables patients to perform daily activities and promote quality of life [20][21] . Whenever the aim is to strengthen the upper limb, the body parts of focus are the elbows and shoulders [22] [23] [24] . The main activities required to strengthen the shoulder muscles are shoulder flexion (SF), shoulder abduction (SA), shoulder extension (SE), shoulder internal rotation (SIR), and shoulder external rotation (SER). In addition, the main activities applied to strengthen the elbow's major muscles are elbow flexion (EF) and elbow extension (EE) [22]. An illustration of these activities is given in Figure 3.

Figure 3:Physical activities used to rehabilitate spinal cord injuries (SCI) patients.



2.2 Use of AI in Rehabilitation

Artificial Intelligence has facilitated the process of rehabilitation with the Human Recognition Systems (HARs). These systems recognize patients' activities using supervised learning algorithms. To understand AI concepts related to these systems, in this section several concepts will be discussed. This includes the definitions of HARs, data segmentation, machine learning algorithms that are commonly used in activity recognition systems, performance measure and cross-validation.

2.2.1 Human Activity Recognition Systems (HARs)

Human Activity Recognition system (HAR) is a technology that analyzes and recognizes several human activities from input data sources, such as sensors. This technology has been significantly used in healthcare support, to be defined as a procedure used for monitoring patients' activities. However, people usually adopt the HAR system as an assistive technology when ensembled with another technology such as machine learning. Figure 4 shows common HARs workflow for machine learning[25]. This workflow includes segmenting the input data (sensor data) using sliding window technique into sampled data, then extracting a suitable feature vector from each sampled data, then using a machine learning model to predict the activity name. This model will rely on the extracted features in the training process.

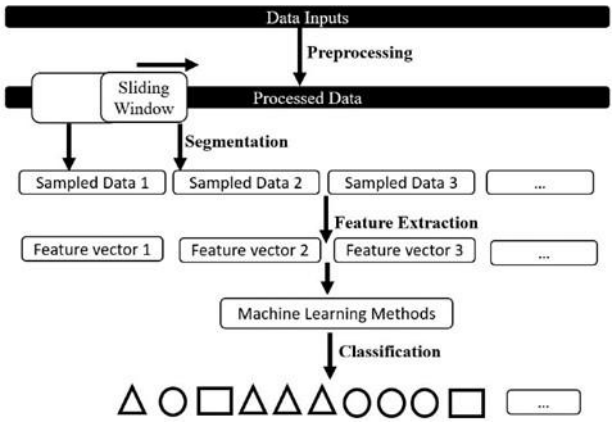


Figure 4: Overview of human activity recognition (HAR) workflow [26]

There are two types of HARs: vision-based HARs and sensor-based HARs, which vary according to the nature of the data that are being monitored. However, there are some drawbacks and limitations of using visual sensors, privacy is the main concern due to compliance and regulatory requirements. Also, computer vision-based techniques for processing images and videos are compute- intensive, where sensors are known as devices with low power and computational capabilities [27].

2.2.2 Data Segmentation

The goal of data segmentation in HARs is to transform the raw sensor data into activities. This is accomplished by dividing the sensor measurement time series into small segments. These small segments are later labeled such that 'similar' segments receive the same label. However, segmentation techniques have a vital role in accurately identifying the activities which are recognized by the HAR system [27] .

The most well-known techniques for data segmentation are Activity-Based segmentation that divides the sensor data stream into segments based on performed activity. Sensor-Based segmentation that divides the sensor data stream into segments by 'n' equal sensor events. Whereas the simplest one is Time-Based segmentation that divides the data stream into time segments with a regular time interval. Different techniques are shown in Figure 5 [28].

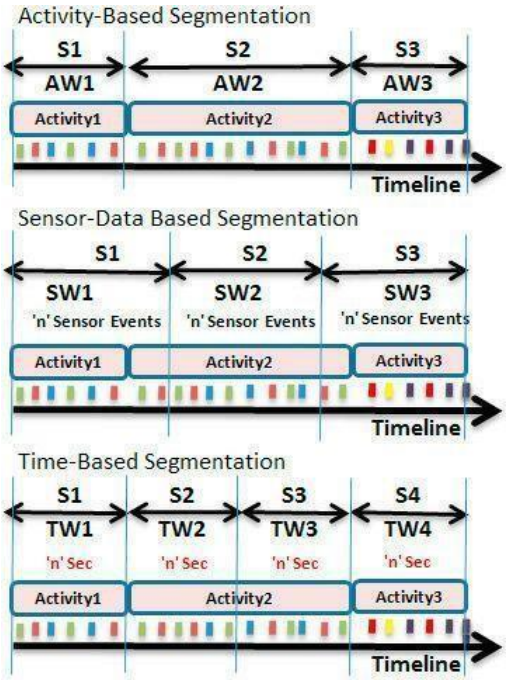


Figure 5: Segmentation Techniques used in Ambient Sensor Data [28]

While the HAR system seeks to find a perfect technique for segmenting activities. This task is difficult to achieve since the segmentation of time series into intervals that represent single activities is not straightforward. Even semantically, it is difficult to define where one activity ends and where the next one begins. Therefore, most complex systems tend to divide the raw data into fixed time intervals and recognize the activity that took place within each interval [29].

Sliding Window Algorithm is a well-known time series data segmentation method, and widely employed in activity recognition [30]. In the sliding window approach, continuous data obtained from sensors are segmented into windows based on time intervals where two parameters have to be fixed: the window size and the shift. Two different algorithms are available: the non-overlapping sliding window and the overlapping sliding window [31].

A. Non-Overlapping Sliding Window

This algorithm is considered a simple segmentation process in which time windows do not intersect. Accordingly, the number of windows can be calculated exactly since no overlap exists [32]. Figure 6 illustrates an example of the segmentation using this algorithm. Although it is easier than overlapping, information loss might occur between the adjacent windows [33].

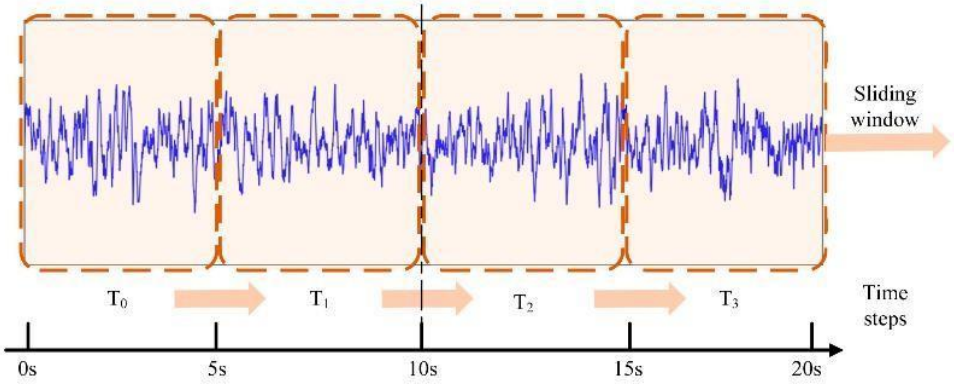


Figure 6: Sliding Window Approach [34].

2.2.3 Machine Learning algorithms

Different algorithms are explained in this section.

A. Random Forests Algorithm

Random forests are a supervised Machine Learning (ML) algorithm that is widely used in regression and classification problems. It produces a satisfactory result most of the time even without the need for complex parameter tuning. Due to its simplicity and great performance, it is considered one of the commonly used algorithms in HARs [35].

It works by building several decision trees on different samples, and the final decision is made based on majority voting, as illustrated in Figure 7 [36]. Each decision tree has a flowchart representation of data that graphically resembles a tree that has been drawn upside down. In this analogy, the root of the tree is a decision that has to be made, the tree's branches are actions that can be taken, and the tree's leaves are potential decision outcomes. The purpose of a decision tree is to partition a large dataset into subsets that contain instances with similar values in order to understand the likely outcomes of specific options. Overall, decision trees are used to predict the class or value of target variables in supervised learning regression and classification algorithms [37] [38].

The main difference between the random forest algorithm and decision tree is that decision trees are graphs that illustrate all possible outcomes of a decision using a branching approach. In contrast, the random forest algorithm output is a set of decision trees that work according to the output [38].

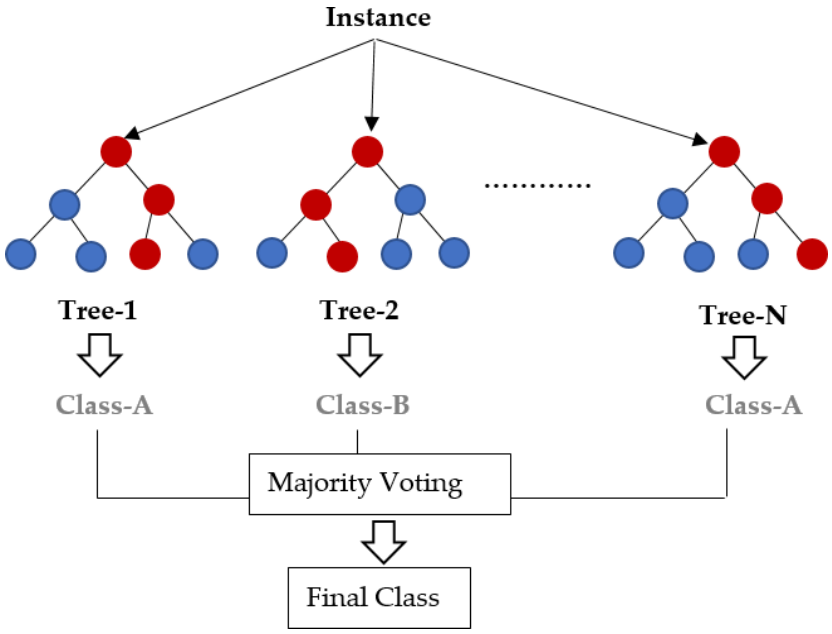


Figure 7: Illustration of Random Forest methodology [39]

B. K-Nearest Neighbors

The k-nearest neighbors' algorithm, also known as KNN or k-NN, is a non-parametric, supervised learning algorithm that can be used for both regression and classification problems. The algorithm relies on the assumption that similar things exist in proximity [40]. It works by taking the K- closest data points in the training dataset before a new data point is assigned to the most common class among its K-nearest neighbors, as shown in Figure 8.

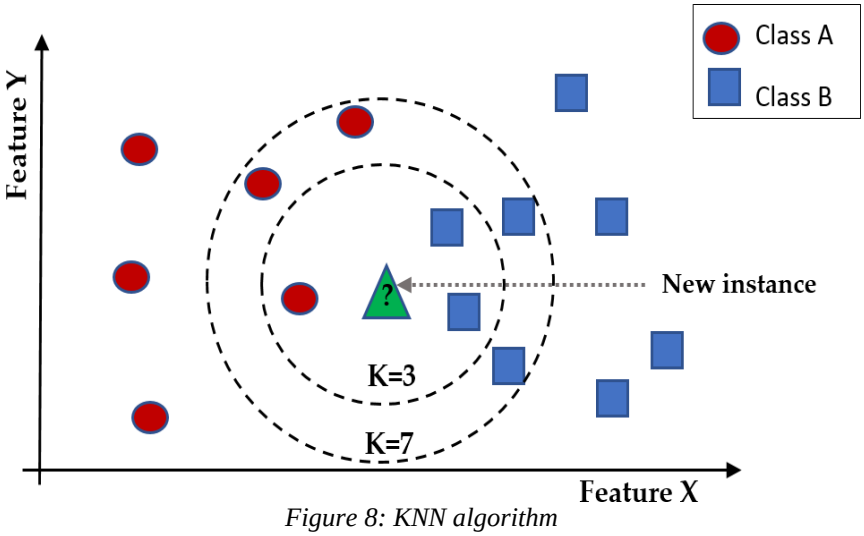


Figure 8: KNN algorithm

For classification problems, a class label is assigned based on a majority vote. Regression problems use a similar concept as classification problems, but the average of the k nearest neighbors is taken to make a prediction about a classification. The main distinction here is that classification is used for discrete values, whereas regression is used with continuous ones.

Before a classification can be made, the distance between data points must be defined. As a result, we will determine which data points are closest to a given query point. The distance metrics help to form decision boundaries, which partition query points into different regions. Several distance measures can be chosen, like Euclidean distance, Manhattan distance, Minkowski distance, Hamming distance and many more. However, Euclidean distance is commonly used in KNN, where the distance between two data points is computed as follows:

$$d = \sqrt{[\,(x_2 - x_1)2 + (y_2 - y_1)2]}$$

Equation 1: Euclidean distance formula [41].

C. Support Vector Machines (SVM)

Support Vector Machines (SVMs) are a type of supervised learning algorithm that can be used for classification or regression tasks. The main idea behind SVMs is to find a hyperplane that maximally separates the different classes in the training data. This is done by finding the hyperplane that has the largest margin, which is defined as the distance between the hyperplane and the closest data points from each class (see Figure 9). Once the hyperplane is determined, new data can be classified by determining on which side of the hyperplane it falls. SVMs are particularly useful when there is a clear margin of separation in the data [42].

SVM can only perform binary classification (i.e., choose between two classes). However, there are various techniques to use for multi-class problems. SVM with multi-class learning has gotten attention in activity recognition systems. There are various supervised learning algorithms by which an activity recognizer can be trained [43]. However, SVM gives good results in comparison with other types of classifiers. It is effective when dealing with quiet small datasets and in high dimensional spaces [44].

SVM works perfectly without any adjustments for linearly separable data. Linearly Separable Data is any data that can be plotted in a graph and can be separated into classes using a straight line.

Kernelized SVM is used for non-linearly separable data. this data can be transformed into two dimensions and the data will become linearly separable [42].

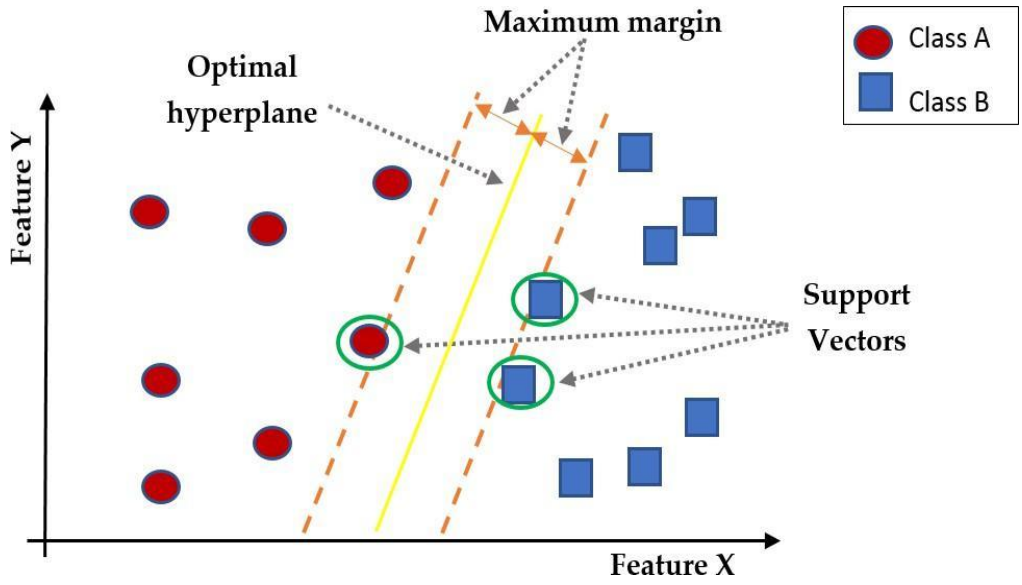


Figure 9: SVM algorithm

D. Naive Bayes (NB)

Naive Bayes is a set of algorithms that follow the same principle. This principle is called the Bayes Theorem as shown in Equation 2. This equation finds the probability of an event occurring given the probability of another event that has already occurred[45]. Where P(A|B) is the conditional probability of event A occurring, given that B is true. P(B|A) is the conditional probability of event B occurring, given that A is true. P(A) and P(B) are the probabilities of A and B occurring independently of one another [46].

$$p(A|B) = \frac{p(B|A)\, p(\mathrm{A})}{p(B)}$$

Equation 2: Bayes' Theorem formula [45]

The Naïve Bayes classifier is a popular supervised machine learning algorithm used for classification tasks, as it is simple and easy to implement. However, Naive Bayes approach assumes that the features of the input data are conditionally independent given the class, allowing the algorithm to make predictions quickly and accurately. To understand the process of Naive Bayes algorithm, you need first to convert the dataset into a frequency table. Then create a likelihood table by finding the probabilities of occurrences. Now, use the Naive Bayes equation to calculate the posterior probability for each class. The class with the highest posterior probability is the outcome of the prediction [46]. The Naive Bayes equation is the same as the

bayes Equation 2 mentioned above.

1.1.1 Performance Measures

Various performance measures are available to evaluate classification performance, including confusion matrix, which is a very popular measure used for classification problems [47]. TheraSense will use a confusion matrix to evaluate the performance. This method was chosen based on a research paper[48][49]that worked on the same domain as TheraSense.

A. Confusion Matrix

A confusion matrix is a numerical representation of the machine learning model's performance on a set of experimental data. It is commonly used to evaluate the accuracy of classification models that are designed to predict a single categorical label for every input instance[47] .

The confusion matrix shows several performance indicators as illustrated in Figure 10, the number of True positives (TP) means the actual value is positive and is protected as positive. Conversely, True negatives (TN) means the actual value is negative and is protected as negative. Furthermore, False positives (FP) means the actual value is positive and is protected as negative. The False negatives (FN) means the actual value is negative and is protected as positive [50].

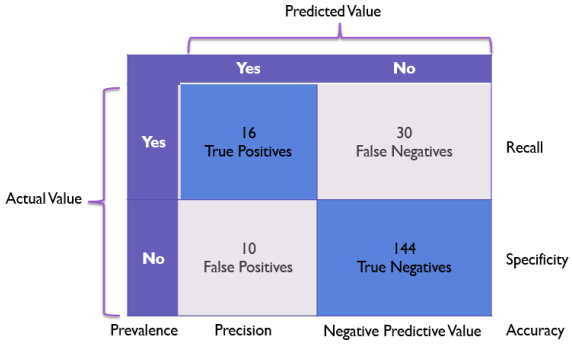


Figure 10: Confusion matrix [51]

There are some equations that can be calculated from the confusion matrix. Accuracy measures a model's ability to accurately predict outcomes across the entire dataset. Recall measures how many of a model's positive class samples were correctly identified. Precision measures the number of predictions that were correct. Finally, an F1 score measures a model's accuracy and provides a summary of a model's predictive performance by combining precision and recall measures. All the mentioned measures will be used to evaluate the performance of TheraSense as shown in Equation 2-5 respectively [52][53].

$$Accuracy = (TP + TN) / (TP + TN + FP + FN)$$

Equation 3: Accuracy formula [54].

$$Precision = TP / (TP + FP)$$

Equation 4: Precision formula [43].

$$Recall = TP / (TP + FN)$$

Equation 5: Recall formula [43].

$$F1 = 2 * (precision * recall) / (precision + recall)$$

Equation 6: F1 score formula [43].

1.1.2 Cross-Validation (CV)

Cross-Validation (CV) is a common technique for evaluating the performance of predictive models. It involves splitting the dataset into subsets, training the model on some of these subsets, and then evaluating its performance on the remaining data. The goal is to estimate how well the model will generalize to unseen data. The process involves partitioning the available dataset into multiple subsets, typically known as folds. The model is then trained and evaluated multiple times, with each fold used as both a testing and validation set, while the remaining data is employed for training. This iterative approach provides a more comprehensive understanding of a model's performance, as it helps identify issues like overfitting or

underfitting. The final evaluation metric is usually an average or aggregate of the performance across all folds.

A. K-fold cross-validation

K-fold cross-validation is a specific implementation of cross-validation, where the dataset is divided into k equal-sized folds or subsets. The model is trained and evaluated k times, using a different fold as the testing set each time. Next, performance measures that are previously discussed will be calculated from each fold, then averaged to estimate the model's generalization performance. This method aids in model assessment, selection, and hyperparameter tuning, providing a more reliable measure of a model's effectiveness [55].

A study shows that using k-fold CV only is not enough to validate the model performance accurately when trained on HAR datasets. As it may overestimate the performance by 10% of activity recognizers, considering that samples produced by the same subjects are likely to be correlated due to diverse factors. Several factors might explain such correlation, including gender, age, or experience. Hence, a new methodology of CV has emerged to present a better way of validation and to avoid misleading results [56].

B. Leave-One-User-Out Cross-Validation (LOUO-CV)

Leave-One-User-Out Cross-Validation (LOUO-CV) is a specialized form of cross-validation designed for scenarios where the dataset consists of data from multiple users or subjects. In LOUO- CV, each user or subject's data is held out as a validation set, and the model is trained on the data from all other users. This process is repeated for each user in the dataset, ensuring that each user's data is treated as a test set once. LOUO-CV ensures that the model's performance is assessed for its ability to generalize across different users or subjects, making it valuable in certain applications like HAR systems where user-specific variations are significant.

3 Literature Review

Recently, the interest in developing rehab monitoring software is increasing, which has encouraged organizations and companies to start developing their own rehab monitoring software solutions. This chapter will introduce these competing software options.

3.1 Competitive Product Analysis

TheraSense faces significant competition from well-known rivals. We have found that there are some similarities as well as differences between TheraSense and those competitors. They have offered useful features for their users. However, they overlooked a few essential features that we will provide for our users.

- Rehab My Patient (RMP)

Figure 11: RMP's Logo [57]

Rehab My Patient (RMP) is exercise prescription software that is used by many clinics around the world. Therapists can add patients, create new exercise plans, customize exercises and deliver it to patients through email or SMS messages. However, the software doesn't enable the therapist to track the exercises performed by patients. My Patient provides various pricing plans with different features [58] .

- TrainFES Rehab

Figure 12: TrainFES's Logo [59]

TrainFES Rehab is a cloud platform mobile application that can be used for online rehabilitation. This application is intended for therapists and patients. Therapists are able to build plans and send them to the patient. The application is used in parallel with the Functional Electrical Stimulation FES device to monitor the patient's real-time progress. However, this device is used to stimulate the paralyzed parts of the body and create a report that can be seen by both the therapist and patient [60].

This application focuses on rehabilitation of the injured/paralyzed part. In contrast our target is to strengthen the functioning part of the body using different types of physical activities. Hence, using FES devices will focus on stimulating the paralyzed parts to make them active again. In such cases, this cannot be applied for the type of rehabilitation that needs only to strengthen patients' parts that are already functioning [60].

Multiple concerns resulted from the use of real-time data. Patients could experience frequent program crashes while using the application. In addition to the security concern due to the data transfer through the network.

- Track rehab

Figure 13: Track Rehab's Logo [61]

Track rehab is a mobile application in healthcare designed to enhance patient rehabilitation by viewing personalized exercise plans provided by the therapists that use RMP application, progress tracking, and improved communication with healthcare providers. It is linked with Rehab My Patient (RMP) to view the features as patients. Whereas RMP is used by therapists.

However, there are potential challenges such as there is no sensor that has been used to track the patients' activity. This application follows a manual input method to track the patient's progress. This may be an unreliable way of tracking since it is fully dependent on patient filled surveys. Track rehab provides multiple subscription plans [62].

- My Rehab Pro

Figure 14: My Rehab Pro's Logo [63]

My Rehab Pro allows communication between the physical therapists and their patients. This application provides extensive HD video libraries about the exercises with detailed techniques. This application helps therapists to prescribe an exercise program to the patients, while the patient can view this prescribed exercise program.

My Rehab Pro does not use a sensor to determine whether the patient did the exercise correctly or not and does not cover exercises of SCI patients. Additionally, it provides multiple subscription plans but before subscribing, the application gives the user a 30-day trial [64].

- re.flex

Figure 15: re.flex's Logo [65]

re.flex is a mobile application that supports patients to recover from joint pain at home. In particular, patients with osteoarthritis of the knee and hip joints. However, this application includes exercises to improve motor skills. It uses a sensor kit that should be worn to have a real-time track of patients while exercising. Using this sensor kit will make the app give live feedback for the patient to correct the performance.

This application is intended for patients only. Hence, therapists are not able to track the patient's activities. Furthermore, the sensor kit has multiple pieces to be worn which is not very convenient for the patient. Thus, it is very time and effort consuming, especially when these activities are performed daily. However, multiple subscription plans are provided in order to use this application [66].

Multiple concerns resulted from the use of real-time data. Patients could experience frequent program crashes while using the application. In addition to the security concern due to the data transfer through the network.

- Rehab Guru Pro

Figure 16: Rehab Guru Pro's Logo [67]

Rehab Guru is an exercise prescription mobile application intended for multiple users including therapists and coaches. This application contains exercises that can be searched for and added to programs. The users can create exercise programs for their patients and clients manually. Once the programs are created, they can be sent to the patients via email address.

This application does not contain an activity recognition system, which means it does not use any kind of sensors to track the patient's activities. Hence, gives the patients full responsibility for sticking to the prescribed program. In general, it is not applicable for situations where therapists need to track patient performance and be updated on the patient's progress. However, multiple subscription plans are provided in order to use this application [68].

1.2 Competitors summary table

TheraSense has many essential features and advantages which are missing in most of the current applications. It utilizes sensors in tracking patient progress. This is more accurate than depending on patients' credibility. TheraSense considers spinal cord injury patients by providing appropriate activities that fit perfectly to their needs. On the other hand, one application currently covers SCI physical activities. Furthermore, the therapist community is an important feature in TheraSense which is missing in most of the applications. TheraSense will be the perfect choice for therapists to rely on in the near future. Table 1 below will show these differences clearly.

Table 1: Competitors' Summary

Application / Feature	Rehab My Patient	TrainFES	Track Rehab	My Rehab Pro	re.flex	Reha Guru Pro	TheraSense (proposed)
Mobile application	✓	✓	✓	✓	✓	✓	✓
Wearable sensor	✗	✓	✗	✗	✓	✗	✓
Therapists contact with patients	✓	✗	✓	✓	✗	✗	✓
Free usage	✗	✓	✗	✗	✓	✗	✓
Therapist's Community	✗	✗	✗	✓	✗	✗	✓
Activity recognition system to track	✗	✓	✗	✗	✓	✗	✓
Chatbot	✗	✗	✗	✗	✗	✗	✓
Covers exercises of SCI patients	✗	✗	✗	✗	✗	✗	✓
Intended for therapists	✗	✓	✗	✓	✗	✓	✓

Real-time data	✕	✓	✕	✕	✓	✕	✕

4 System Design and Development

In this section, TheraSense's methodology and user's characteristics are explained in general, multiple methods are discussed for requirements elicitation with its findings. The system architecture is provided with a high-level diagram that illustrates the decomposition of system components.

4.1 Methodology

The application "TheraSense" was developed using an agile technique. The agile approach is defined as an iterative method to software development and project management that aids in the delivery of valuable increments of the product. The agile methodology was implemented by going through 5 sprints, reevaluating and amending our plans on a regular basis to stay on schedule and adapting to changing requirements, and lastly releasing two releases.

There are three roles in the scrum framework: product owner, developer, and scrum master. "TheraSense" had a single product owner who established the vision and set the priorities for "TheraSense." In addition, the product owner served as a connection between the stakeholders and the developers. The developers have the abilities required to fulfill the product vision, create deliverable features, breakdown user stories, react to changes, and bring the vision to life. Finally, there is the scrum master, who coaches and advises the team to ensure that the ideals and principles of agile methodology are followed, arranges meetings, and gives feedback. During the "TheraSense" application life cycle, five events took place, starting with the sprint that set the sprint's timeframe. Then, at the start of each sprint, we determine which user stories will be worked on this sprint based on their priority in the product backlog, as well as how they will be developed and completed.

There is a daily scrum meeting during the sprint to assess progress and how close we are to the sprint objective, examine problems that emerged during the sprint, and refigure how to address those problems. Furthermore, a sprint review was held between "TheraSense" developers and the product owner in order to gather input, evaluate problems, and respond to changes. Prior to the start of the next sprint, a sprint retrospective meeting is held to review the process, the team's progress, and to highlight any issues that have arisen during the sprint so that they can be averted in the upcoming sprint.

There are three scrum artifacts that “TheraSense” is expected to deliver: Product backlog: it displays a list of features ordered by priority as user stories with acceptance criteria, that are expected to be developed throughout sprints.

Product increment: At the end of each sprint, "TheraSense" produces a product increment in which we merge the previous increments with the current sprint increment. Sprint backlog: a list consisting of the chosen user stories from “TheraSense” product backlog to be worked on and developed during the sprint. The tools that have been used to achieve the “TheraSense” objectives are GitHub [1]and Jira[2]. Jira is software that assists developers in tracking bugs and issues, organizing tasks, and managing agile teams. This software has simplified the project management process by setting the system requirements, tracking the progress, and documenting what was achieved as meeting notes. Meanwhile, GitHub is a website and cloud-based service that helps developers store and manage their code, as well as track and control changes to their code. We were able to easily handle the collaboration of "TheraSense" application code through GitHub, commit new modifications among the "TheraSense" team, and observe these modifications on the source code with no conflicts or missing components.

4.2 System Requirements

In this section the system requirement has been introduced, which includes describing the system users and requirements elicitation and analysis process in detail as well as User Interactions and roadmap and product backlog.

4.2.1 System Users

Users of TheraSense are therapists who will use the application to monitor their patient’s rehabilitation progress. They should have a high level of education and are familiar with the English language. Additionally, they should have experience with SCI patients’ is required. However, TheraSense users require little knowledge of dealing with mobile applications.

[1] 2023-1st-gp14.atlassian.net
[2] https://github.com/Sihamkhalid/2023-GP2-14.git

4.2.2 Requirements Elicitation and Analysis

TheraSense users are a specific type of users with an expertise in a very narrow domain. For requirements elicitation, we chose to distribute a questionnaire to understand the influence of TheraSense application on our users. However, the challenge of reaching qualified therapists was a very underestimated task, which resulted in a limited number of responses. Therefore, we decided to conduct interviews with these therapists to get to know them more. The last few days of requirements elicitation, we have reached a sufficient number of questionnaire's responses.

In this section, the interview and questionnaire findings are discussed to express our general observations about the therapists.

A. Interview Findings

After conducting interviews with six Interviewees, 2 of them are women and 4 of them are men, we found that they have similar experiences. Most of them have a range of 1-8 years of experience, but there is one therapist that has 20 years of experience and another that has 30 years of experience, with an average age of 35. Furthermore, all interviewees agree that Spinal Cord Injuries (SCI) need specialized care and attention. Especially after the injury immediately, while in other SCI cases it depends on the level of injury. In general, they need more care.

Many challenges the therapists have faced during the rehabilitation of SCI patients, including the lack of a good testing method to give accurate evaluation. Furthermore, an unreliable sensor was mentioned for being unable to show if the limb was moving as it should; it has been used at COVID-19 quarantine. Additionally, the 6 months at the beginning of the program are the most difficult ones. As patients are not aware of the importance of the commitment to the rehab program and are not open to talk about their weaknesses and limitations. However, families' support was considered a huge challenge which influenced the patient's commitment.

Currently, different methods are used for evaluation. The self-reported methods depend on patient credibility, either by using an application or using surveys. These are considered unreliable methods of evaluation so usually they depend on conducting a test for the patients to measure their ability to do certain exercises.

Therapists need to get advice or to discuss their ideas with other therapists to enhance the rehabilitation program. However, it is difficult to reach out to those experts to benefit from

their experiences. Especially, if they are not in the same health center or if they do not know them in person. Sometimes, they can contact an expert therapist on social media, however they are not available all the time.

There is no direct way to know the reason for a patient's prescribed program failure. Unless the patient does not interact well through the sessions and has not achieved significant progress, this gives an intuition to low commitment. Therefore, it slows down the progress pace and lengthens it by months. In general, there is no complete failure in the rehabilitation program. For more details, see Appendix A.

In conclusion, they have assured us to consider the privacy concerns. Additionally, one of the interviewees mentioned that the physiotherapist must be refreshing the information about cases and what is new to evaluate.

B. Questionnaire Findings

We received 30 responses to the questionnaire from the therapists who work in different clinics and hospitals in Riyadh including clinics and hospitals inside and outside the King Saud University. Responses have been collected from 23 women and 7 men participants, aged from 26-50. The results obtained from the questionnaire found that 43.3% of responses usually face patients with SCI. The percentage is low due to the fact that not all hospitals in Riyadh offer long-term rehabilitation. And some patients discontinued the rehabilitation program for different reasons. Moreover, 86.7% of responses agreed that they rely on patients' feedback to verify their adherence to the prescribed therapy program. 93.3% of responses believe that an activity recognition system will be helpful in measuring patients' adherence more effectively. 93.3% of responses were more likely to believe that sharing their experience among other therapists is beneficial. 90% of responses agreed with the need for a mobile app providing feedback on patient adherence using an activity recognition system. 55% of these responses that support having a mobile application also prefer a concise feedback method, while 44.4% of these responses prefer a detailed feedback method. Moreover, 60.4% of these responses also think that sending the performance report that is generated in the application to the patient without requiring a visit is helpful. However, 10% of responses disagree about the mobile application.

Both sections have an open-ended question, and the answers enriched us with wonderful inspirations and recommendations to improve our application now and for future work to best fit their needs. The answers are summarized by the following:

- Make the graph representation as the default view, and detailed representation as an option.
- Consider the privacy concerns of patients' information and control the accessibility and authorization.
- Add an Arabic version of the report, considering different ages and knowledge.
- Make the exercises as a list so that it is much easier to select by therapists.
- Raising awareness of neuro rehab is essential for the patients and therapists, involving its stages and the best time to begin treatment.

4.2.3 User Interactions

As demonstrated in Figure 17, the use case diagram has all possible functions that TheraSense users can perform in the application. In the beginning, TheraSense users start their journey by creating an account. Then they can sign in with the registered information to have access to the application. TheraSense users also have the option to edit their account information. TheraSense users are able to add and delete patients, where in some cases this information can be edited. Moreover, TheraSense users are able to add a rehab program for any patient and update this program when necessary. After the rehab program has been added and the rehab program period comes to an end, TheraSense users can generate a report showing patient performance. However, the generated report can be viewed by different timeframes(weekly-monthly) and this report can be printed if needed. TheraSense users can use the search feature to find any patient by ID. Once TheraSense users have viewed a patient page, they can see the patient's prescribed program along with any generated report. TheraSense users can also contact patients whenever a rehab program has been added or updated. Furthermore, TheraSense users can rank patients' performance. This filters patients according to their commitment to the rehab program. Moreover, TheraSense users have the ability to write and publish an article allowing them to spread knowledge and share experiences. Consider that TheraSense users are always allowed to delete any published articles if needed. Meanwhile, TheraSense users can read other users' published articles. Additionally, TheraSense users can start a chat with the chatbot either to ask the chatbot one of the Frequently Asked Questions

(FAQs) about the application, or to take a quiz that is specially designed for TheraSense users. This helps assess and refresh their information about rehabilitation. Finally, TheraSense users can sign out anytime to keep their accounts secure.

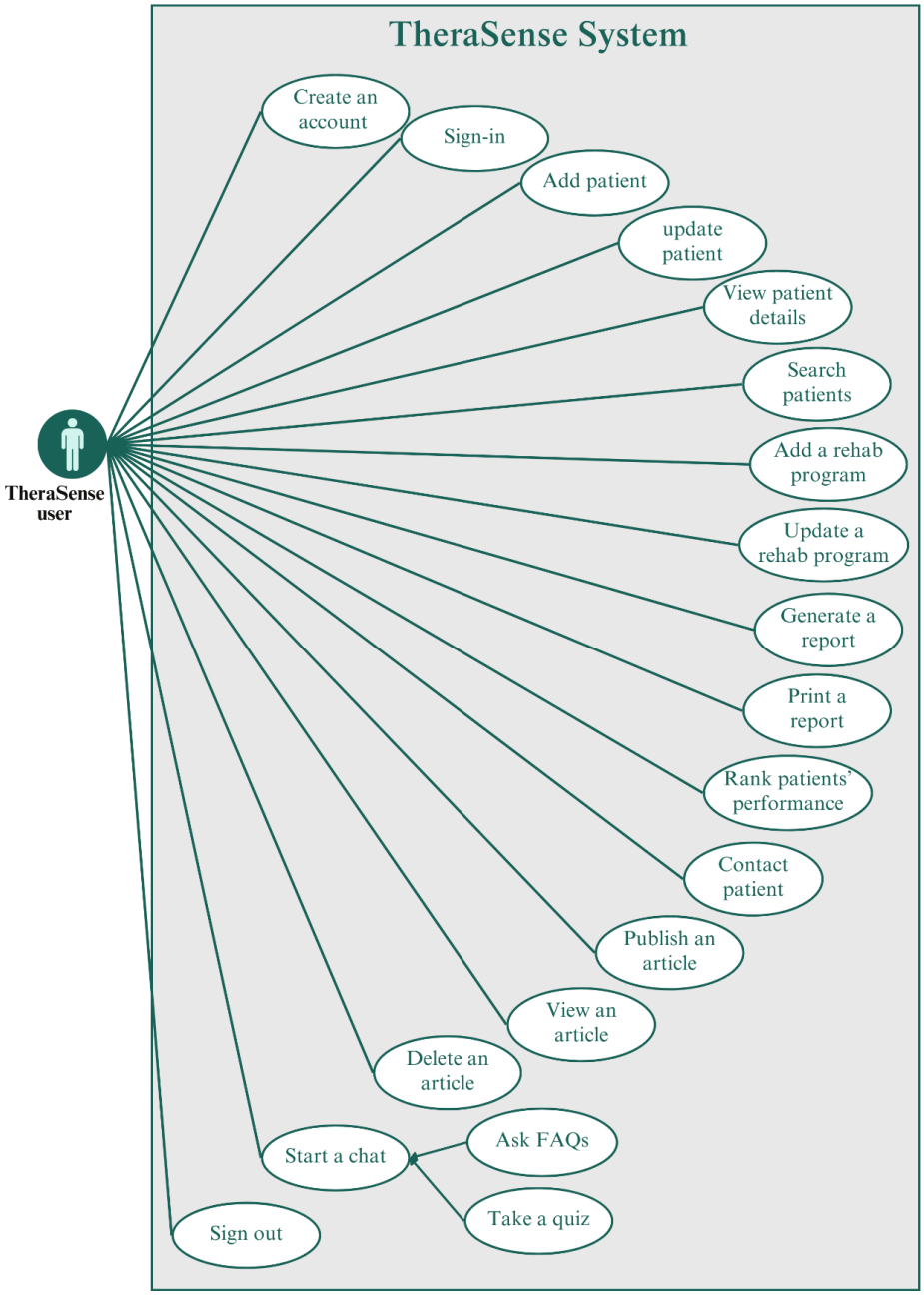


Figure 17: Use Case Diagram[67]

1.2.1 Roadmap and Product Backlog

A. Product Roadmap

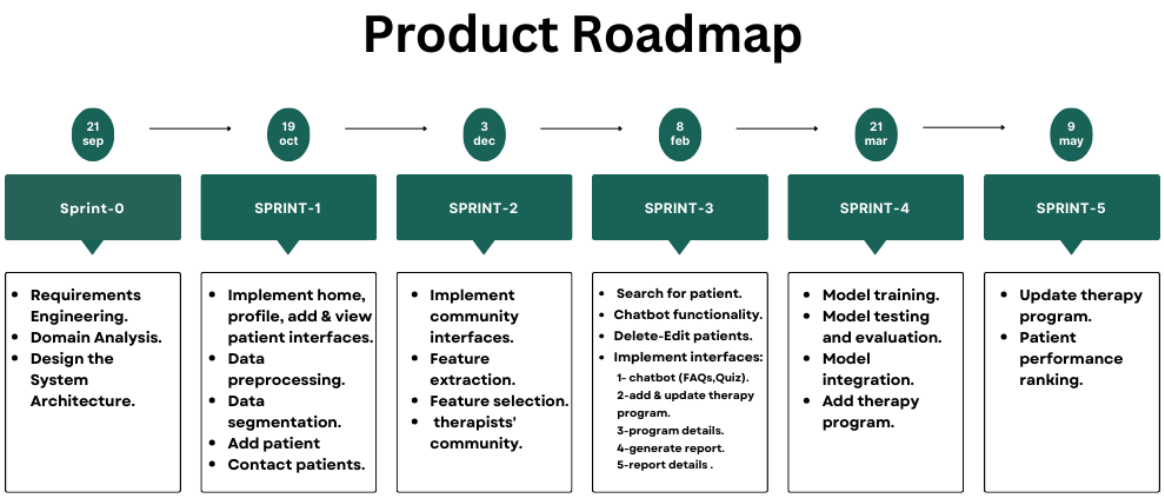


Figure 18: Product Roadmap[67]

B. Product Backlog

Table 2: Product Backlog table.

ID	PBI	Size	Type	Status	Acceptance Criteria
GP-1	As a TheraSense user, I want to create an account, so that I can sign-in to my account.	3	Feature	Done	1. As a TheraSense user, if I click the sign-up button, then I should fill out the sign-up form with a username, email, phone number and password. 2. As a TheraSense user, if I fill out sign-up form with

ID	PBI	Size	Type	Status	Acceptance Criteria
					valid information, at that point my information will be stored in the database. 3. As a TheraSense user, if my information was invalid, then I should receive an error message.account should be created, and my
GP-2	As a TheraSense user, I want to sign-in to my account, so that I can use the application.	3	Feature	Done	1. As a TheraSense user, if I click the sign in button, then I should fill out the sign-in form with my phone number and password. 2. As a TheraSense user, if I fill out sign-in form with information, at that point my information should be validated from the database. 3. As a TheraSense user, if my

ID	PBI	Size	Type	Status	Acceptance Criteria
					information was correct, then the application should give me access to my profile. 4. As a TheraSense user, if my information was incorrect, then I should receive an error message.
GP-3	As a TheraSense user, I want to edit my account information, so that I have my account with updated information.	3	Feature	Done	1. As a TheraSense user, if I click on my profile page, then I should see an edit button. 2. As a TheraSense user, if I click on the edit button, I should be able to edit my account information. 3. As a TheraSense user, if I edited my account information, a confirmation message should appear indicating the edit. 4. As a TheraSense user, if my inputs were

ID	PBI	Size	Type	Status	Acceptance Criteria
					invalid, then I should receive an error message.
GP-4	As a TheraSense user, I want to sign-out from my account, so that I can keep my information secure.	1	Feature	Done	As a TheraSense user, If I click the sign-out button, then I should be signed out from my account.
GP-5	As a TheraSense user, I want to add a patient, so that I can track patient's progress.	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see an add button. 2. As a TheraSense user, if I click on the add button then I should fill out a form with valid patient inputs. 3. As a TheraSense user, if I added the patient a confirmation message should appear indicating the addition. 4. As a TheraSense user, if I fill out the form with invalid inputs,

ID	PBI	Size	Type	Status	Acceptance Criteria
					then I should receive an error message.
GP-6	As a TheraSense user, I want to edit a patient's information, so that I can recover from any mistaken inputs.	2	feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page and see the patient edit button. 3. As a TheraSense user, if I edited the patient information, a confirmation message should appear indicating the edit. 4. As a TheraSense user, if I fill out the form with invalid inputs, then I should receive an error message.
					1. As a TheraSense user, if I enter the

ID	PBI	Size	Type	Status	Acceptance Criteria
GP-7	As a TheraSense user, I want to delete a patient, so that the patient does not appear on my page.	3	Feature	Done	application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page and see patient delete button. 3. As a TheraSense user, if I click the delete button, a pop-up message will appear to confirm patient deletion. 4. As a TheraSense user, if I deleted the patient a confirmation message should appear indicating the deletion.
					1. As a TheraSense user, if I enter the application, then I should be able to see all my

ID	PBI	Size	Type	Status	Acceptance Criteria
GP-8	As a TheraSense user, I want to contact the patient for any reason, so that I can improve the treatment quality.	3	Feature	Done	patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page. 3. As a TheraSense user, if I click the patient contact button, I should be able to send a message via SMS or Email to the patient.
GP-9	As a team member, I want to utilize a dataset comprising raw sensor data that represents physical activities, so that it can be used in building the classification model.	2	knowledge acquisition	Done	The dataset is utilized in building the classification model.
GP-10	As a team member, I want to preprocess the dataset, so that I have cleaned data to be used for modeling.	3	knowledge acquisition	Done	The dataset is cleaned and ready to be used in building the model.
GP-11	As a TheraSense user, I want to be able to read any article, so that I gain insights into the experiences of fellow therapists and enhance my knowledge.	3	Feature	Done	1. As a TheraSense user, if I click on the community button from the menu, I should be directed to the community page.

ID	PBI	Size	Type	Status	Acceptance Criteria
					2. As a TheraSense user, if I click on any article from the community page, I should be able to read it.
GP-12	As a TheraSense user, I want to be able to search for any article by a keyword, so that I can find related articles to the keyword.	3	Feature	Done	1. As a TheraSense user, if I click on the community button from the menu, I should be directed to the community page. 2. As a TheraSense user, if I write a keyword on the search bar on the community page, I should be able to find related articles.
GP-13	As a TheraSense user, I want to write an article and publish it on the community page, so that others can read it.	3	Feature	Done	1. As a TheraSense user, if I click on my articles button from the menu, I should be directed to my articles page. 2. As a TheraSense user, if I click on the write button,

ID	PBI	Size	Type	Status	Acceptance Criteria
					I should be able to write an article on my articles page to publish it on the community page. 3. As a TheraSense user, if I published an article a message should appear indicating the publishment.
GP-14	As a TheraSense user, I want to be able to delete any of my articles, so that other users can't read it.	3	Feature	Done	1. As a TheraSense user, if I click on my articles button from the menu, I should be directed to my articles page. 2. As a TheraSense user, if I click on any article on my articles page, I should see the delete button. 3. As a TheraSense user, if I click the delete button, a pop-up message will appear to confirm article

ID	PBI	Size	Type	Status	Acceptance Criteria
					deletion. 4. As a TheraSense user, if I deleted the article a confirmation message should appear indicating the deletion.
GP-15	As a team member, I want to extract all possible features, so that I can train the model based on these features.	2	knowledge acquisition	Done	All possible features have been extracted.
GP-16	As a team member, I want to select a subset of relevant features, so that I improve the model's performance by reducing dimensionality and eliminating irrelevant features.	2	knowledge acquisition	Done	The appropriate features have been selected.
GP-17	As a TheraSense user, I want to add a rehabilitation program to a specific patient, so that I can measure the patient's performance.	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page. 3. As a TheraSense user, if I click the add program

ID	PBI	Size	Type	Status	Acceptance Criteria
					button, the program should be added. 4. As a TheraSense user, if I added the patient a confirmation message should appear indicating the addition.
GP-18	As a TheraSense user, I want to search for a specific patient by ID, so that I can view the patient's details.	2	Feature	Done	As a TheraSense user, if I click the search button I can search for any patient by his/her ID to view the patient's details.
GP-19	As a TheraSense user, I want to be able to have application Frequently Asked Questions (FAQs) answered by the chatbot so that I can resolve any issues or confusion I encountered while using the app.	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see a button that directs me to the chatbot section. 2. As a TheraSense user, if I enter the chatbot section I should be able to ask the chatbot from the application

ID	PBI	Size	Type	Status	Acceptance Criteria
					FAQs. 3. As a TheraSense user, if I ask the chatbot a question from the application FAQs, then the chatbot should be able to answer this question.
GP-20	As a TheraSense user, I want to be able to take a chatbot quiz, so that I can refresh my knowledge.	3	feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see a button that directs me to the chatbot section. 2. As a TheraSense user, if I enter the chatbot section I should be able to ask the chatbot for a quiz. 3. As a TheraSense user, if I ask the chatbot for a quiz, then the chatbot should be able to give me a question. 4. As a TheraSense user, if I answer

ID	PBI	Size	Type	Status	Acceptance Criteria
					the question the chatbot should tell if it is the right answer.
GP-21	As a team member, I want to split the data, so that I can use one for training and the other for testing the model.	3	knowledge acquisition	Done	The dataset is splitted into training and testing sets.
GP-22	As a team member, I want to train the Random Forest model using the segmented dataset, so that I can train the model.	3	knowledge acquisition	Done	The model is trained using the Random Forest algorithm and the training set.
GP-23	As a team member, I want to train the K-Nearest Neighbors model using the segmented dataset, so that I can train the model.	3	knowledge acquisition	Done	The model is trained using the K-Nearest Neighbors algorithm and the training set.
GP-24	As a team member, I want to train the SVM model using the segmented dataset, so that I can train the model.	3	knowledge acquisition	Done	The model is trained using the SVM algorithm and the training set.
GP-25	As a team member, I want to train the Naïve base model using the segmented dataset, so that I can train the model.	3	knowledge acquisition	Done	The model is trained using the Naïve base algorithm and the training set.
GP-26	As a team member, I want to test the Random Forest model using a segmented testing set, so that I can apply the performance measure on the model.	3	knowledge acquisition	Done	The Random Forest algorithm is tested using the testing set.

ID	PBI	Size	Type	Status	Acceptance Criteria
GP-27	As a team member, I want to test the K-Nearest Neighbors model using a segmented testing set, so that I can apply the performance measure on the model.	3	knowledge acquisition	Done	K-Nearest Neighbors algorithm is tested using the testing set.
GP-28	As a team member, I want to test the SVM model using a segmented testing set, so that I can apply the performance measure on the model.	3	knowledge acquisition	Done	The SVM algorithm is tested using the testing set.
GP-29	As a team member, I want to test the Naïve Bayes model using a segmented testing set, so that I can apply the performance measure on the model.	3	knowledge acquisition	Done	The Naïve Bayes algorithm is tested using the testing set.
GP-30	As a team member, I want to compare the testing results of all pervious algorithms, so that I can choose the appropriate algorithm for TheraSense.	2	knowledge acquisition	Done	The test results provide a clear indication of the algorithm that is most appropriate for the TheraSense.
GP-31	As a team member, I want to integrate the selected model with the application, so that I can generate the patient performance report for the therapists.	3	knowledge acquisition	Done	1. The model has been integrated with the applicatio n. 2. The integrated model generates the patient’s

ID	PBI	Size	Type	Status	Acceptance Criteria
					performance report.
GP-32	As a TheraSense user, I want to generate reports about the patient's performance on a specific time frame (weekly, monthly), so that I can view the report.	5	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page. 3. As a TheraSense user, if I click the Generate report button, then I should choose a time frame. 4. As a TheraSense user, if I chose a time frame, then the report should be generated.
GP-33	As a TheraSense user, I want to send an updated rehabilitation	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients.

ID	PBI	Size	Type	Status	Acceptance Criteria
	program to the patient, so that the patient is kept up to date with the new program.				2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page. 3. As a TheraSense user, if I click the patient program, I should be able to view the program. 4. As a TheraSense user, if I click send the program button the program should be sent to the patient.
GP-34	As a TheraSense user, I want to rank patients according to their commitment, so that I make further actions on patients with low commitment whenever needed.	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I click on the rank button, I should be able to rank the patients according to their commitment.
					1. As a TheraSense

ID	PBI	Size	Type	Status	Acceptance Criteria
GP-35	As a TheraSense user, I want to print the generated report, so that I can use it for many purposes.	2	Feature	Done	user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page. 3. As a TheraSense user, if I click the patient report, I should be able to view the report. 4. As a TheraSense user, if I click the print report button the report should be printed.
GP-36	As a TheraSense user, I want to view a patient's performance report, so that I can evaluate the rehabilitation program.	5	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be able to view patient's

ID	PBI	Size	Type	Status	Acceptance Criteria
					report
GP-37	As a TheraSense user, I want to update the patient's program, so that I can improve the patient's rehabilitation progress.	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's information page. 3. As a TheraSense user, if I click on the update program button, then I should be able to update the patient's program details.
GP-38	As a TheraSense user, I want to extend the patient's program, so that I can improve the patient's rehabilitation progress.	3	Feature	Done	1. As a TheraSense user, if I enter the application, then I should be able to see all my patients. 2. As a TheraSense user, if I tap on one of my patients, then I should be directed to this patient's

ID	PBI	Size	Type	Status	Acceptance Criteria
					information page. 3. As a TheraSense user, if I click on the update program button, then I should be able to update the patient's program details.
GP-39	As a TheraSense user, I want to upload my article as a PDF, so that it can be easily shared and viewed in its original format by others within the Application.	3	Feature	Done	1. As a TheraSense user, if I click on community from the navigation bar, I should be directed to the articles page. 2. As a TheraSense user, if I click on the write button, I should be able to upload the Article as PDF to publish it on the community page. 3. As a TheraSense user, if I published an article a message should appear indicating the publication.
					1. As a TheraSense

ID	PBI	Size	Type	Status	Acceptance Criteria
GP-40	As a TheraSense user, I want to view articles as a PDF, so that I can read them in a consistent and accessible format that preserves the original layout and design.	2	Feature	Done	user, if I click on the community button from the navigation bar, I should be directed to the articles page. 2. As a TheraSense user, if I click on any article on the articles page, I should see the PDF button if the article has a pdf associated with it. 3. As a TheraSense user, if I click the PDF button, the pdf should appear on the screen.
GP-39	As a TheraSense user, I want the application to be available 99% of the time on the workdays, so that I can see the progress of the patient.		Non-functional	Done	The application should be available 99% of the time on the workdays when the user launches it.
GP-40	As a TheraSense user, I want all pages to display within 6 seconds, so that I can navigate in an efficient way.		Non-functional	Done	All pages are displayed within 6 seconds.
GP-41	As a TheraSense user, I want to get feedback within 10 seconds		Non-	Done	The feedback of an action should

ID	PBI	Size	Type	Status	Acceptance Criteria
	with no delay, so that I can be assured that the action I have done is executed.		functional		be displayed within 10 seconds after making an action.
GP-42	As a TheraSense user, I want the application to be simple, so that I can use the application with no error making after 10 minutes of learning.		Non-functional	Done	The user should be able to use the application with no errors after 10 minutes of learning.
GP-43	As a TheraSense user, I want to be able to log out, so that my session is not used by someone else.		Non-functional	Done	The user's session should be deleted after logging out.

1.3 System Design

This chapter will go over system analysis and design. It is an activity that identifies TheraSense software components and relationships based on TheraSense users' requirements.

1.3.1 Architectural Diagram

TheraSense is a mobile application that is interactive and uses a similar concept to a Client-Server architecture. This mobile application is utilized by multiple therapists to divide the workload

between client requests. Then, the centralized server (host computer) responds to those requests. The client-side interface acts as a channel between the server and the user, allowing the user to request a service from the server and view the output from the server [69]. This type of model allows for a greater number of clients and servers to be integrated into the system, thus enhancing the performance with low-cost maintenance [70].

As illustrated in Figure 18, TheraSense users can Sign in if they have an account. Using their email and password. This will enable TheraSense users to access the application and add their patients. Hence, TheraSense users are able to generate a patient's performance report. However,

this can be done by the following scenario, the raw sensor data has been collected, the extracted features data has been stored in the database. Then the network will forward the extracted sensor data to the server, where the Machine Learning (ML) model already exists.

ML model aims to analyze the database and classify what activities the patient had performed and the frequencies of each activity to generate the patient's performance report. The initial step in generating a patient's performance report is data collection, which is achieved through the use of an accelerometer sensor. As mentioned, the extracted sensor data is stored in a database, then entered into a ML model that will be built using either SVM, Random Forest, K-nearest or Naïve Bayes algorithm. The decision is based on the highest algorithm's performance.

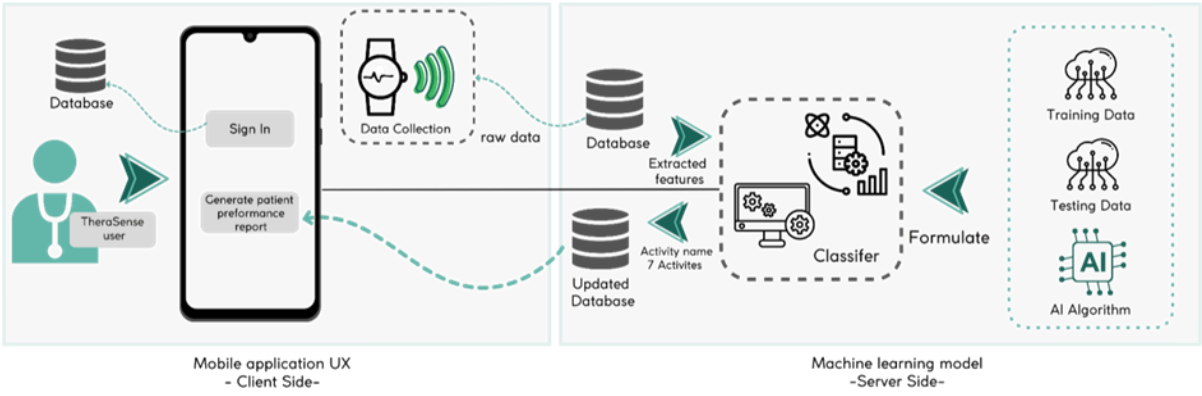


Figure 18: TheraSense Architecture Diagram.

1.3.2 Data Flow Diagram(DFD)

In this section, the flow of data through the system will be illustrated along with the inputs and outputs of each entity and the processes itself, as shown in Figure 19.

In the data flow diagram of TheraSense, we start the data flow from the sign in or sign up page that needs firebase to get the authentication credentials. If the user forgot his/her password, then click the forgot password from the sign in page. The sign in page will forward the sign in credentials to the Forget Password page, the new password will be stored in firebase. The system will get Articles and Patients information to be displayed on the Home page. Then the Article's ID goes to the Article page, and the Patient's ID goes to the Patient page.The Patient information can be edited and forwarded to firebase to save changes. After that, the contact will receive the patient's contact information; this data will be forwarded to the appropriate

app. Gmail, SMS or WhatsApp depending on the chosen contact data. The community page will retrieve all the Articles from firebase to be displayed and the ID of the Article will be forwarded to the Article page to have access to the Article. The Article information can be edited/deleted and forwarded to firebase to save changes. The Patient information will be inserted into the firebase once the patient is added. The Article information will be inserted into the firebase once the Article is added as well. The Therapist Information will be given to the profile page from the authentication class after making sure that the user is authentic and signed in. The therapist information can be edited and forwarded to firebase to save changes. Another choice is to pass the old password info to the change password page to validate the user, then after the password has been changed, the new password will be stored in firebase. The system will get the Patient information to be displayed on The patient page. Then the Patient's ID goes to both the Programs Page and the Reports Page. The Programs page will retrieve all the programs from firebase to be displayed and the ID of the Program will be forwarded to the Program details page to have access to the Program. The Program information can be edited and forwarded to firebase to save changes. Additionally, The Programs page forwards the patient id to the Add Program page which in turn forwards the Authentic Info, Patient Number, Program ID, Start Date, End Date, NumberOfActivities to the Add Activities page, this page is responsible for storing the program information to firebase. The Reports page retrieves all the Reports from firebase to be displayed and the ID of the Report will be forwarded to the Report details page to have access to the Report. Also it will forward the patient id to the Add report page, after adding a report this page forward the program id to the Report details page to view the added report. Additionally,The Chatbot page retrieves FAQs and their corresponding answers, as well as quiz questions, options, and correct answers from Firebase.

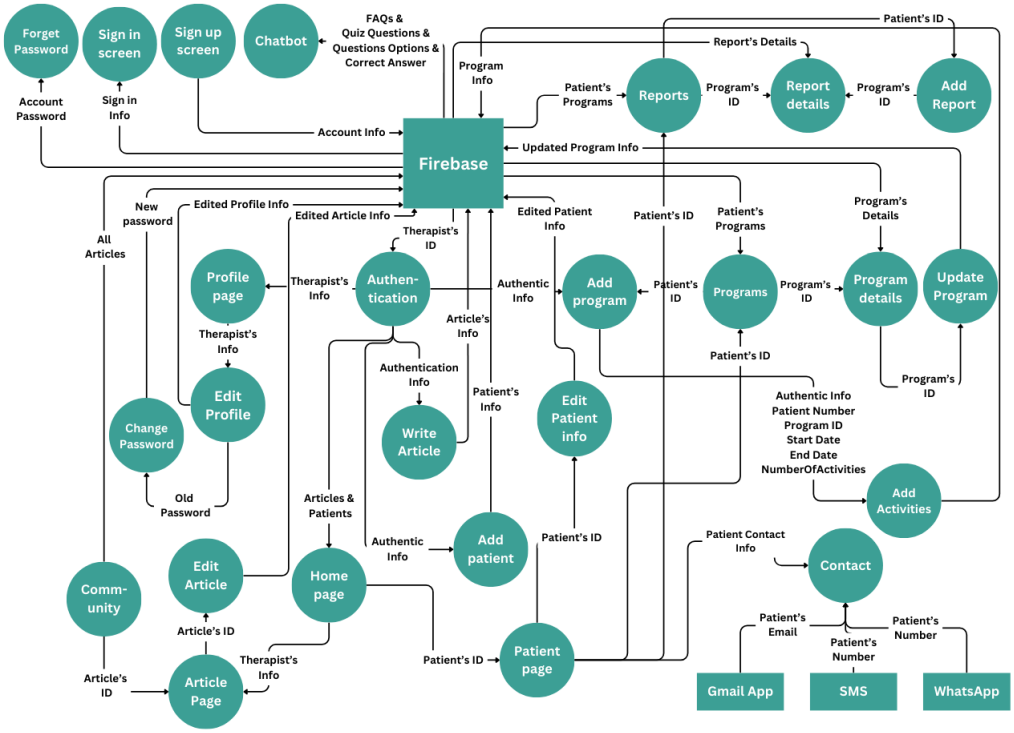


Figure 19: TheraSense DFD.

4.2.4 Component Level Design

In this section a pseudocode will be provided for five functions which are Add patient, Publish an article and Search for article, Add program, Start a chat, respectively.

- Add patient Pseudocode

```
Function Add patient():
 dataToSave = {
                'Patient Name': _patientnameController.text,
                'Patient Number': _patientnumberController.text,
                'Phone Number': _phoneController.text,
                'Email': _emailController.text,
                'TheraID': user.uid,
                'Gender': selectedGender,
                 }

  IF any of (Patient Name, Patient Number,  Phone Number, Email) is empty THEN
       Show`message 'Please fill out all the fields.'
  End If

  patientNumberExists = check If patientNumberExists(patientNumber)
  IF patientNumberExists THEN
       Show message 'Patient number already exists!'
  ELSE:
       Save data to Firestore(dataToSave)
       Navigate To Homepage()
       Show message 'The Patient is in your list now!'
  END IF
End Function
```

Figure 20:Add patient pseudocode.

- Publish an Article Pseudocode

```
Function publishArticle()
    dataToSave = {
        'PublishTime': GetCurrentTimestamp(),
        'Title': _titleController.text,
        'Content': _articleController.text,
        'KeyWords': _keywordsController.text,
        'image': imageUrl,
    }
    IF AllFieldsNotEmpty(dataToSave) THEN
       Save data to Firestore(dataToSave)
       NavigateToHomepage()
       Show message 'The article is published now!'
    ELSE
       Show Error Message('Please fill out the fields.')
    END IF
END Function
```

Figure 21:Publish an Article pseudocode.

- Search for Article Pseudocode

```
Function searchArticles(keywordOrTitle):
  articles = getArticles()
  filteredArticles = []
 FOR article in articles:
  IF article.title.contains(keywordOrTitle) or
     article.content.contains(keywordOrTitle)
  THEN
     filteredArticles.append(article)
  END IF
  IF filteredArticles.length == 0 THEN
  return;
  ELSE
  return filteredArticles
 END IF
 END FOR
END Function
```

Figure 22:Search for Article pseudocode.

- Add program Pseudocode

```
Function: AddProgramPage
  Display Title "Add Program"
  Display Start Date Field:
    - Allow user to select the start date of the program
  Display End Date Field:
    - Allow user to select the end date of the program
  Display Number of Activities Dropdown:
    - Allow user to select the number of activities in the program
  Display Next Button:
    - Button to proceed to the next step (Add Activities Page)
End Function

Function: AddActivitiesPage
  Display Title "Add Activities"
  For each Activity:
    - Display Activity Number
    - Display Dropdown to select Activity Type
    - Display Dropdown to select Frequency
    - Display Dropdown to select Days Per Week
  Display Submit Button:
    - Button to submit the activities and finalize the program
End Function
```

Figure 23:Add program pseudocode.

- Start a Chat Pseudocode

```
Function: _handleUserMessage(text: String)
  Send user message
  Handle user input based on commands or text
  Add chatbot message to _messages list
  Display chatbot message with optional buttons
End Function

Function: _handleButtonPressed(text: String)
  Handle button press actions based on input text
  Display FAQs, start quiz, or handle exit
End Function

Function: _startQuiz
  Retrieve random questions from Firestore
  Shuffle and select questions
  Display current quiz question with options
  Listen for user input and handle answers
  Check if answer is correct
  Update score and proceed to next question or end quiz
  Display quiz result with score and options to restart or exit
  Display correct answers for quiz questions
  Display options to restart quiz, view FAQs, or exit
End Function

Function: _displayFAQs
  Retrieve FAQs from Firestore
  Display FAQs with options to view answers or return to main menu
End Function
```

Figure 24:Start a chat pseudocode.

4.3 Data Design

In this section a data design will be provided for NoSQL database including ER diagram and non-relational data model. In addition, data collection and preparation to demonstrate the processing on the dataset.

4.3.1 Data Models

- ER Diagram

  The Entity Relationship (ER) diagram shown in Figure 25 represents the current structure of the used NoSQL database. The ER diagram has a Therapist collection which refers to the user. The Therapist document can have no or many patients and articles. The Program document can be created by only one therapist and for only one patient and have at most one report. The FAQ and Quiz are stand-alone entities that store only questions and answers shared between all therapists. The Program document includes a list of activities. This list includes one or many activities. Each activity is identified by its name, frequency and number of repetitions per week. The Report document includes a list of Weeks Performance, this list stores week by week performance as a percentage for each activity name. The Report document includes a list of Months Performance as well, this list stores month by month performance as a percentage for each activity name.

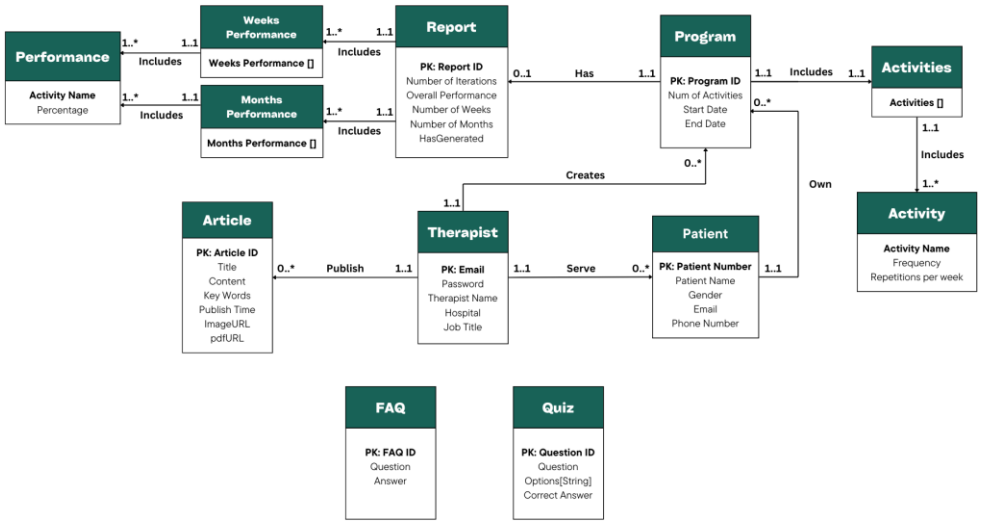


Figure 25:TheraSense ER..

- Non-Relational Data Model

  The non-relational data model shown in Figure 26 represents the current design of the application. This data model follows a combination of reference and embedding approach. However, the following data model illustrates the database structure as a form of parent-child relationship.

  The ‘Therapist’ document contains a set of attributes including email, password, full name, hospital and job title along with a set of ‘Patient’ documents or/and ‘Article’ documents. The ‘Patient’ document which is referenced by the therapist document id contains a set of attributes including patient number, patient name, gender, email, phone number along with a set of ‘Program’ documents. The ‘Program’ document which is referenced by the patient number contains a set of attributes including program id, start date, end date, number of activities and an embedded list of ‘Activities’. Each ‘Activity’ object embedded in the ‘Activities’ list contains information about the activity including the activity name, frequency and repetitions per week. Moreover, the ‘Program’ document can also contain ‘Report’ documents which are referenced by the program id, and include report id, number of weeks, number of months, number of iterations, overall performance, hasGenerated and two embedded lists. These two lists are weeks performances and months performances. Each list embeds performance information for each week/month. The performance information includes activity name and percentage. In addition, the data model has two other documents that are not related to the rest of the documents, ‘FAQ’ and ‘Quiz’ documents. The ‘FAQ’ document

contains a set of attributes including faq id, pre-defined question and answer. The 'Quiz' document contains quiz id, pre-defined question and answer as well along with the options list.

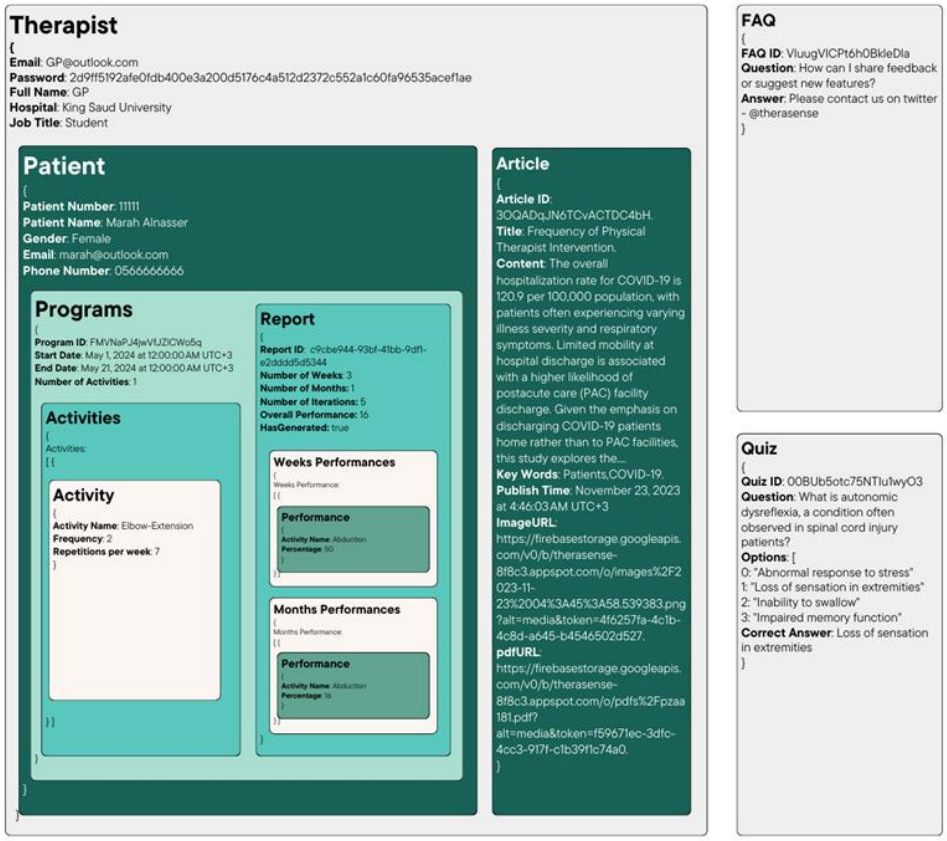


Figure 26:Non-Relational data model.

4.3.2 Data Collection and Preparation

In this section, the data collection process will be demonstrated along with data preparation, including data preprocessing, data segmentation, feature extraction and feature selection.

A. Data Collection

During the in-home rehabilitation process, data will be acquired from wearable sensors worn by patients. Subsequently, the collected data will go through a processing phase intended to improve its quality and suitability for analysis. This data takes the form of signals, whose inherent nature may introduce noise and variations, potentially compromising the accuracy of subsequent classification processes.

For our dataset, it has 10 individual files for each activity. To ease the preprocessing tasks, we concatenated these files into a single combined DataFrame named complete_dataframe as shown in Figure 27.

complete_dataframe

	X	Y	Z	Activity
0	-3.600132	-8.780723	-0.312846	Abduction
1	-3.589581	-8.787952	-0.281064	Abduction
2	-3.600934	-8.797590	-0.232737	Abduction
3	-3.615687	-8.837349	-0.170439	Abduction
4	-3.636997	-8.854217	-0.104616	Abduction
...	...	...	...	...
52261	-4.205159	-9.760241	0.407226	Sh Flexion
52262	-3.779635	-9.689157	0.354828	Sh Flexion
52263	-3.249704	-9.648193	0.187828	Sh Flexion
52264	-2.960981	-9.586747	0.011139	Sh Flexion
52265	-2.567207	-9.526506	-0.235849	Sh Flexion

52266 rows × 4 columns

Figure 27: Complete_dataframe.

B. Data Preprocessing

A Moving Average Filter (MAF) is a preprocessing task that is crucial for removing noise and signal smoothing. This method seeks to mitigate noise effects and ensure the robustness of the signals for more accurate and reliable analyses. MAF was chosen specifically because it is known for its simplicity and effectiveness [71]. Different trials of window size were undertaken to find the best window size parameter value. The experiment demonstrates that the signals lose their unique patterns and become extremely smooth with window size above '10'. While they become very noisy when the number is less than "10", see Appendix D for more details about these attempts. However, a window size of ‘10’ is the most efficient choice due to the ability to remove the noise and keep track of the original pattern of the signals as shown in Figure 28.

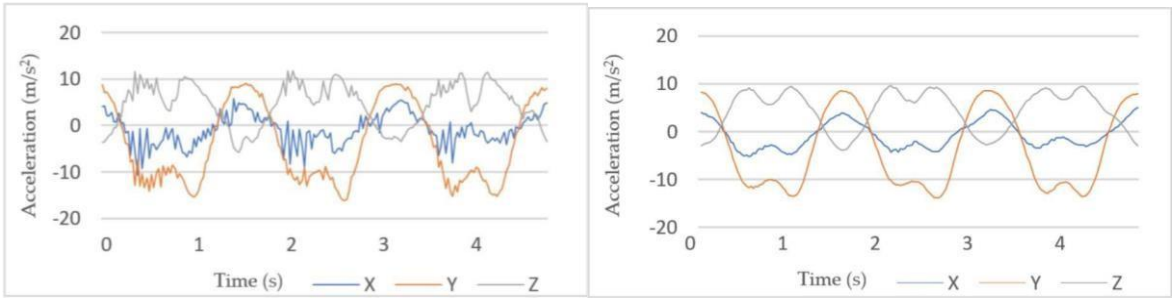


Figure 28: Before and after applying MAF, window size=10.

C. Data Segmentation

Furthermore, segmentation will be applied to the data, which is also considered as one of the preprocessing tasks. It aims to transform raw sensor data into identifiable activities achieved by specifying the start and end of each activity. This process includes dividing the sensor measurement time series into small segments, which are then labeled based on similarity. The Sliding Window Segmentation is the chosen method to be used for activity recognition as it shows a good result [72]. The research tested different values for window size. The test result clearly shows that the 2s window length yields the highest exercise recognition accuracy, the segmentation using this parameter is illustrated in Figure 29.

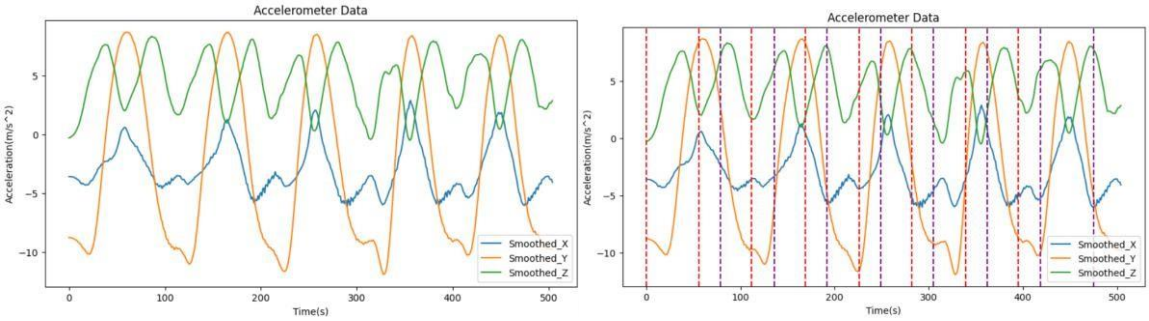


Figure 29: Sliding Window segmentation, window size=2s.

D. Feature Extraction

The field of feature extraction was researched in several research papers, as it proves its effect on the performance of classifiers. Most of these features used in these research papers [73 - 75] include mean, max, min, standard deviation (SD), range, and Root Mean Square (RMS). In Table 3 below, the equation for each feature has been clarified. All these features are computed for each of the X, Y, and Z components of the accelerometer sensor that exists in the dataset, then appended as new columns to the original dataset. Magnitude(M), will be calculated for (X,Y,Z) and will be stored in one column. Magnitude formula is shown in Equation 7.

$$M = \sqrt{x^2 + y^2 + z^2}\ .$$

Equation 7: Magnitude Formula

Table 3: Extracted features Definitions.

Name	Definition
Mean	$Mean = \frac{\sum_{i=1}^{n} x_i}{n}$
Max	$Max = \max(x_1, x_2, \dots, x_n)$
Min	$Min = \min(x_1, x_2, \dots, x_n)$
Standard Deviation (SD)	$SD = \sqrt{\frac{\sum_{i=1}^{n} (x - Mean)^2}{n}}$
Range	$\max(x_1, x_2, \dots, x_n) - \min(x_1, x_2, \dots, x_n)$
Root Mean Square (RMS)	$RMS = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x^2}$

E. Feature Selection

In the Feature Selection phase, our goal is to analyze how features extracted from X, Y, and Z affect the accuracy of activity recognition, and which features may be combined to maximize classification performance. However, this selection will be evaluated in the experimental results section. If the features selected outperform all features, then we will accept these selected features, if not, then all features will be used.

We used Random Forest Classifier to help in selecting the most important features. Figure x shows the scores of all features. Let's take 0.05 as a threshold score, then the selected features as shown in Figure 30 will be the top 10 features out of 20 features. The selected features by Random Forest Classifier are Mean_X, Max_X, Min_Y, Max_Y, Mean_Z, Range_X, Min_Z, Max_Z, Range_Y, RMS_Y.

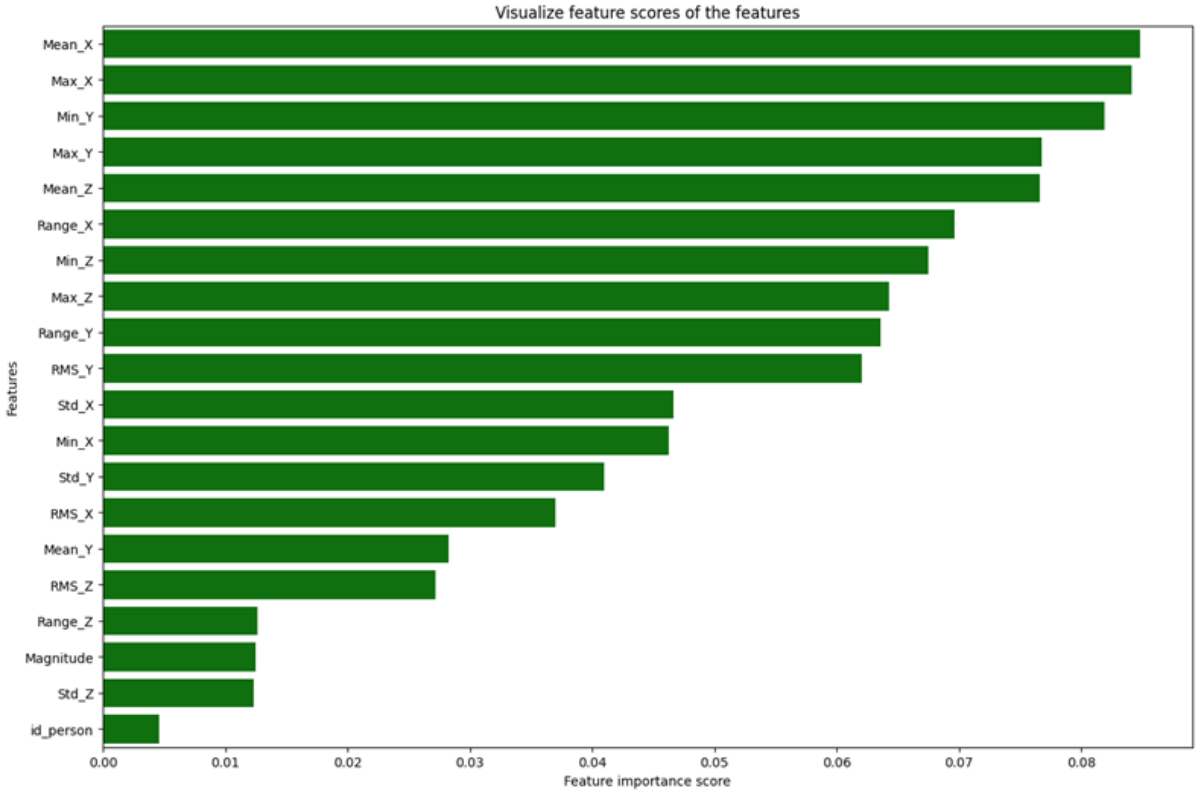


Figure 30: The Correlation Matrix of the Selected Features.

1.4 Interface Design

In the user navigation diagram as illustrated in Figure 31 highlighting TheraSense's central access point for modeling objects and their associated screens, along with the available navigation paths within TheraSense.

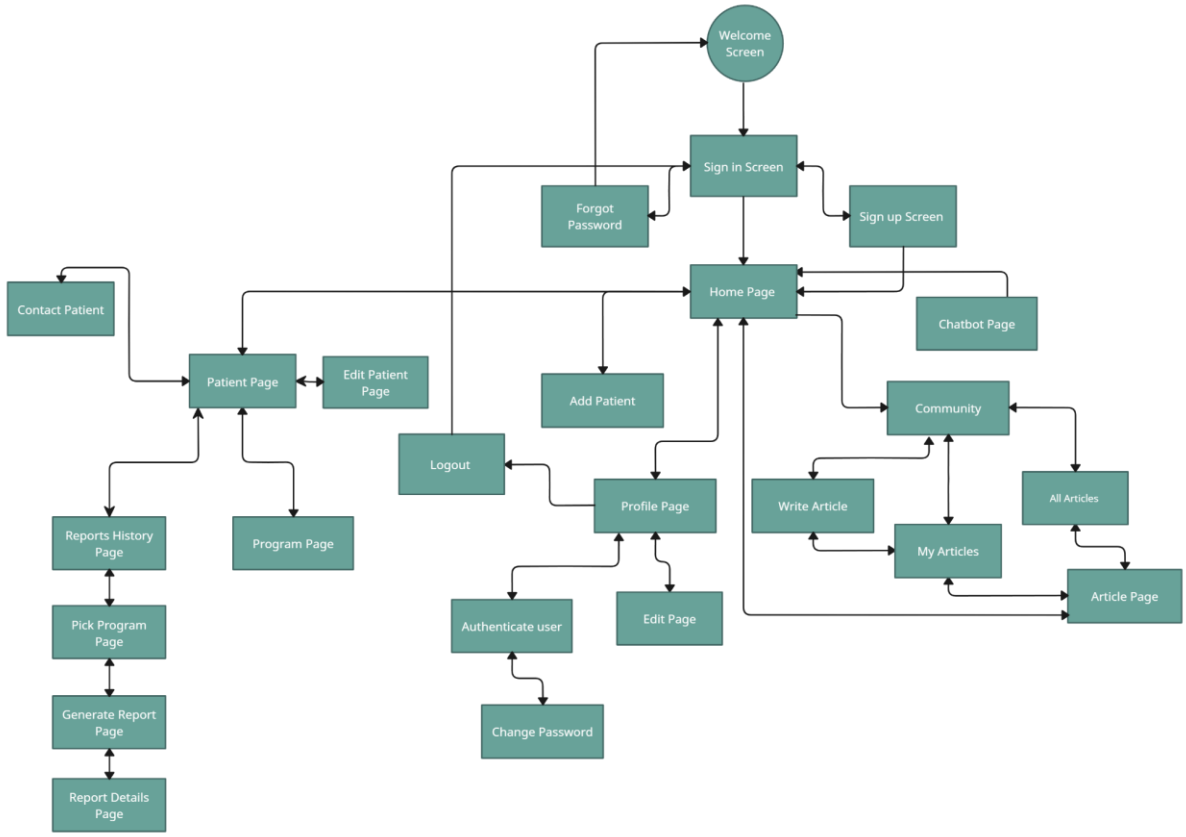


Figure 31: Navigation Diagram

1.4.1 UX Guidelines

- **Learnability**

  For the learnability principle, TheraSense followed three guidelines: predictability, familiarity and generalizability, that are easing in the use of TheraSense application.

  1- For predictability: users can predict that the contact button using "WhatsApp", will

let them contact through WhatsApp as shown in **Figure 32**.

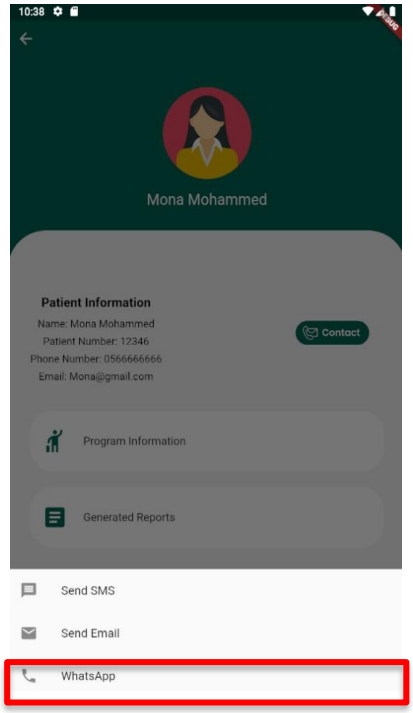


Figure 32: Patient Details Screen

2- For familiarity: The profile tab in the navigation bar has a profile icon that is familiar for users as shown in **Figure 33.**

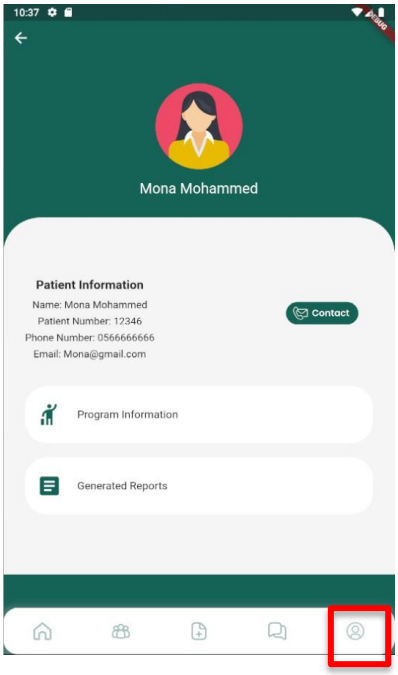


Figure 33: Navigation Bar

3- For generalizability:” Forgot password” in the sign in page similar to other applications as shown in **Figure 34**.

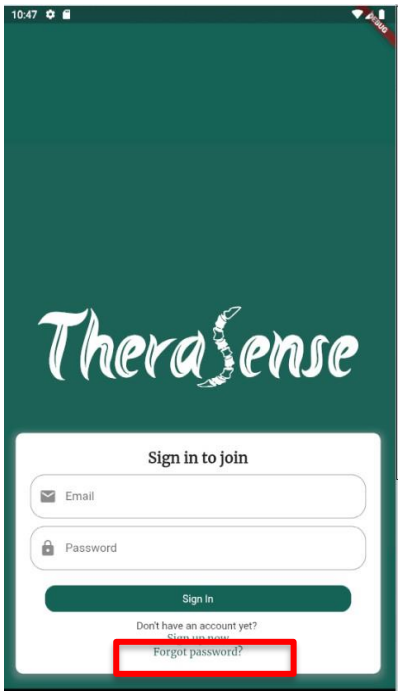


Figure 34: Sign in Screen

- **Flexibility**

For the flexibility principle, TheraSense followed the dialog initiative guideline, this guideline refers to who initiates dialog flow, in this case it is system pre-emptive. This helps the user perceive the first action from the system which enhances usability.

1- The system initiates the dialog to delete the article when the user clicks the button as illustrated in **Figure 35.**

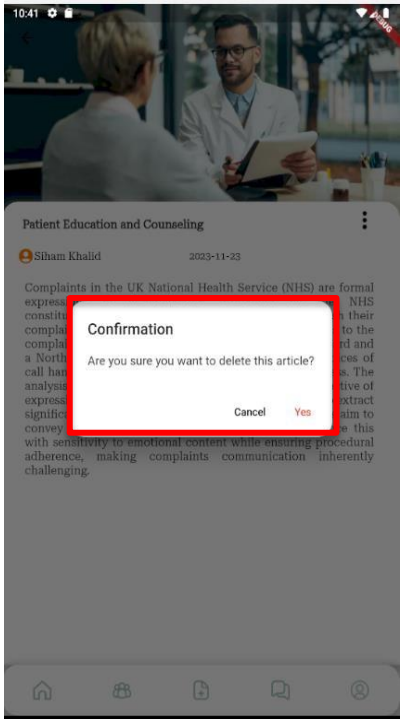


Figure 35: Article Screen.

- **Robustness**

  For the robustness principle, TheraSense followed two guidelines: reachability and recoverability, these guidelines improve the robustness of TheraSense application. Hence, the user can use the application and have full user experience with minimal errors.

  1- For reachability, in TherSense, the bottom navigation bar takes the user to their desired page as displayed in **Figure 36**

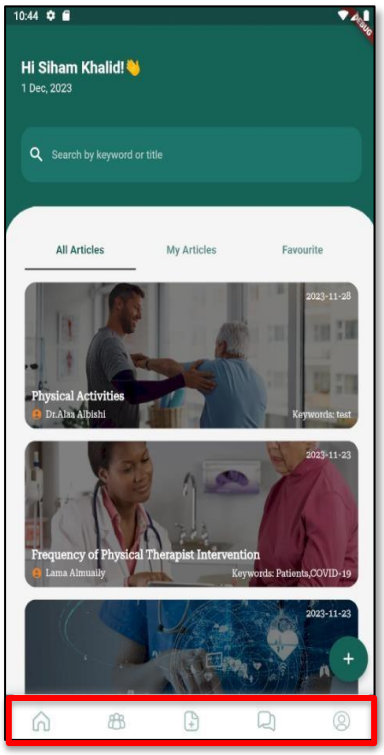


Figure 36: Community Screen.

2- For recoverability, TheraSense used immediate response for validation instead of response after the button is clicked as much as possible in add patient form to avoid user errors as seen in **Figure 37.**

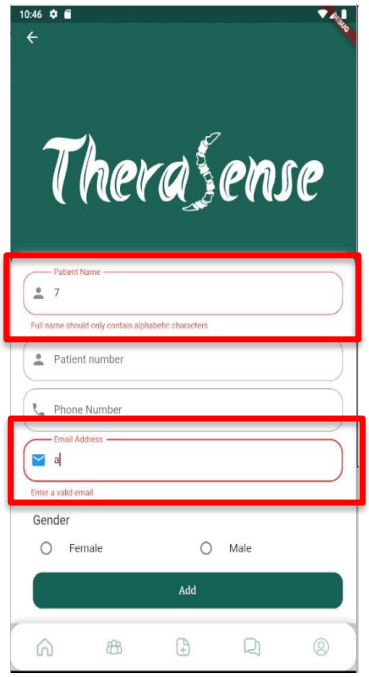


Figure 37:Add Patient Screen.

1.5 Implementation

In this section, important and significant code snippets are demonstrated, and the rest of the code will be provided in the GitHub repository.

- **Write an Article Page**

The provided Flutter code in Figure 38, 39 defines a widget for image upload functionality. The widget begins with vertical spacing, and a text element labeled "Image" with a specified font size and font family. To follow this, there is a Column widget that encapsulates various components for image display and upload. If an imageUrl is available, an Image widget loads the image from the network with specified dimensions. An ElevatedButton is present to initiate the image selection process through the _pickImage function. This button has a distinct style, the button includes an upload icon and the text "Upload Image". Subsequently, if a selectedImage is available, it is displayed using the Image.file widget with specified dimensions. In cases where selectedImage is null and the pressed variable is true, a text element reading "No image selected" is rendered. This code collectively constructs a user interface for image upload, allowing users to select and view images with corresponding upload functionality.

```
//image upload
SizedBox(height: 20),
Text(
  'Image:',
  style: TextStyle(
    fontSize: 18,
    fontFamily: 'Merriweather',
  ), // TextStyle
), // Text
SizedBox(height: 10),
Column(
  mainAxisAlignment: MainAxisAlignment.start,
  crossAxisAlignment: CrossAxisAlignment.start,
  children: [
    imageUrl != null
        ? Image.network(
            imageUrl!,
            width: 100,
            height: 100,
            fit: BoxFit.cover,
          ) // Image.network
        : Container(),
    ElevatedButton(
      onPressed: _pickImage,
      style: ElevatedButton.styleFrom(
        foregroundColor: Colors.grey,
        backgroundColor: Colors.white,
        fixedSize: Size(150, 40),
        padding: EdgeInsets.symmetric(
            vertical: 10, horizontal: 5), // EdgeInsets.symmetric
        shape: RoundedRectangleBorder(
          borderRadius: BorderRadius.circular(10),
          side: BorderSide(color: Colors.grey),
        ), // RoundedRectangleBorder
      ),
```

Figure 38: Upload Function Code.

```
      child: Row(
        children: [
          Icon(
            Icons.upload,
            size: 25,
          ), // Icon
          SizedBox(width: 6),
          Text(
            'Upload Image',
            style: TextStyle(
              fontSize: 15,
            ), // TextStyle
          ), // Text
        ],
      ), // Row
    ), // ElevatedButton
  ],
), // Column
Stack(
  children: [
    if (selectedImage != null)
      Padding(
        padding:
            const EdgeInsets.fromLTRB(0, 0, 0, 0),
        child: Image.file(
          selectedImage!,
          width: 120,
          height: 120,
        ), // Image.file
      ), // Padding
    if (selectedImage == null && pressed)
      Visibility(
        visible: selectedImage == null && pressed,
        child: Text(
          'No image selected',
          style: TextStyle(
            fontSize: 16,
            color: Color.fromARGB(255, 196, 0, 0),
          ), // TextStyle
        ), // Text
      ) // Visibility
  ],
```

Figure 39: Upload Function Code.

- **Search for an article.**

The provided Flutter code in Figure 40 involves working with a list of Article objects. The cards list is initialized using the data obtained from a snapshot. If the snapshot data is null, an empty list is assigned to cards. Subsequently, a new list called filteredCards is created by filtering the cards list based on a specified condition. The searchQuery is converted into lowercase version then used by a where function to check whether the lowercase version of either the Title or KeyWords of each Article object. The result is a filtered list, stored in the filteredCards variable, which perhaps contains only the Article objects that match the specified search criteria.

```
//Filtered list will be excuted once the user interact
List<Article> cards = snapshot.data ?? [];

List<Article> filteredCards = cards
    .where((article) =>
    article.Title.toLowerCase().contains(
      searchQuery.toLowerCase()) ||
        article.KeyWords.toLowerCase().contains(
            searchQuery.toLowerCase()))
    .toList();
```

Figure 40: Search Function Code

- **Contact Patient**

The code in **Figure 41** consists of three ListTile widgets in a Flutter application. The first one enables sending an SMS when tapped, using the phone number prefixed with the Saudi country code with the patient number. The second one triggers sending an email with a patient email address that is stored in firebase. The third one opens WhatsApp with a specific phone number of the chosen patient. Each ListTile is designed to perform a communication-related action when clicked. The canLaunch function ensures that the app checks if the required apps can be launched before attempting to open them.

```
ListTile(
  leading:
      const Icon(Icons.message),
  title: const Text('Send SMS'),
  onTap: () async {
    final phoneNumber =
        '+966$phone';
    final url =
        'sms:$phoneNumber';

    if (await canLaunch(url)) {
      await launch(url);
    } else {
      throw 'Could not launch $url';
    }

    Navigator.pop(context);
  },
), // ListTile
```

```
ListTile(
  leading:
      const Icon(Icons.email),
  title:
      const Text('Send Email'),
  onTap: () async {
    final url = 'mailto:$email';

    if (await canLaunch(url)) {
      await launch(url);
    } else {
      throw 'Could not launch $url';
    }

    Navigator.pop(context);
  },
), // ListTile
```

```
ListTile(
  leading:
      const Icon(Icons.phone),
  title: const Text('WhatsApp'),
  onTap: () async {
    final phoneNumber =
        '+966$phone';
    final url =
        'https://api.whatsapp.com/send?phone=$phoneNumber';

    if (await canLaunch(url)) {
      await launch(url);
    } else {
      throw 'Could not launch $url';
    }

    Navigator.pop(context);
  },
), // ListTile
```

Figure 41: Contact Function Code.

- **Models class**

The provided Flutter code in **Figure 42 includes** a file that has multiple classes that represent objects in our application, such as Therapist, Patient and Article. For example, Therapist class includes attributes that exist as fields in the 'Therapist' collection. Name, jobTitle,

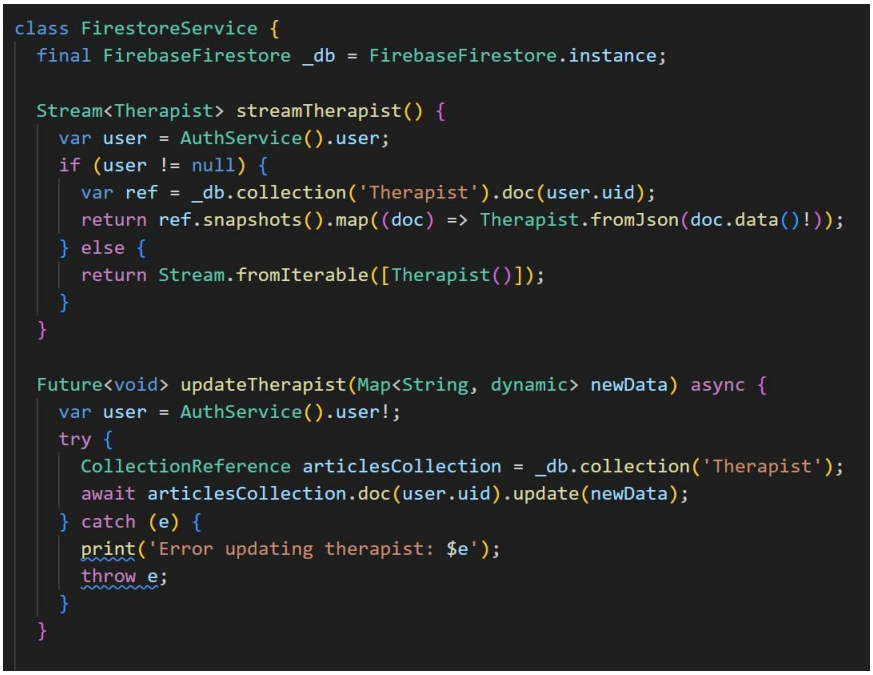
hospitalClinic, email and password. This class helps to make json responses returned from a Firestore database serializable, and easier to be accessed through other classes. This is done with the use of the json_serializable package. However, objects can be transformed to json format as well to be inserted in the Firestore database.

```dart
@JsonSerializable()
class Therapist {
  final String name;
  final String jobTitle;
  final String hospitalClinic;
  final String email;
  final String password;

  Therapist({
    this.name = '',
    this.jobTitle = '',
    this.hospitalClinic = '',
    this.email = '',
    this.password = '',

  });
  factory Therapist.fromJson(Map<String, dynamic> json) =>
      _$TherapistFromJson(json);
  Map<String, dynamic> toJson() => _$TherapistToJson(this);
}
```

Figure 42: Models class code.

- **FirestoreService Methods**

The provided Flutter code in **Figure 43** includes a class that has multiple stream and Future methods to ease the interaction with the Firestore database. Two methods are shown. The first method is streamTherapist that is needed to retrieve Therapist object that contains information about the current signed in user, this happens after transforming the json response to object as discussed in Models class. A therapist is identified by using the user id (uid) of the signed in user from AuthService () class, and it keeps listening to the Firstore database for any changes. The second method is updateTherapist which takes newData to update Therapist information, this happens by again using the (uid) of the current user to access his document. However, both need to handle any exceptional issues that could arise while communicating with the Firestore database.



```dart
class FirestoreService {
  final FirebaseFirestore _db = FirebaseFirestore.instance;

  Stream<Therapist> streamTherapist() {
    var user = AuthService().user;
    if (user != null) {
      var ref = _db.collection('Therapist').doc(user.uid);
      return ref.snapshots().map((doc) => Therapist.fromJson(doc.data()!));
    } else {
      return Stream.fromIterable([Therapist()]);
    }
  }

  Future<void> updateTherapist(Map<String, dynamic> newData) async {
    var user = AuthService().user!;
    try {
      CollectionReference articlesCollection = _db.collection('Therapist');
      await articlesCollection.doc(user.uid).update(newData);
    } catch (e) {
      print('Error updating therapist: $e');
      throw e;
    }
  }
```

Figure 43: FirestoreService class code.

- **Chatbot**

1) FAQs

The provided Flutter code in Figure 44 initializes a chatbot that offers options to view frequently asked questions (FAQs). Upon initialization in the **initState** method, the chatbot sends a welcome message with options for the user, including 'FAQs'. When the user selects the 'FAQs' option, the **_handleButtonPressed** method is triggered with the text 'FAQs'. This method checks if the text is 'FAQs' or '1', and if so, it sends the message 'FAQs' to the chat and calls **_displayFAQs()** to fetch and display the FAQs. The **_displayFAQs** method fetches a list of FAQss objects from Firestore using FirestoreService().getFAQs(). The fetched FAQ data is mapped to a list of ChatActionButton widgets, each displaying a question and showing the corresponding answer when pressed. These buttons are then passed to **_receiveMessage**, which updates the chat interface to display the FAQ buttons, allowing users to interact and view the answers dynamically.

```
void initState() {
  super.initState();
  _receiveMessage("Hello, I'm your chatbot. How can I assist you?", [
    ChatActionButton(
      text: '1- FAQs',
      onPressed: () {
        _handleButtonPressed('FAQs');
      },
    ),
```

```
void _handleButtonPressed(String text) {
  if (text.toLowerCase() == 'faqs' || text == '1') {
    _sendMessage(text, false);
    _displayFAQs();
```

```
Future<void> _displayFAQs() async {
  List<FAQss> faqs = await FirestoreService().getFAQs();
  List<ChatActionButton> faqButtons = faqs.map((faq) {
    return ChatActionButton(
      text: faq.question,
      onPressed: () {
        _sendMessage(faq.question, false);
        _sendMessage(
            faq.answer, true); // Sending the answer as a chatbot message
```

```
}).toList();
_receiveMessage('Here are some frequently asked questions:', faqButtons);
```

Figure 44: chatbot FAQ class code.

2) Quiz

As shown in Figure 45, the provided Flutter code includes a "Quick Quiz" functionality within a chatbot interface. The _startQuiz method initializes the quiz by resetting the current questions, index, score, and completion status, and then calls _getRandomQuestions() to fetch random quiz questions from Firestore using FirestoreService().getRandomQuizz(). The fetched questions are shuffled and a subset is selected for the quiz.

```
Future<void> _getRandomQuestions() async {
  var random = Random();
  List<Quizz> allquestions = await FirestoreService().getRandomQuizz();
  allquestions.shuffle(random);
  _currentQuestions = allquestions.sublist(0, min(4, allquestions.length));
  _askQuestion();
}
```

Figure 45: chatbot Quiz class code.

- **View Report**

The provided Flutter code in **Figure 46, 47** defines The pickProgram widget which is responsible for displaying a list of programs associated with a patient and allowing the user to select a program to view a report. It utilizes Firebase Firestore to fetch program data and stream it to the UI in real-time. The UI consists of a list of programs. Programs with associated reports are visually differentiated from those without reports. Users can select a program by tapping on it, and if a program is selected and has an associated report, they can view a report by tapping the "view report" button. The widget also includes error handling for cases where no programs are found or when attempting to generate a report without selecting a program or when the report data is not ready. Additionally, it provides navigation functionality to the ReportDetails page to display the report details for the selected program.

```
const Text(
  'Select program to view report',
  style: TextStyle(
    fontFamily: 'Merriweather',
    fontSize: 22,
    fontWeight: FontWeight.bold,
  ), // TextStyle
), // Text
```

Figure 46: View Report class code.

```
GestureDetector(
  onTap: () {
    final selectedProgram =
        Provider.of<SelectedProgram>(
            context,
            listen: false);
    if (selectedProgram
                ._selectedProgram !=
            null &&
        !programsWithReport.contains(
            selectedProgram
                ._selectedProgram)) {
      Navigator.push(
            context,
            MaterialPageRoute(
              builder: (context) =>
                  ReportDetails(
                pid: selectedProgram
                    ._selectedProgram!
                    .pid,
              ), // ReportDetails
            ), // MaterialPageRoute
          );
```

Figure 47: View Report class code.

- **Generate Report**

The provided Python code in **Figure 48-49** performs several key tasks to generate a report and store it in Firestore. Initially, it processes a dataset stored in a CSV file, implementing smoothing techniques and segmenting the data into smaller intervals based on timestamp information. Features are then extracted from each segment using the 'extract_features' function. Following this, a pre-trained machine learning model (Random Forest) stored in a file is loaded, and predictions are made on the extracted features for each segment, with activity labels converted into human-readable format through label encoding and inverse transformation. Subsequently, the code calculates the percentage distribution of predicted activities within each segment, expressing the frequency of each predicted activity label as a percentage of the total number of predictions. Finally, the calculated percentages, along with other relevant information such as program ID, number of activities, patient number, and number of weeks, are saved to Firestore using the 'save_Report_to_firestore' function, facilitating retrieval of the generated report from the application.

```
# Define the file path
file = '/content/drive/MyDrive/testData3_modified.csv'

# Call smoothing function
smoothed_dataset = smoothing(file, columns=['X', 'Y', 'Z'], span=10)

# Call segment_and_overlap function
segmented_dataset = segment_and_overlap(smoothed_dataset,2)
```

```
# Convert 'Timestamp' column to datetime if not already
segmented_dataset['Timestamp'] = pd.to_datetime(segmented_dataset['Timestamp'], format='%m/%d/%Y %H:%M:%S')

# Count the number of unique weeks(have changed dt.week => dt.strftime('%Y-%U'))
num_weeks = segmented_dataset['Timestamp'].dt.strftime('%Y-%U').nunique()
```

```
# Here split the segmented_dataset into weeks using Timestamp
weekly_groups = segmented_dataset.groupby(pd.Grouper(key='Timestamp', freq='W'))

# Iterate over groups and create smaller DataFrames
weekly_dataframes = []
for name, group in weekly_groups:
    weekly_dataframes.append(group)

# Call extract_features function for all weeks
extractedFeatures_weeks = []
for week in weekly_dataframes:
    extracted_dataset = extract_features(week)
    extractedFeatures_weeks.append(extracted_dataset)
```

Figure 50: FirestoreService class code.

```
# Here split the segmented_dataset into months using Timestamp
monthly_groups = segmented_dataset.groupby(pd.Grouper(key='Timestamp', freq='M'))

# Iterate over groups and create smaller DataFrames
monthly_dataframes = []
for name, group in monthly_groups:
    monthly_dataframes.append(group)

# Call extract_features function for all weeks
extractedFeatures_months = []
for month in monthly_dataframes:
    extracted_dataset = extract_features(month)
    extractedFeatures_months.append(extracted_dataset)
```

```
Dataset2 = pd.read_csv('/content/drive/MyDrive/OverlapConcatenatedData.csv')
model = joblib.load("/content/drive/MyDrive/FinalRF_rf_model.pkl")
```

Figure 51: FirestoreService class code.

```
  # Predict on the test set
  y_pred = model.predict(X)
  activity_predictions = label_encoder.inverse_transform(y_pred)
  weeks_predictions.append(activity_predictions)

# Call calculate_percentage function
overall_percetage, weeks_percentages = calculate_percentage_weeks(weeks_predictions, activity_dict)
print(f'{overall_percetage}%')
```

Figure 52: FirestoreService class code.

```
weeks_percentages

[{'Activities': [{'Activity Name': 'Abduction', 'Percentage': 100.0},
   {'Activity Name': 'Elbow-Extension', 'Percentage': 0}]},
 {'Activities': [{'Activity Name': 'Abduction', 'Percentage': 100.0},
   {'Activity Name': 'Elbow-Extension', 'Percentage': 0}]},
 {'Activities': [{'Activity Name': 'Abduction', 'Percentage': 100.0},
   {'Activity Name': 'Elbow-Extension', 'Percentage': 0}]}]

months_percentages

[{'Activities': [{'Activity Name': 'Abduction', 'Percentage': 33.33},
   {'Activity Name': 'Elbow-Extension', 'Percentage': 0}]}]
```

Figure 53: FirestoreService class code.

```
# Save predictions to firestore
save_Report_to_firestore(program_id, overall_percetage,  num_activities, total_iterations ,Patient_Numb

Activity Percentages saved to Firestore in the 'Report' collection.
```

Figure 54: FirestoreService class code.

- GitHub Repository: https://github.com/Sihamkhalid/2023-GP2-14.git

5 System Evaluation

In this section the AI models' experimental results and user acceptance testing results will be presented. The AI models were trained and evaluated in order to discover the model that garnered the best overall result, then it will be used to generate the report predictions. Tests were conducted on the completed TheraSense application with the help of the application's potential users. These tests were performed with the aim of evaluating the system's compliance with its specified requirements.

5.1 Experimental Results

The model training and testing processes have been conducted on a platform called Google Colab. Google Colab is a free, cloud-based environment that allows users to write and execute Python code. It features support for Jupyter notebooks and provides powerful computing resources, including GPUs, for rapid and scalable machine learning and data analysis. For a speedier procedure, the comparison of the four models was performed using Google Colab.

The general process began by importing the preprocessed dataset into Google Colab, where it had already been smoothed and segmented, as discussed in the data collection and preparation section. Next, a table was created to visualize the data. Finally, the dataset was fed to each ML model.

5.1.1 ML Models

To get the best possible performance, we have trained multiple models with different algorithms including SVM, Random Forest, K-Nearest Neighbor and Naive Bayes. All models are trained on the dataset segmented using non-overlapping technique with a window size of 2s which had the best performance. Moreover, all models have been trained using all the extracted features mentioned in the data collection and preparation section. The best performance algorithm will be used to train another model using only the selected features for comparison purposes.

A. SVM

SVM classifier works by finding the optimal hyperplane that separates different classes in the feature space, maximizing the margin between them by using kernel functions.

As shown in figure 55, the confusion matrix shows that SVM got most of the misclassifications while predicting ER and Sh-Flexion. This can conclude with an assumption that the reason behind that could be the behavior of ER and Sh-Flexion activities are similar to the behavior of Abduction.

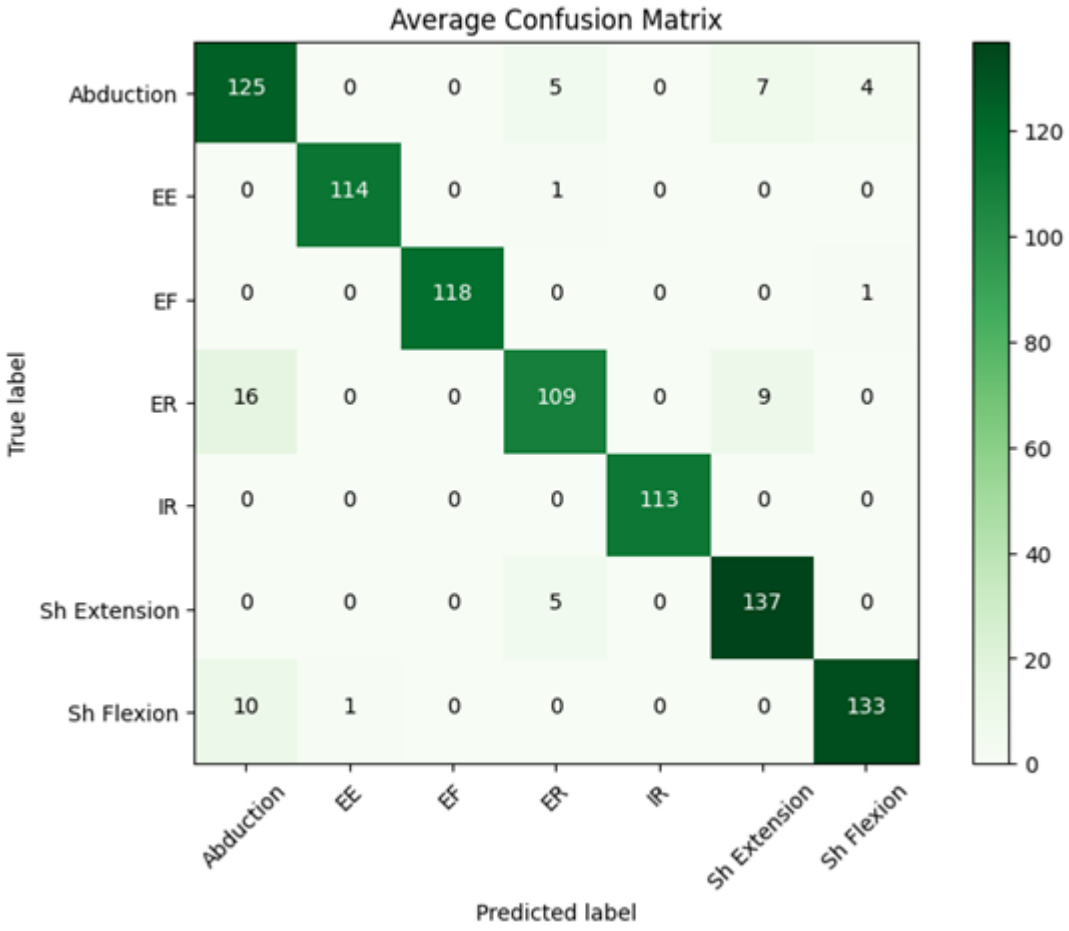


Figure 55: SVM Confusion Matrix

B. Random Forest

The Random Forest (RF) classifier is constructed to build multiple decision trees, each independently making predictions based on subsets of features and samples from the training data.

As shown in figure 56, the confusion matrix shows that RF got most of the misclassifications while predicting ER and Sh-Extension activities, which are different errors from SVM. This classifier is more capable of distinguishing Sh-Flexion than SVM.

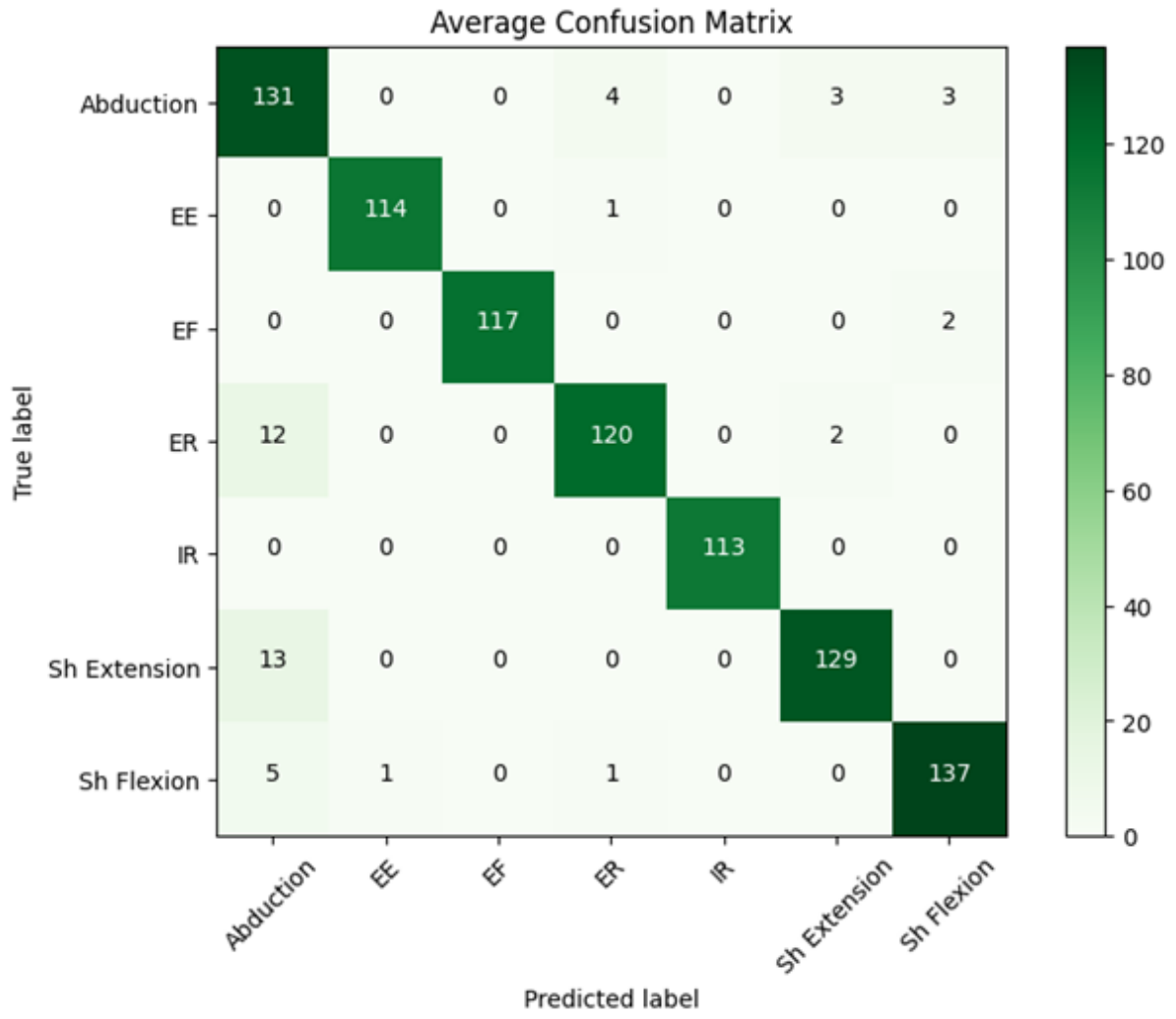


Figure 56: RF Confusion Matrix

C. K-Nearest Neighbor

K-Nearest Neighbor (KNN) algorithm classifies data points based on the labels of the K closest neighbors, using distance measures like Euclidean distance.

As shown in figure 57, the confusion matrix of KNN shows that the model does not have a clear distinction between ER and Abduction activities. As the misclassifications happen both directions; predicting Abduction when it is actually an ER, and predicting ER when it is actually an Abduction. In addition, to the misclassification that occurs while predicting Sh-Flexion.

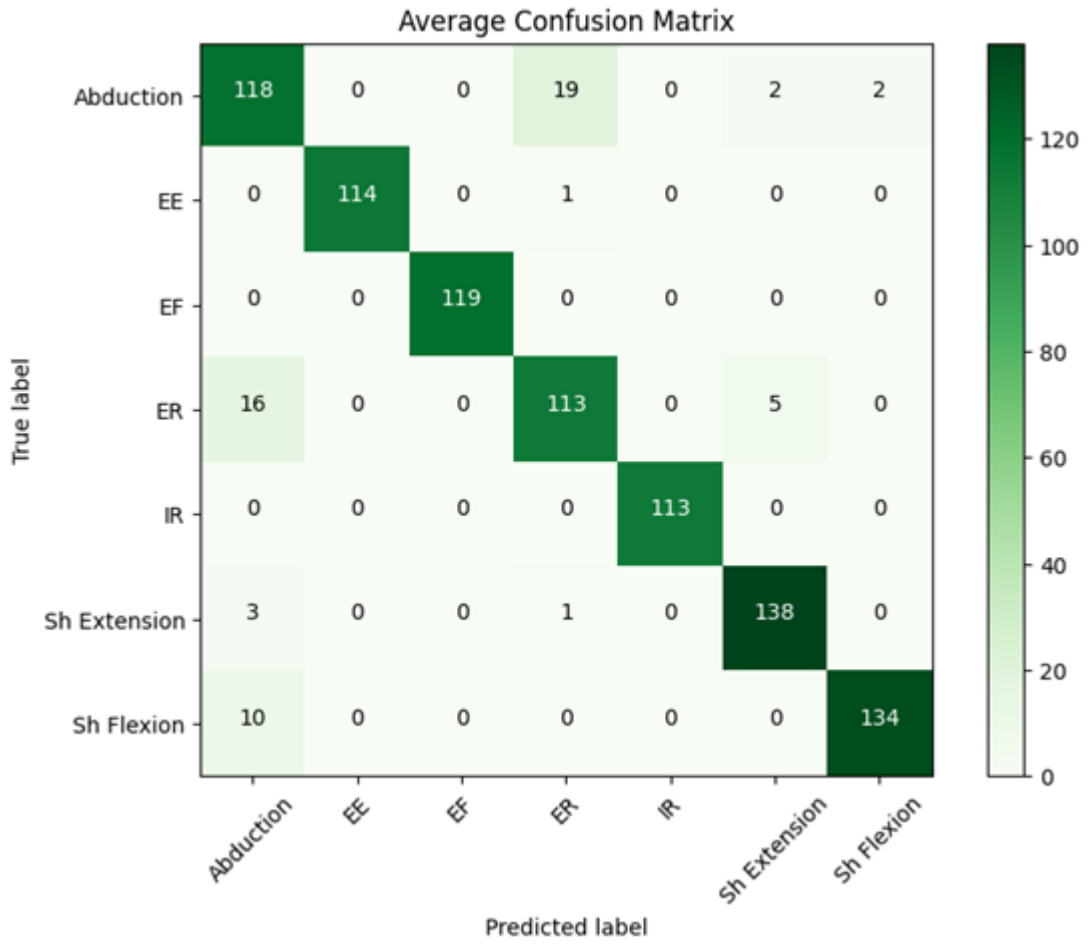


Figure 57: KNN Confusion Matrix

D. Naive Bayes

Naive Bayes (NB) model is a probabilistic classifier based on Bayes' theorem, assuming independence between features.

As shown in figure 58, the confusion matrix of NB shows the same discussed misclassifications that already occur in previous models. This can validate our assumption that this can be due to the similarity between activities.

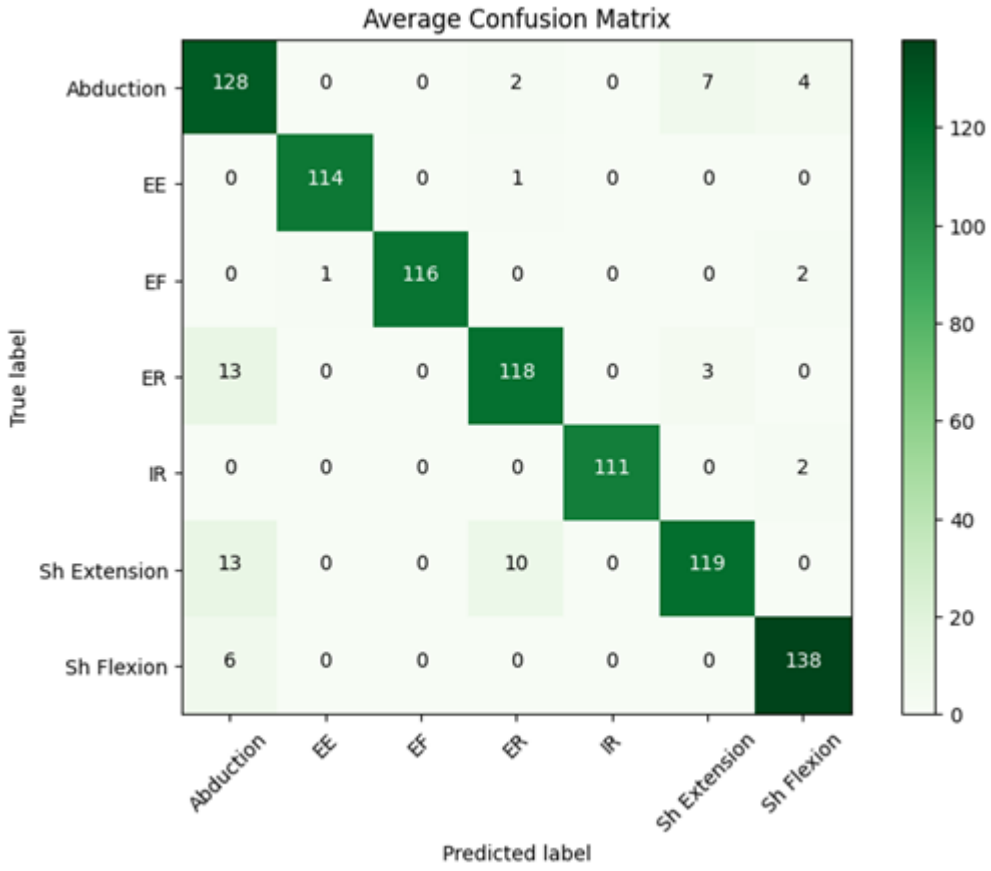
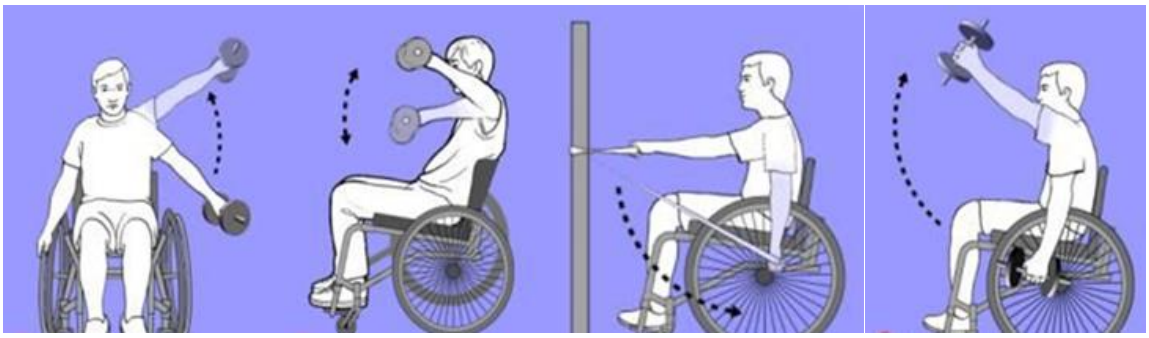


Figure 58: RF Confusion Matrix

1.5.1 Investigating the results of the misclassifications

To investigate more of the reason behind the same misclassification between activities over all models, we view the activities in figure 59. Clearly, we can notice that the movement of the sensor would be a vertical movement for all the shown activities. This can cause some confusion to the model, which results in misclassifications.



Abduction ER Sh Extension Sh Flexion

Figure 59: Activities.

Discussion of results for all algorithms

Table 4 shows the performance of all models on different performance measures including precision, recall, f1-score, training accuracy and testing accuracy for the left user. Clearly, RF classifier outperforms other models in all performance measures.

Table 4: Performance of all Models

	Testing Accuracy	Training Accuracy	Precision	F1-Score	Recall
SVM	0.936	0.963	0.951	0.935	0.938
RF	**0.950**	**0.983**	**0.967**	**0.949**	**0.952**
NB	0.933	0.955	0.953	0.932	0.935
KNN	0.938	0.980	0.944	0.934	0.939

To validate if the selected features would improve the performance, we have trained another model using the best performance algorithm RF on the selected features. Table 5 shows the difference in performance when all the 20 features are included during training the RF classifier and when only the 10 selected features are included. Although the number of features was reduced by half, there is no big difference in performance. However, still using all features is better, then we will not use the selected features.

Table 5: The affect of selected features on performance

	Testing Accuracy	Training Accuracy	Precision	F1-Score	Recall
RF with All Features	0.950	0.983	0.967	0.949	0.952
RF with the Selected Features	0.948	0.972	0.956	0.949	0.948

5.2 User Acceptance Testing

In this section, we will check if the completed TheraSense application fulfills business requirements when it is performed by the targeted end users. To do this testing, a testing team composed of twenty therapists were given a set of instructions to be followed. These instructions are related to the project requirements. This helps therapists to evaluate TheraSense efficiently. Then, they were given a questionnaire of eighteen questions, that measures the acceptance concerning user interface, technical aspects, major strengths and major weaknesses. Later, the questionnaire results were discussed and analyzed.

5.2.1 Demographics of Participants

After we conducted a User Acceptance Testing (UAT) on twenty therapists of different age categories and technical experiences using our application TheraSense. To gain feedback on their experience, we prepared a questionnaire with eighteen questions (see Appendix B). The results obtained from the questionnaire as follows:

Figure 52 shows that therapists' participants were from different age ranges with the majority of 18-30 years with a percentage of 80%. Additionally, Figure 60 illustrates that therapists' participants Advanced technical experiences. 70% of them 25% of them have Advanced technical experience and the other 5% have Novice technical experience. allowing us to

observe how users are familiar with mobile applications. This encourages us to go for further new features, and make sure that technical skill will not be an obstacle for them to learn these features.

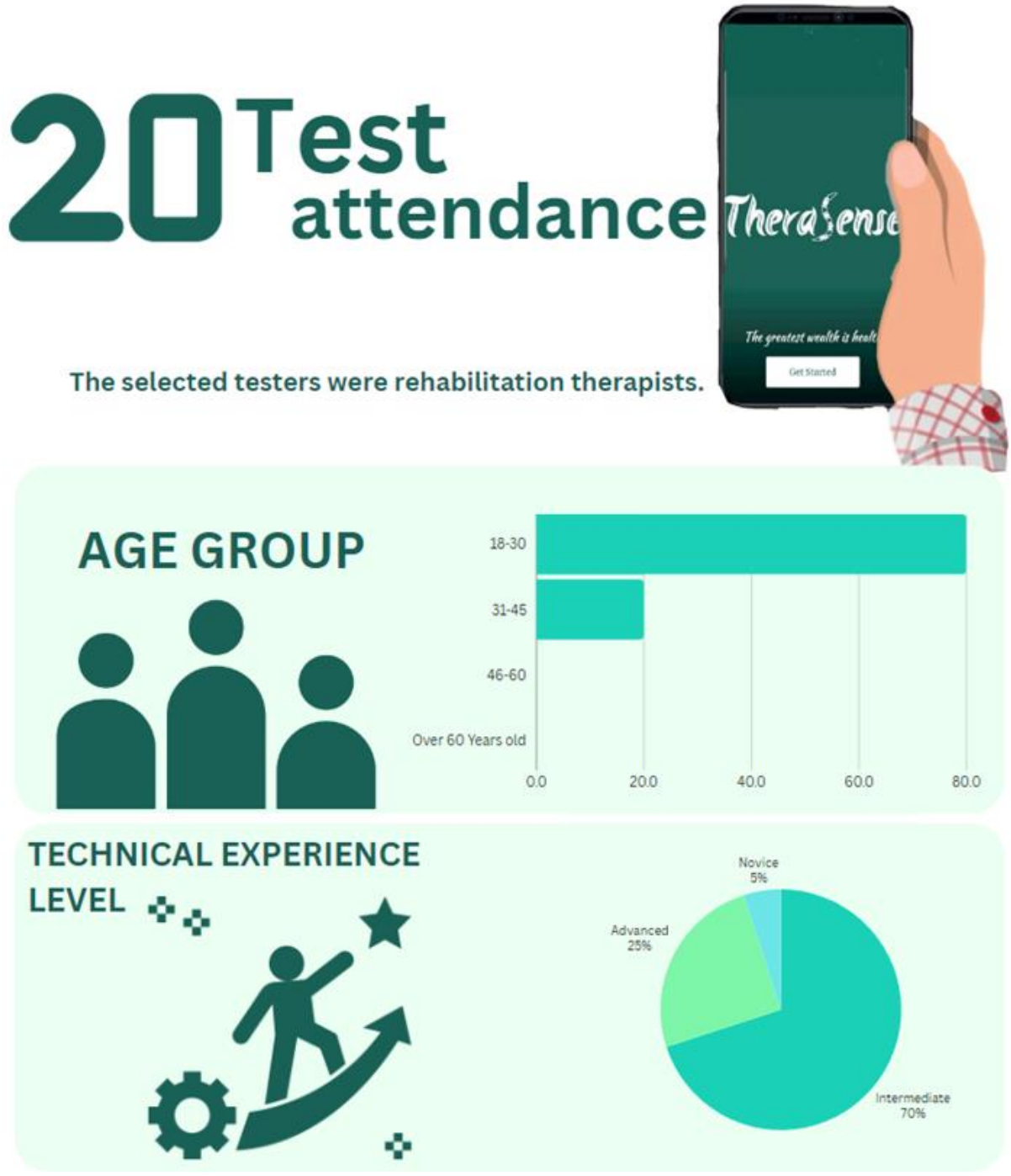


Figure 60: Demographics of participants.

1.5.2 Questionnaire/Interview Results

Furthermore, after we asked about the familiarity of the sign in process. The majority with the percentage of (90%) strongly agreed that it was familiar to them. While (10%) of participants agreed as shown in **Figure 61**.

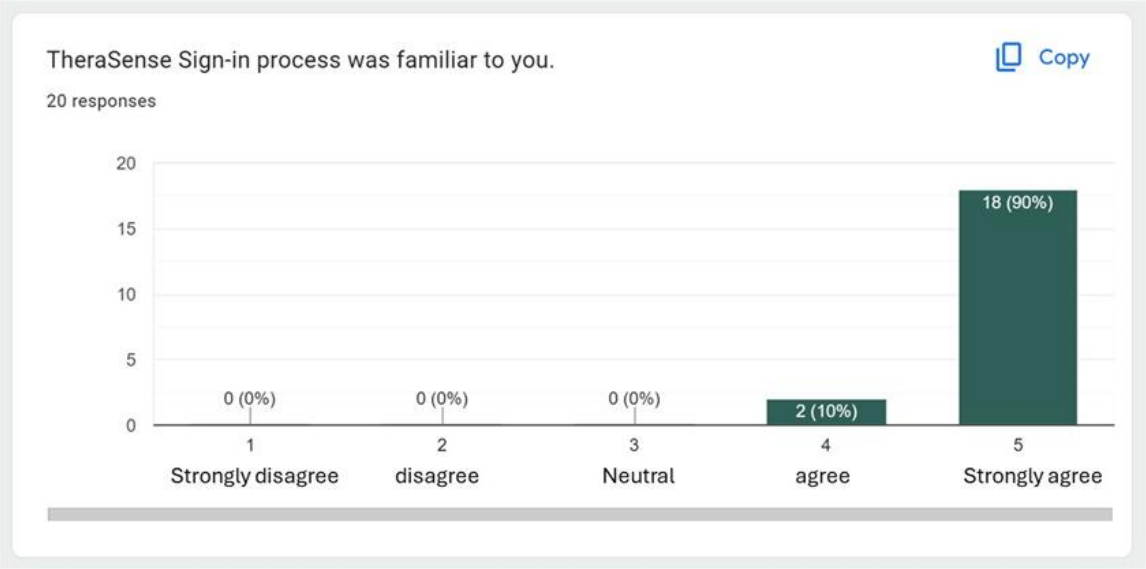


Figure 61: Measure the familiarity of Sign in process.

Moving on to the add patient page, the participants have different opinions regarding the sufficiency of patient's details as shown in **Figure 62.** (65%) strongly agreed that it was sufficient, while (25%) of participants agreed and the other two participants (10%) vary between neutral and disagree regarding sufficiency. That indicates that the sufficiency of a patient's details may vary from therapist to another.

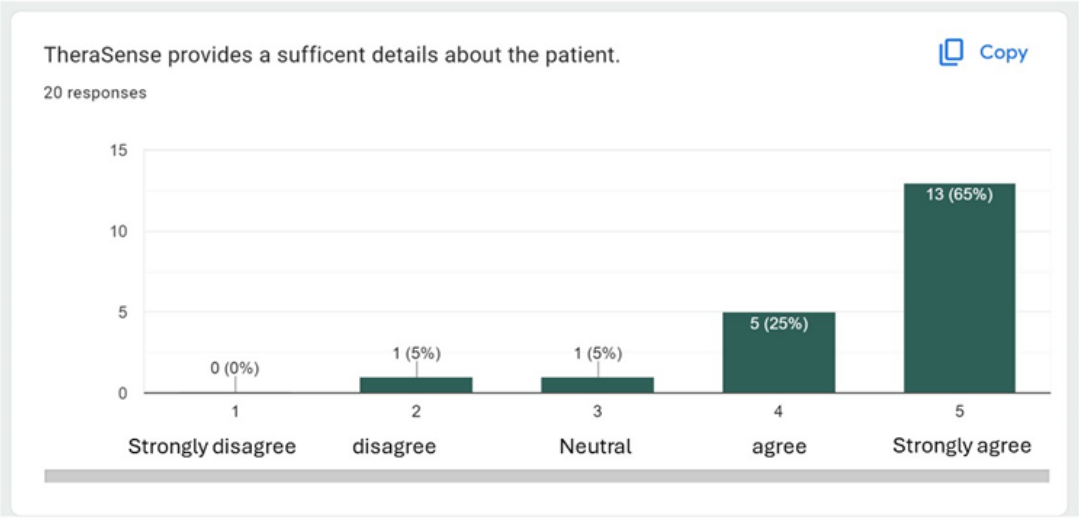


Figure 62: Measure the sufficiency of patient information.

Going to the Add program page, **Figure 63** shows that the participants have similar opinions regarding the clearness of adding a therapy program. (95%) of participants strongly agreed that it was very clear, while one participant agreed, resulting in an overall clear task.

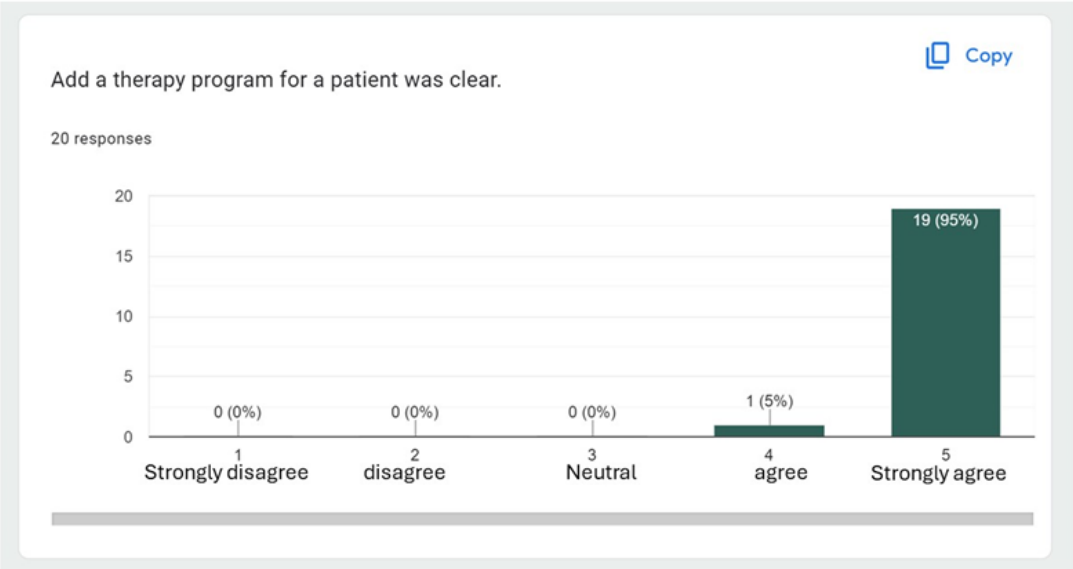


Figure 63: Measure the clearness of adding a therapy program in TheraSense application.

Figure 64 shows that the majority agreed that it was very easy to update a therapy program for a patient with a percentage of (85%). Whereas (15%) agreed it was easy. resulting in an overall easy task.

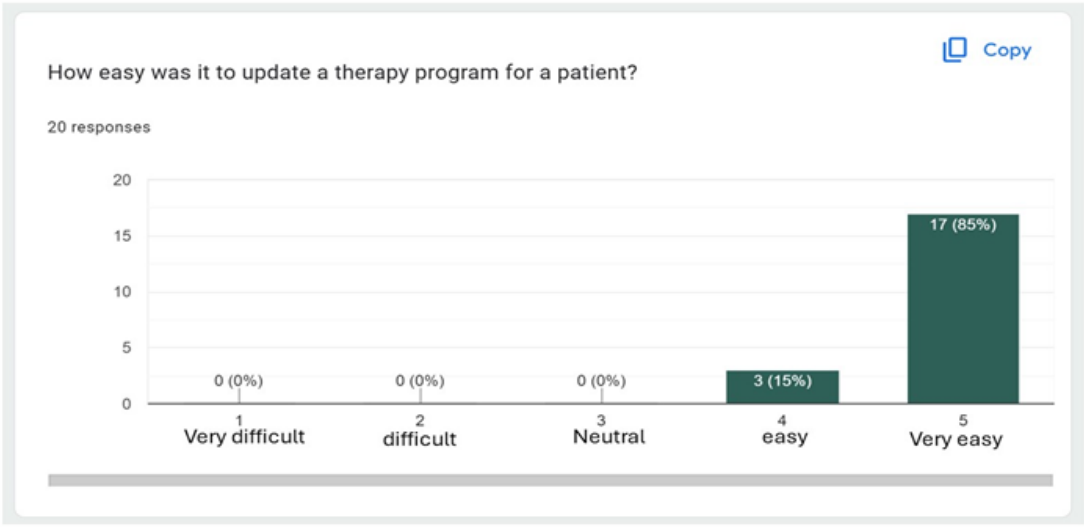


Figure 64: Measure the easiness of updating a therapy program.

Moving on to generating report functionality, From **Figure 65** we can see that the majority with a percentage of (90%) strongly agreed that it was very clear to generate a report. Whereas two participants (10%) agreed that it was clear. resulting in an overall clear task.

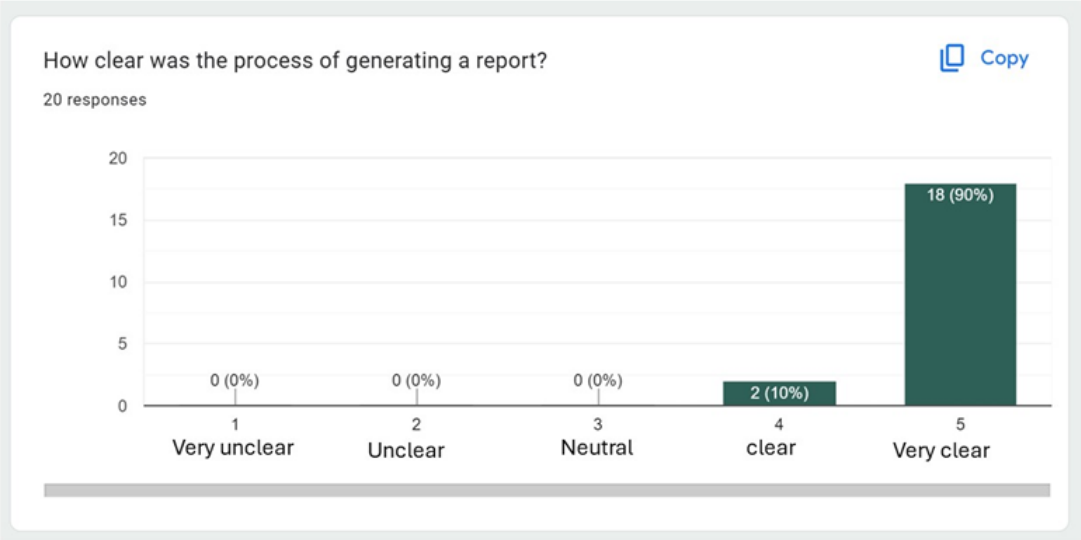


Figure 65: Measure the clearness of generating a report.

Figure shows that the participants have similar opinions regarding the importance of sending reports with patients. (95%) of participants strongly agreed that it is important, while one participant agreed, concluding that TheraSense provides an important feature.

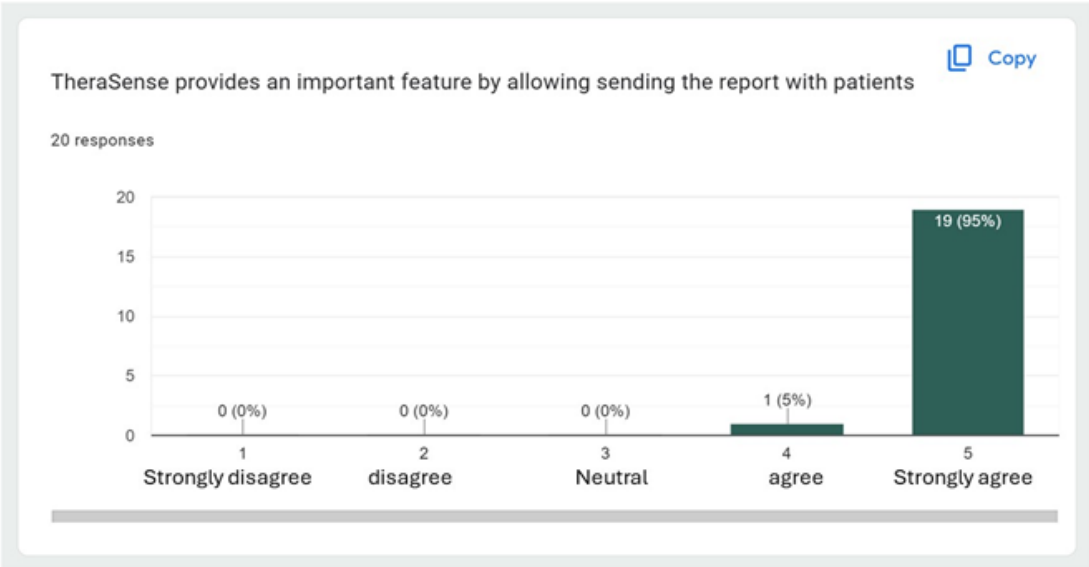


Figure 66: Measure the importance of sharing a report with a patient.

Figure **67** shows that the participants have similar opinions regarding the quickness of printing reports. (95%) of participants strongly agreed that it is completed quickly, while one participant agreed, concluding that printing a report is easy and quick.

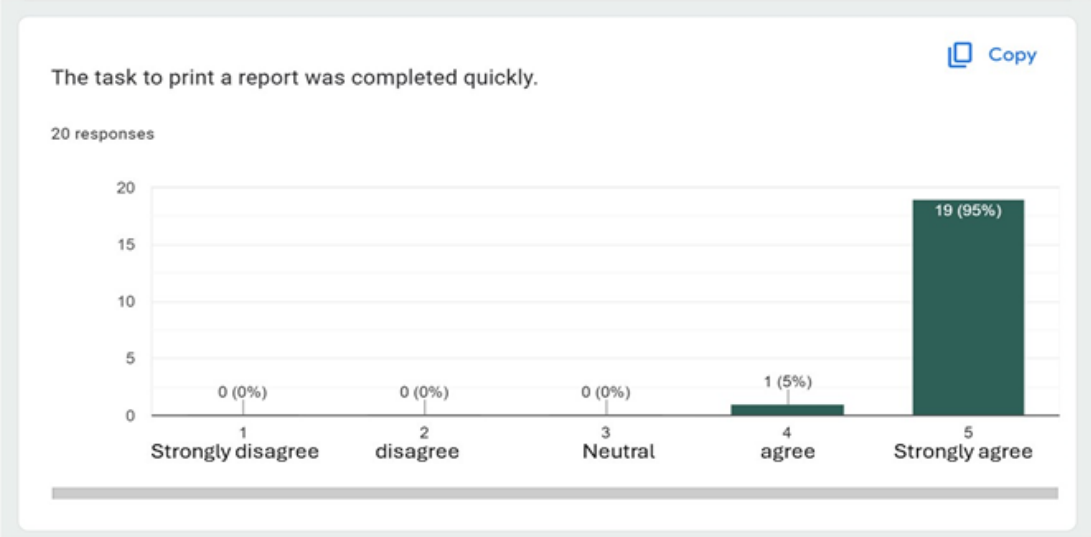


Figure 67: Measure the quickness of printing a report.

Moving to the chatbot page, **Figure 68** shows that the participants have different opinions regarding the user-friendliness of the chatbot for FAQs and quizzes. (80%) of participants rate it as excellent Whereas (10%) rate as good, while the other two participants (10%) vary between fair and poor regarding user-friendliness. That indicates that the user-friendliness of the chatbot for FAQs and quizzes may vary from therapist to another.

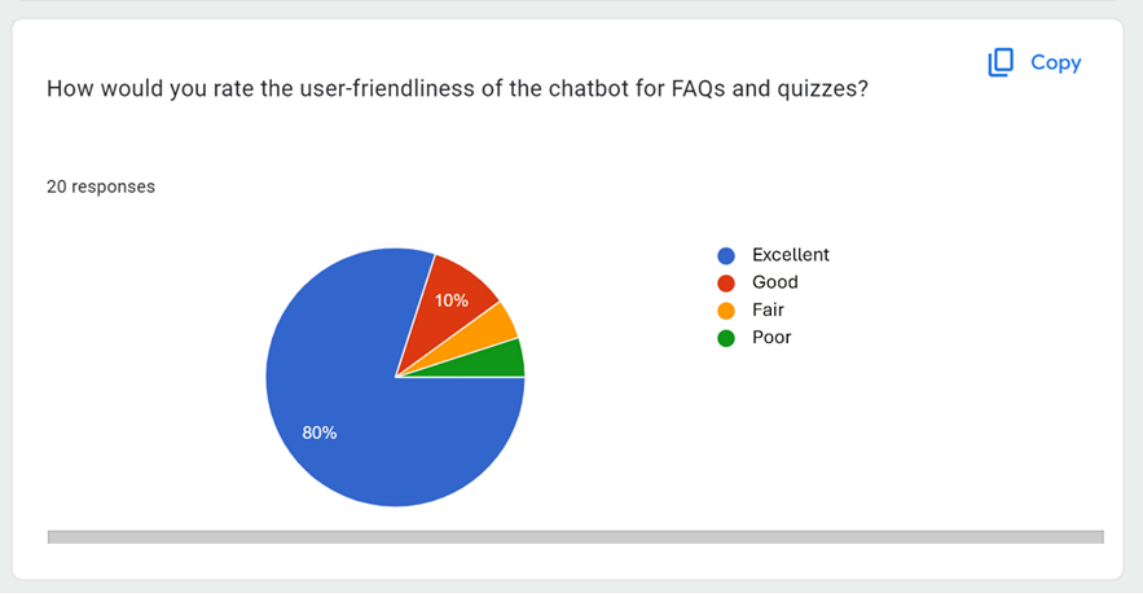


Figure 68: Measure the user-friendliness of the chatbot for FAQs and quizzes.

About search patient functionality, **Figure 69** shows that the majority agreed that it was very effective to search for a specific patient with the percentage of (90%). Whereas two participants who agreed it was effective with a percentage of (10%). This large percentage indicates that the search functionality is facilitating the finding process for a specific patient, that helps therapists to reach their desired patient efficiently.

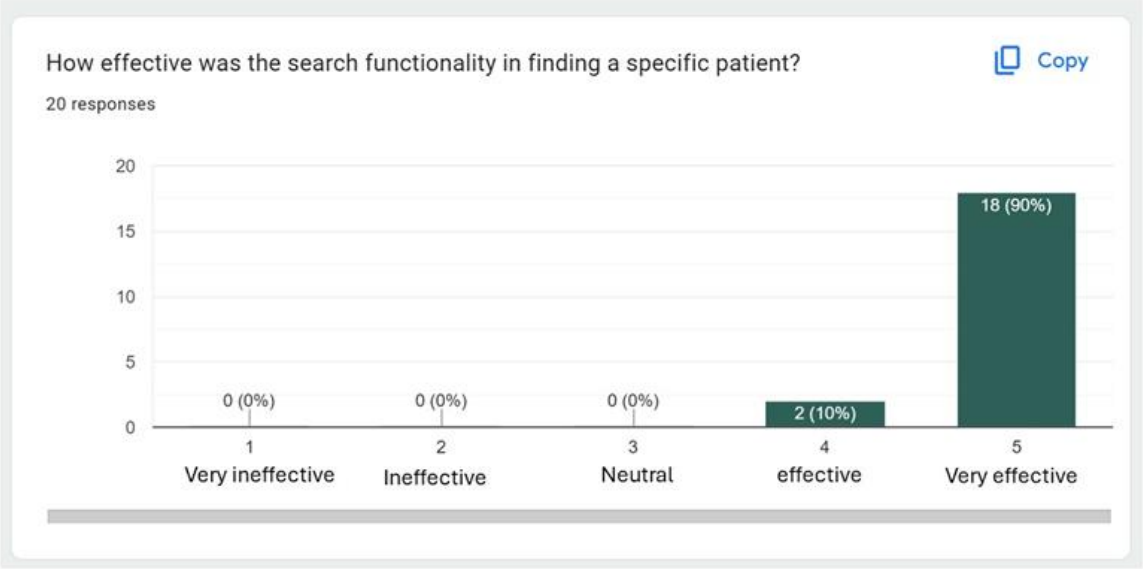


Figure 69: Measure the effectiveness for the search article functionality.

In addition, **Figure 70** shows that (80%) of the participants found the option for ranking patient performance was very easy to reach and (10%) rate it as easy. Whereas some participants (10%) considered it neutral.

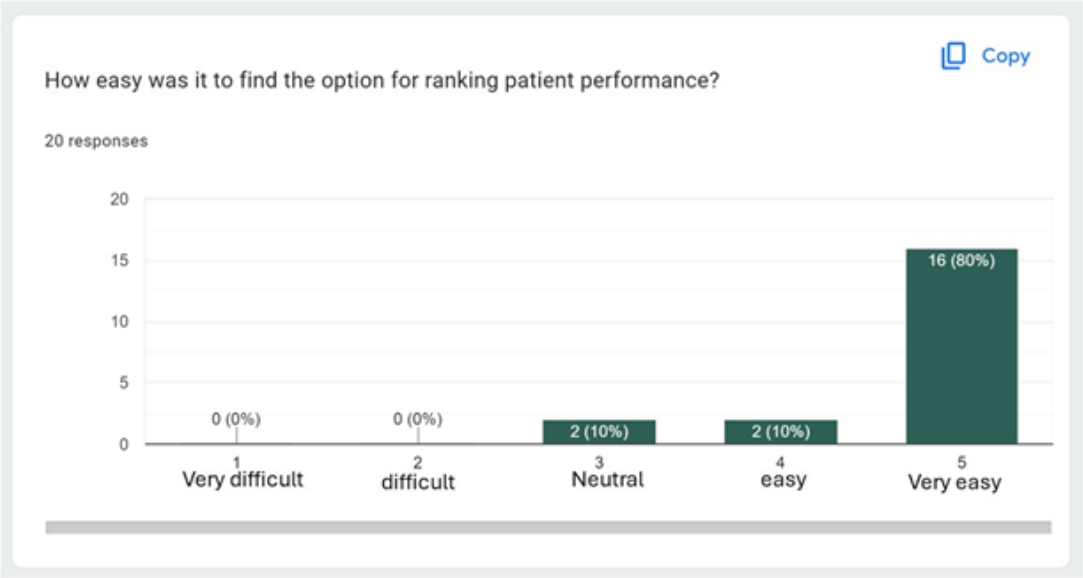


Figure 70: Measure the easiness of finding the rank patient performance option.

From **Figure 71**, we can see that the majority of participants agreed that it was very easy to navigate between weekly and monthly tabs and switch between text and chart views in the report with a percentage of (80%). Whereas some participants (20%) considered it a challenging task.

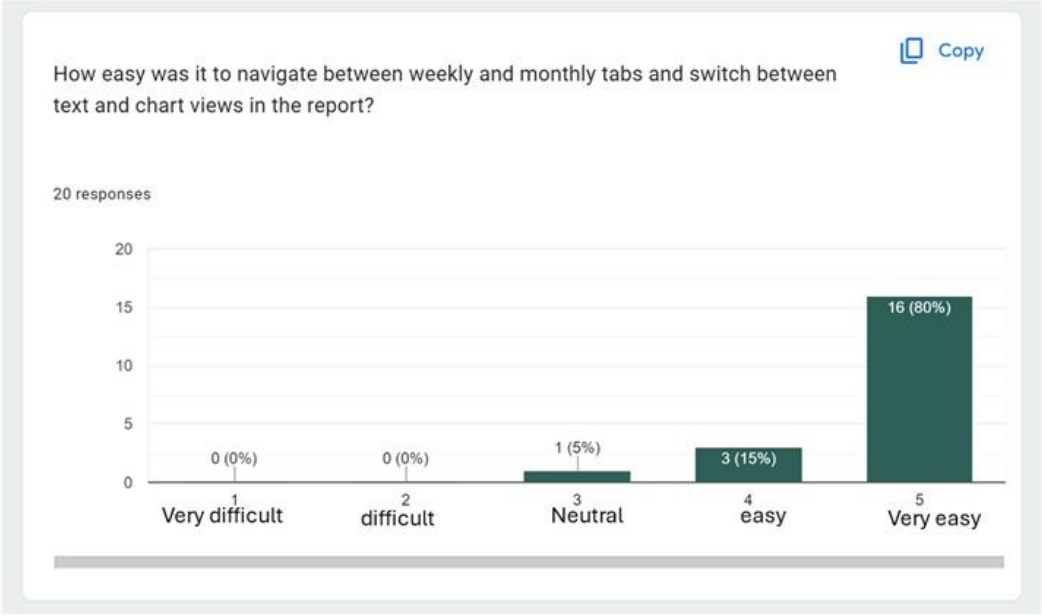


Figure 71: Measure the easiness of navigating between weekly and monthly tabs and switch between text and chart views in the report.

Additionally, as shown in **Figure 72** the majority with a percentage of (95%) strongly agreed that TheraSense application has a user-friendly interface and is easy to navigate. Whereas one participant agreed. Indicating that TheraSense is an easy-to-use app.

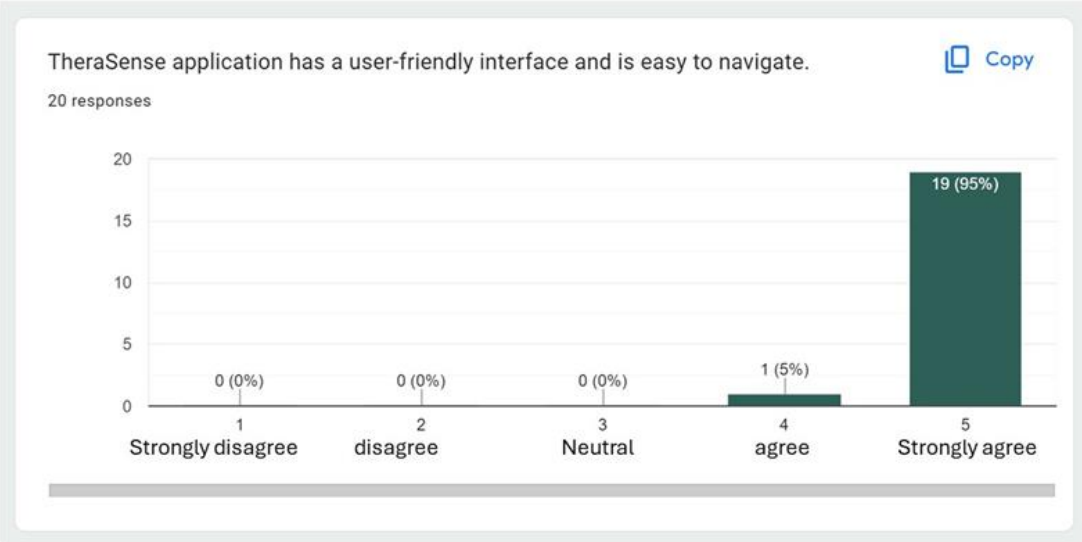


Figure 72: Measure the usability of TheraSense application.

For **Figure 73**, it illustrates that all participants have a good overall impression about the application. (90%) of participants were very satisfied and (10%) were satisfied.

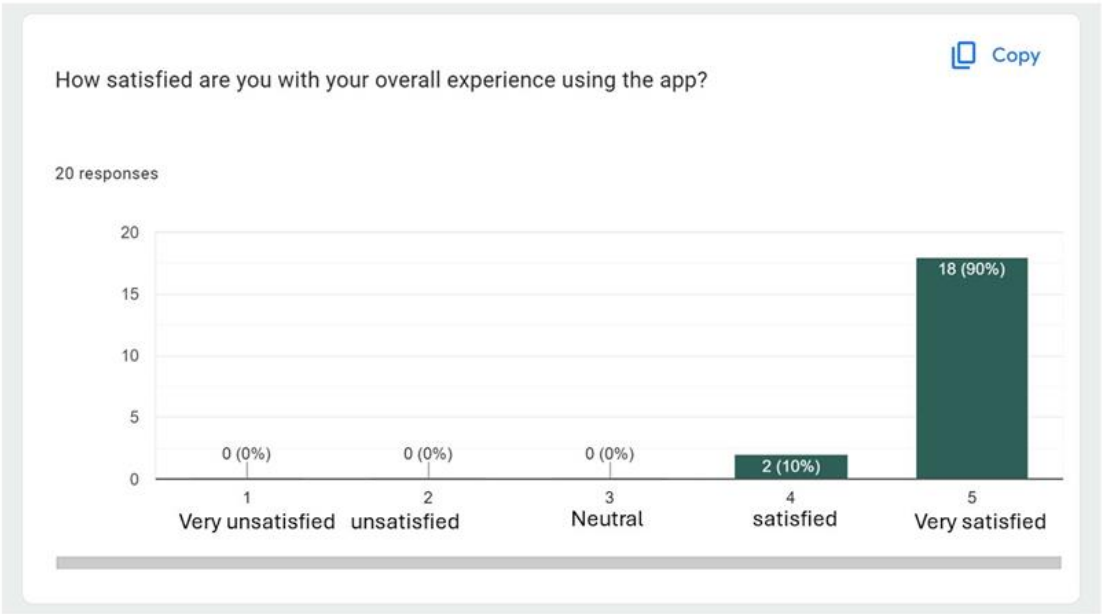


Figure 73: Measure the overall experience of using the app by therapists.

Moreover, the participants were asked if there are any features or functionalities you found confusing or unclear. We received some comments regarding some functionalities. But overall, their experience with the application was clear as shown in **Figure 74**.

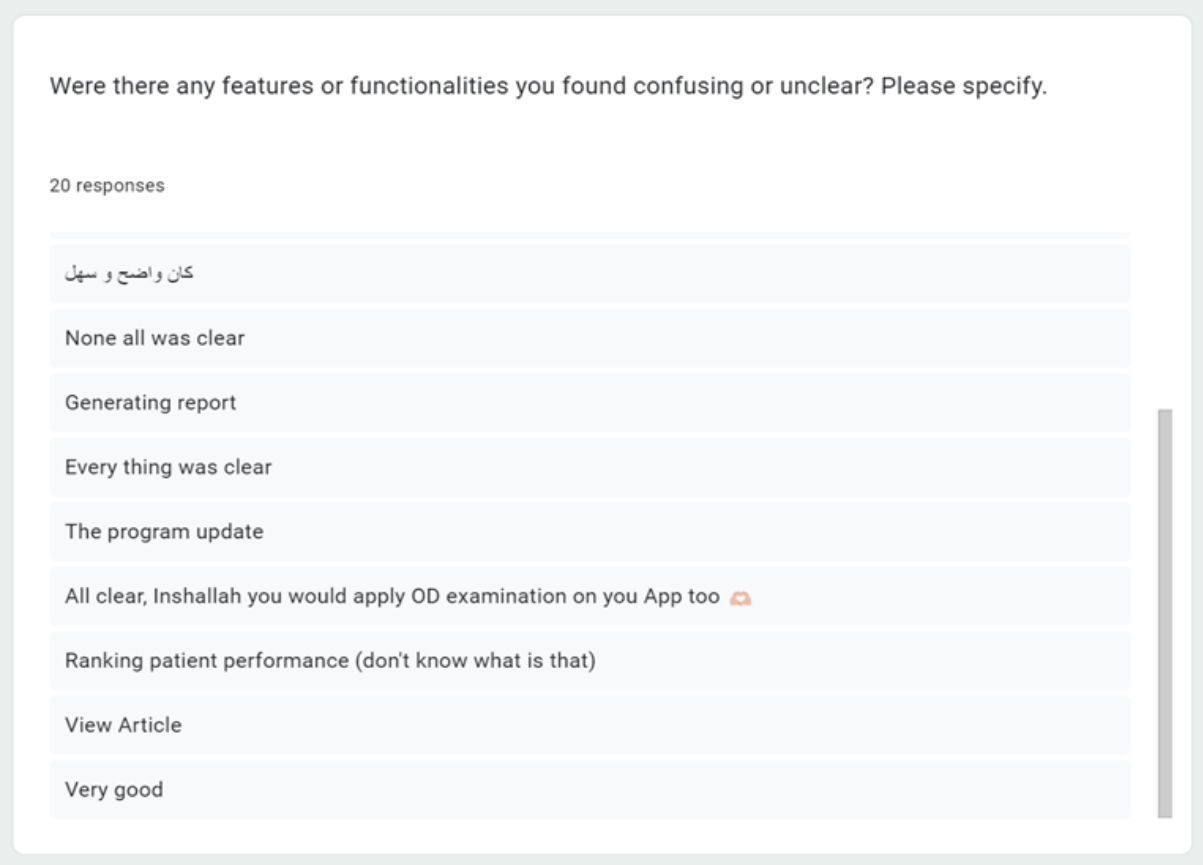


Figure 74: The unclear functionalities that have been found by therapists.

For **Figure 75**, most of the participants did not encounter any technical issues while using the app, where some participants encountered an issue related to the Wifi.

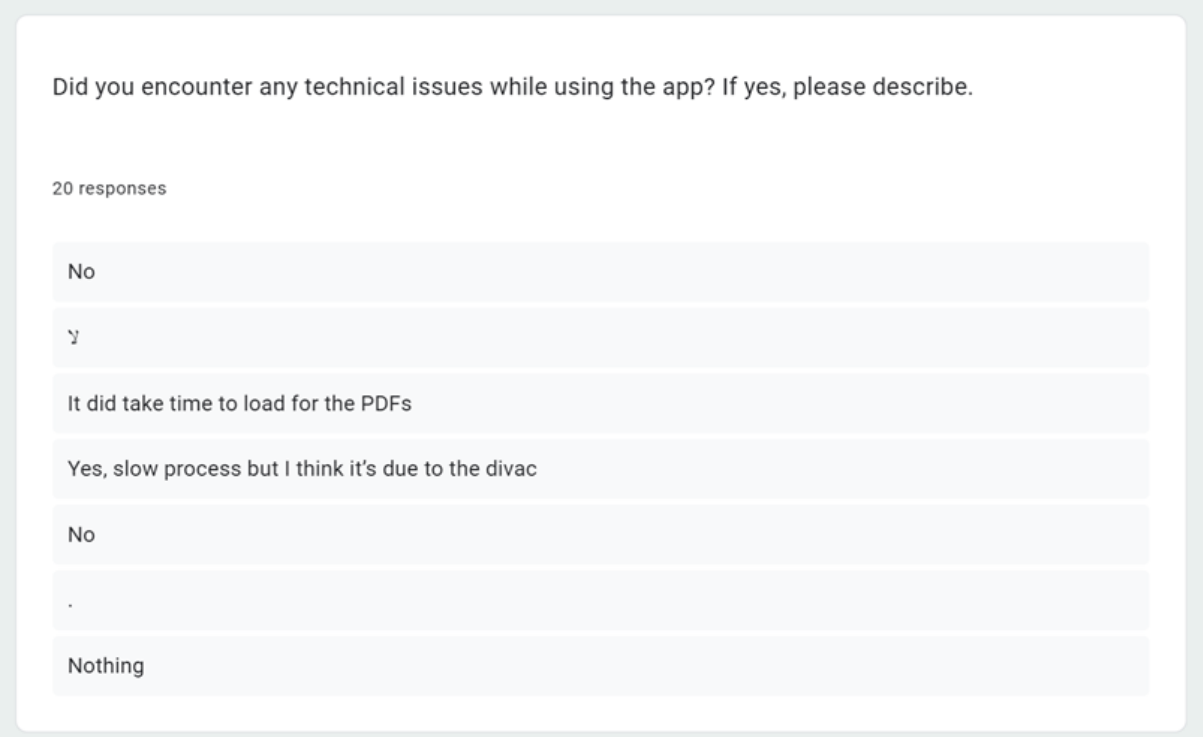


Figure 75: The technical issues during therapists' interactions with the application.

Finally, the participants were asked if they have any suggestions for future work. We received some suggestions regarding the UI/UX in the update program. Also, they suggest adding more details about the patient and adding videos in the program page to share it with the patient. Additionally, they suggest adding more activities to the application as shown in **Figure 76.**

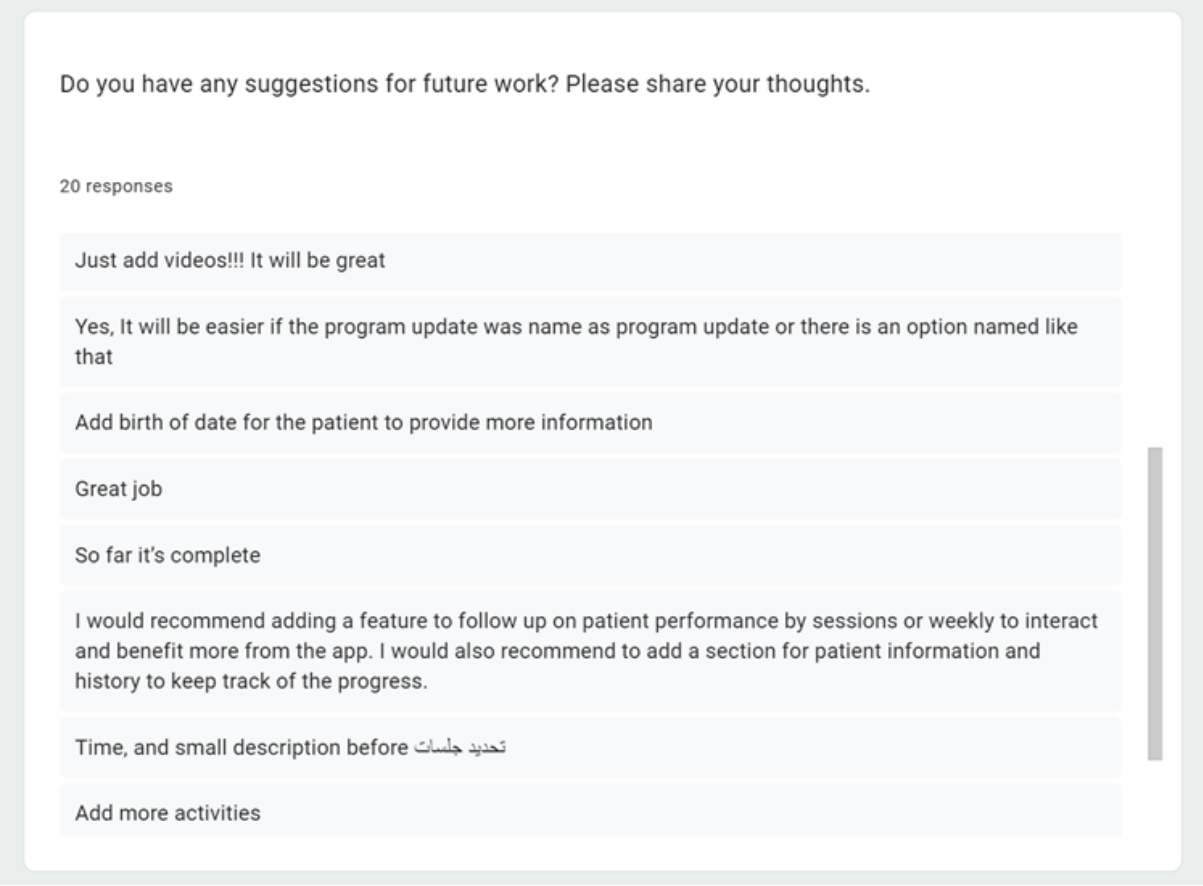


Figure 76: Therapists' suggestions for future work

1.6 Quality Attributes (NFR testing)

In this section, we explained how TheraSense's non-functional testing has been done and its results as shown in Table 6.

Table 6: Quality Attributes NFR Testing

User story	Quality Attribute	Measure	Results
As a TheraSense user, I want the application to be available 99% of the time on the workdays, so that I can see the progress of the patient.	**Availability:** How often is the application accessible and operational when users need it?	Compute the uptime percentage of the application during workdays.	1. A group of users was selected. 2. We measure the percentage of time the system was available. Results: The app was available 100% of the time on workdays.
As a TheraSense user, I want all pages to display within 6 seconds, so that I can navigate in an efficient way.	**Performance:** How responsive is the system and its components?	The response time for loading pages in TheraSense application.	1- A group of users was selected. 2- Users were asked to perform several tasks to test the application. 3-We measure the loading time for pages while the user is performing the testing process. Results: Min time: 1.25s Max time: 3.2 Avg time: 2.26

User story	Quality Attribute	Measure	Results
As a TheraSense user, I want to get feedback within 10 seconds with no delay, so that I can be assured that the action I have done is executed.	Responsiveness: How quickly does the system acknowledge and process user inputs, providing feedback and confirmation of actions taken?	Compute the time it takes for the system to provide feedback after an action is taken.	1- A group of users was selected. 2- The users were asked to try several features of the application. 3- We use a stopwatch to measure the time the feedback appeared to the user after each action. Results: Min time:0.5s Max time:25s Avg time:12.8

User story	Quality Attribute	Measure	Results
As a TheraSense user, I want the application to be simple, so that I can use the application with no error making after 10 minutes of learning.	**Usability:** How easy is it for users to learn and use the application effectively and efficiently?	Compute the time it takes for users to learn and use the application without errors.	1- A group of users was selected. 2- Provide the users with the mobile device and the list of tasks. 3- Instruct the users to complete each task using the mobile interface and write down how long it took for them to understand how to perform the task. 4- Record the time taken to complete each task. Results: Min time: 4 minutes Max time: 6 minutes Avg time: 5 minutes

User story	Quality Attribute	Measure	Results
As a TheraSense user, I want to be able to log out, so that my session is not used by someone else.	**Security:** How well does the application protect against unauthorized access and ensure that users' data and sessions are secure?	Test the functionality of the logout feature to ensure it works correctly.	Users are able to log out successfully.

1.7 Discussion

The results provided in the earlier parts will be interpreted in this subsection. Overall, the system evaluation phase achieved satisfactory findings. By examining the user acceptance tables in the User Acceptance Testing, we noted that the majority of our non-functional requirements and their acceptance criteria were met. Most functions were completed by users without errors and within a reasonable time frame. We also provided a questionnaire to testers to gather feedback on their experience with TheraSense and reviewed the results in the Questionnaire/Interview Results section. According to the collected responses, testers were pleased with the application's interface and functionalities. Testers provided feedback on potential enhancements. For example, Participants suggested improving UI elements like button color changes to indicate actions and adding more detailed patient case descriptions, also they suggested having a patient as a second user so that they can interact through the application. Only a minor percentage encountered technical issues, primarily related to page refreshing. Moving forward to NFR testing results interpretation. The uptime percentage during workdays was 100%, demonstrating high Availability. Page loading times had a minimum of 1.25s, a maximum of 3.2s, and an average of 2.26s, indicating efficient system performance. Feedback time after user actions had a minimum of 0.5s, a maximum of 25s, and

an average of 12.8s, showing room for improvement in ensuring consistently rapid feedback. Time taken for users to learn and use the application without errors ranged from 4 to 6 minutes, with an average of 5 minutes, demonstrating that the application is user-friendly and easy to learn. Users were able to log out successfully, indicating effective security measures.

The UAT and NFR results show that TheraSense is generally well-received and performs effectively in key areas. The application's high availability and good performance metrics support a smooth user experience.

Conclusions and Future Work

In this section we will talk about the conclusion, which is a bridge to help our readers make the transition back to their daily lives. This section will help visualize why the development effort is worthwhile.

This document describes our TheraSense journey, beginning with the idea, and growing this idea through all stages we went through, beginning with the introduction chapter, which explains the idea and provides a general introduction to TheraSense. Following the introduction is the background chapter, which plays an important role in helping the reader understand the details of TheraSense, by providing a brief explanation of knowledge aspects in which TheraSense falls. For example, SCI, what is Rehabilitation, and Use of AI in Rehabilitation.

In order to deliver an application that addresses the gaps in the applications market and to specify the TheraSense features. We reviewed and discussed the mobile apps in the same field as TheraSense and were represented in this literature review chapter. Once we had an idea of what TheraSense could do, we started with the system analysis & design chapter, which turns the TheraSense features into a form used for the implementation of the application and helps the reader understand some TheraSense features and how they work together. After the system analysis, we started developing the TheraSense using the Flutter framework and tested it to make sure that it fulfills system requirements.

A. Global and local impact

- Local Impact

TheraSense's impact extends beyond the rehabilitation process, empowering therapists with detailed performance reports to make informed decisions about patients' health status and adherence to programs. This holistic approach enhances healthcare outcomes, promotes independent living, and contributes to the realization of Vision 2030's commitment to enhancing public health by improving healthcare access, quality, and embracing digital health, an overarching goal of a healthier and technologically advanced society in Saudi Arabia.

- Global Impact

It is difficult to find tracking applications used by therapists to monitor SCI patients. TheraSense's impact lies in its potential to inspire and inform healthcare transformations beyond national borders. In addition, technological advancements and personalized rehabilitation approaches have the ability to contribute to a more inclusive and efficient global healthcare landscape.

B. Problems and challenges encountered during software development

In the second release, we encountered several implementation challenges. Firstly, the add activity page experienced issues where selecting an activity from the drop-down menu resulted in the specified fields being hidden for all selections, leading to null values in Firebase. Additionally, when adding all details of a new program in the add program page, the data was not saved for the chosen patient. Secondly, within the report page, difficulties arose with the switch button for toggling between text and chart results, as well as encountering the same issue when attempting to switch between weekly and monthly views. Despite successful PDF uploads to Firebase, we faced hurdles in retrieving and displaying these articles within the application. Furthermore, despite the implementation of loading pages after each build stream, a recurring red error persisted, indicating that data was not yet loading when starting the application.

C. Limitations of the system

During the development of the TheraSense application, we anticipate facing certain challenges. These include expanding the chatbot's functionality beyond FAQs and quizzes by incorporating Reinforcement Learning and NLP techniques. Additionally, in the community section, therapists will not only be able to upload articles but will also have the capability to communicate directly with each other.

D. The main contribution of the project

We are specialized focus on SCI patients, employing wearable sensors for efficient data collection during in-home rehabilitation. The activity recognition system, featuring a mobile app and wrist sensor, utilizes machine learning to precisely classify and monitor upper limb activities. The resulting report provides therapists with a comprehensive overview, enabling an accurate evaluation of the patient's performance and adherence to the rehabilitation program.

E. Future work

TheraSense team has big plans for the future, and one of them is to expand the reach and impact of the project. One of the key elements of their plan is to make the application more accessible, with a particular emphasis on making it available in Arabic to reach a wider audience. TheraSense also plans to expand its reach to more users and platforms. TheraSense team wants to deploy the project on popular app stores like the App Store or Google Play, so that more people can benefit from improving the therapist's assessment process on their phones. Another important aspect of the plan is to make TheraSense easier to use for IOS users. TheraSense plans to make the project more compatible with IOS devices, so that users can easily download and install the app. This will make the project easier to use and enhance the therapist's assessment process. In an effort to enhance TheraSense's functionality, we plan to add more activities for recognition and reporting. In addition to transforming the app into an interactive platform, allowing users including patients as a second user to engage in various activities. The app will then generate detailed

reports providing valuable insights into user engagement, progress, and potential areas for improvement.

2 Achievements

Participating in competitions is a crucial part of the development process for any project, and TheraSense has fully utilized these opportunities to demonstrate its capabilities and potential.

TheraSense has participated in a number of competitions in Saudi Arabia. Firstly, TheraSense, our innovative project, was proudly recognized in the Health Hackathon Conducted by King Saud bin Abdulaziz University for Health Sciences, an event that saw participation from over 1,000 teams. Out of the 120 teams that advanced, TheraSense achieved an impressive 8th place. This achievement underscores our commitment to enhancing healthcare through advanced technology, particularly in activity recognition and rehabilitation monitoring. Our success in the hackathon highlights the potential impact and effectiveness of TheraSense in real-world healthcare applications.

Furthermore, TheraSense participated in the 14th annual Scientific Forum, held by King Saud University. TheraSense has passed four stages of the competition, then TheraSense team presented to a committee of experts, to get their feedback and enhance our project.

Moreover, TheraSense was invited to the Scientific Research Day 2024 at the College of Applied Medical Science, King Saud University, with Dr. May Alrashed, Vice Dean for Female Students, in attendance. The event provided an opportunity for TheraSense to showcase its innovative approach as an activity recognition system.

Additionally, we were honored to be nominated in the SheCodes competition at Princess Nourah Bint Abdulrahman University (PNU), which indicates the greatness of the idea and highlights the potential impact and effectiveness of TheraSense in real-world healthcare applications.

The feedback and recognition received from these events have and will continue to inspire the TheraSense team to continue developing and improving on TheraSense, ultimately leading to its continued success.

3 Acknowledgements

Words cannot express our gratitude to our supervisor, Dr. Nora Alhammad for her support and feedback throughout this journey. Turning this project into a real working application would not have been possible without her valuable insights and encouraging words. We would like to extend our gratitude to all the faculty members in the help desk for always being generous to answer any question. Many thanks to Dr. Luluh Aldhubayi and Dr. Sahar Bayoumi Ali for the constructive advices that have been taken into consideration to improve the project.

We must also thank all the faculty members from the college of Applied Medical Science in King Saud University for being part of the testing process and for the rich suggestions. Many thanks to the GP committee for providing all the tools and resources needed to complete this project. Finally, we cannot end this project without expressing our deepest gratitude to our families and friends for the love and support we were fulfilled with during this whole year.

4 References

[1] A. A. Robert and M. M. Zamzami, "Traumatic spinal cord injury in Saudi Arabia: a review of the literature," *Pan Afr. Med. J.*, vol. 16, p. 104, Nov. 2013, doi: 10.11604/pamj.2013.16.104.2902.

[2] C. A. Warms, J. D. Whitney, and B. Belza, "Measurement and description of physical activity in adult manual wheelchair users," *Disabil. Health J.*, vol. 1, no. 4, pp. 236–244, Oct. 2008, doi: 10.1016/j.dhjo.2008.07.002.

[3] M. T. Leving, H. L. D. Horemans, R. J. K. Vegter, S. de Groot, J. B. J. Bussmann, and L. H. V. van der Woude, "Validity of consumer-grade activity monitor to identify manual wheelchair propulsion in standardized activities of daily living," *PloS One*, vol. 13, no. 4, p. e0194864, 2018, doi: 10.1371/journal.pone.0194864.

[4] "Shimmer3 IMU Unit," *Shimmer Wearable Sensor Technology*. https://shimmersensing.com/product/shimmer3-imu-unit/ (accessed Sep. 20, 2023).

[5] "A Survey on Approaches of Motion Mode Recognition Using Sensors | IEEE Journals & Magazine | IEEE Xplore." https://ieeexplore.ieee.org/document/7726001 (accessed Sep. 20, 2023).

[6] I. Pernek, G. Kurillo, G. Stiglic, and R. Bajcsy, "Recognizing the intensity of strength training exercises with wearable sensors," *J. Biomed. Inform.*, vol. 58, pp. 145–155, Dec. 2015, doi: 10.1016/j.jbi.2015.09.020.

[7] X. García-Massó, P. Serra-Añó, L. M. Gonzalez, Y. Ye-Lin, G. Prats-Boluda, and J. Garcia- Casado, "Identifying physical activity type in manual wheelchair users with spinal cord injury by means of accelerometers," *Spinal Cord*, vol. 53, no. 10, pp. 772–777, Oct. 2015, doi: 10.1038/sc.2015.81.

[8] P. Siirtola, P. Laurinen, J. Röning, and H. Kinnunen, "Efficient accelerometer-based swimming exercise tracking," Apr. 2011, pp. 156–161. doi: 10.1109/CIDM.2011.5949430.

[9] "Motion Sensors Explainer." https://www.w3.org/TR/motion-sensors/#accelerometer-sensor (accessed Sep. 20, 2023).

[10] "accelerometer sensor – شراء accelerometer sensor على شحن مجاني مع AliExpress version." https://ar.aliexpress.com/w/wholesale-accelerometer-sensor.html?catId=0&initiative_id=SB_20230910071542&SearchText=accelerometer+sensor&spm=a2g0o.detail.1000002.0 (accessed Sep. 20, 2023).

[11] "Spinal Cord: Function, Anatomy and Structure," *Cleveland Clinic*. https://my.clevelandclinic.org/health/body/21946-spinal-cord (accessed Sep. 18, 2023).

[12] "Spinal cord anatomy," *Physiopedia*. https://www.physio-pedia.com/Spinal_cord_anatomy (accessed Sep. 18, 2023).

[13] "Spinal cord injury." https://www.who.int/news-room/fact-sheets/detail/spinal-cord-injury (accessed Sep. 18, 2023).

[14] "Spinal cord injury - Symptoms and causes," *Mayo Clinic*. https://www.mayoclinic.org/diseases-conditions/spinal-cord-injury/symptoms-causes/syc-20377890 (accessed Sep. 18, 2023).

[15] "Oklahoma Spinal Cord Injury Lawyers Fighting for the Injured." https://www.tawlaw.com/personal-injury/spinal-cord-injury (accessed Sep. 18, 2023).

[16] "Rehabilitation." https://www.who.int/news-room/fact-sheets/detail/rehabilitation (accessed Sep. 18, 2023).

[17] "Occupational Therapy vs. Physical Therapy: How Do They Differ?," *Healthline*, Mar. 11, 2020. https://www.healthline.com/health/occupational-therapy-vs-physical-therapy (accessed Sep. 20, 2023).

[18] "Physical activity." https://www.who.int/news-room/fact-sheets/detail/physical-activity (accessed Sep. 18, 2023).

[19] "Exercise after Spinal Cord Injury | MSKTC." https://msktc.org/sci/factsheets/exercise-after-spinal-cord-injury (accessed Sep. 18, 2023).

[20] *O'Sullivan, S.B.; Schmitz, T.J.; Fulk, G. Physical Rehabilitation, 7th ed.; F.A. Davis Co.: Philadelphia, PA, USA, 2019.*

[21] A. S. Burns *et al.*, "Type and Timing of Rehabilitation Following Acute and Subacute Spinal Cord Injury: A Systematic Review," *Glob. Spine J.*, vol. 7, no. 3 Suppl, pp. 175S-194S, Sep. 2017, doi: 10.1177/2192568217703084.

[22] "Physiotherapy Exercises." https://english.physiotherapyexercises.com (accessed Sep. 18, 2023).

[23] K. Nas, L. Yazmalar, V. Şah, A. Aydın, and K. Öneş, "Rehabilitation of spinal cord injuries," *World J. Orthop.*, vol. 6, no. 1, pp. 8–16, Jan. 2015, doi: 10.5312/wjo.v6.i1.8.

[24] M.-P. Côté, M. Murray, and M. A. Lemay, "Rehabilitation Strategies after Spinal Cord Injury: Inquiry into the Mechanisms of Success and Failure," *J. Neurotrauma*, vol. 34, no. 10, pp. 1841–1857, May 2017, doi: 10.1089/neu.2016.4577.

[25] L. Minh Dang, K. Min, H. Wang, Md. Jalil Piran, C. Hee Lee, and H. Moon, "Sensor-based and vision-based human activity recognition: A comprehensive survey," *Pattern Recognit.*, vol. 108, p. 107561, Dec. 2020, doi: 10.1016/j.patcog.2020.107561.

[26] "Sensors | Free Full-Text | Impact of Sliding Window Length in Indoor Human Motion Modes and Pose Pattern Recognition Based on Smartphone Sensors." https://www.mdpi.com/1424-8220/18/6/1965 (accessed Sep. 18, 2023).

[27] S. Gupta, "Deep learning based human activity recognition (HAR) using wearable sensor data," *Int. J. Inf. Manag. Data Insights*, vol. 1, no. 2, p. 100046, Nov. 2021, doi: 10.1016/j.jjimei.2021.100046.

[28] K. Rajamohan and S. Binu, "Performance Evaluation of Area-Based Segmentation Technique on Ambient Sensor Data for Smart Home Assisted Living," *Procedia Comput. Sci.*, vol. 165, pp. 314–321, Jan. 2019, doi: 10.1016/j.procs.2020.01.044.

[29] H. Najeh, C. Lohr, and B. Leduc, "Dynamic Segmentation of Sensor Events for Real-Time Human Activity Recognition in a Smart Home Context," *Sensors*, vol. 22, no. 14, Art. no. 14, Jan. 2022, doi: 10.3390/s22145458.

[30] Y. BenYahmed, A. Abu Bakar, A. RazakHamdan, A. Alshareef, and S. M. S. Abdullah, "Adaptive sliding window algorithm for weather data segmentation," vol. 80, pp. 322–333, Oct. 2015.

[31] B. Quigley, M. Donnelly, G. Moore, and L. Galway, "A Comparative Analysis of Windowing Approaches in Dense Sensing Environments," *Proceedings*, vol. 2, no. 19, Art. no. 19, 2018, doi: 10.3390/proceedings2191245.

[32] A. Dehghani, O. Sarbishei, T. Glatard, and E. Shihab, "A Quantitative Comparison of Overlapping and Non-Overlapping Sliding Windows for Human Activity Recognition Using Inertial Sensors," *Sensors*, vol. 19, no. 22, Art. no. 22, Jan. 2019, doi: 10.3390/s19225026.

[33] L. Bao and S. S. Intille, "Activity Recognition from User-Annotated Acceleration Data," in *Pervasive Computing*, A. Ferscha and F. Mattern, Eds., in Lecture Notes in Computer Science, vol. 3001. Berlin, Heidelberg: Springer Berlin Heidelberg, 2004, pp. 1–17. doi: 10.1007/978-3-540- 24646-6_1.

[34] Y. Wang *et al.*, "Computer-Aided Intracranial EEG Signal Identification Method Based on a Multi-Branch Deep Learning Fusion Model and Clinical Validation," *Brain Sci.*, vol. 11, no. 5, Art. no. 5, May 2021, doi: 10.3390/brainsci11050615.

[35] S. Sakka, V. Liagkou, and C. Stylios, "Exploiting Security Issues in Human Activity Recognition Systems (HARSs)," *Information*, vol. 14, no. 6, Art. no. 6, Jun. 2023, doi: 10.3390/info14060315.

[36] A. Saini, "An Introduction to Random Forest Algorithm for beginners," *Analytics Vidhya*, Oct. 19, 2021. https://www.analyticsvidhya.com/blog/2021/10/an-introduction-to-random-forest-algorithm-for-beginners/ (accessed Sep. 18, 2023).

[37] "Decision Tree," *Techopedia*, Jul. 25, 2023. https://www.techopedia.com/definition/28634/decision-tree (accessed Sep. 18, 2023).

[38] "KDnuggets," *KDnuggets*. https://www.kdnuggets.com (accessed Sep. 18, 2023).

[39] "Fig. 5. Flowchart of classification using RF algorithm.," *ResearchGate*. https://www.researchgate.net/figure/Flowchart-of-classification-using-RF-algorithm_fig3_332298301 (accessed Sep. 18, 2023).

[40] D. Bzdok, M. Krzywinski, and N. Altman, "Machine learning: supervised methods," *Nat. Methods*, vol. 15, no. 1, pp. 5–6, Jan. 2018, doi: 10.1038/nmeth.4551.

[41] "Euclidean Distance Formula - Derivation, Examples," *Cuemath*. https://www.cuemath.com/euclidean-distance-formula/ (accessed Sep. 18, 2023).

[42] "Introduction to Support Vector Machines (SVM) - GeeksforGeeks." https://www.geeksforgeeks.org/introduction-to-support-vector-machines-svm/ (accessed Sep. 19, 2023).

[43] S. Bakheet, A. Al-Hamadi, M. Elmezain, B. Michaelis, and U. Sayed, "Human activity recognition via temporal moment invariants," Dec. 2010, pp. 79–84. doi: 10.1109/ISSPIT.2010.5711729.

[44] G. B. II, "How is SVM different from other classifiers?," *TimesMojo*, Jul. 07, 2022. https://www.timesmojo.com/how-is-svm-different-from-other-classifiers/ (accessed Sep. 19, 2023).

[45] "Naive Bayes Classifiers," *GeeksforGeeks*, Mar. 03, 2017. https://www.geeksforgeeks.org/naive-bayes-classifiers/ (accessed Sep. 19, 2023).

[46] "What Is Bayes Theorem: Formulas, Examples and Calculations | Simplilearn," *Simplilearn.com*. https://www.simplilearn.com/tutorials/statistics-tutorial/bayes-theorem (accessed Sep. 19, 2023).

[47] "Confusion Matrix - an overview | ScienceDirect Topics." https://www.sciencedirect.com/topics/engineering/confusion-matrix (accessed Sep. 19, 2023).

[48] "(PDF) Performance Metrics for Activity Recognition." https://www.researchgate.net/publication/220527444_Performance_Metrics_for_Activity_Recogniti on (accessed Sep. 19, 2023).

[49] "Fig. 5. The confusion matrix for our activity recognition experiments.," *ResearchGate*. https://www.researchgate.net/figure/The-confusion-matrix-for-our-activity-recognition- experiments_fig3_221021875 (accessed Sep. 19, 2023).

[50] A. Suresh, "What is a confusion matrix?," *Analytics Vidhya*, Jun. 22, 2021. https://medium.com/analytics-vidhya/what-is-a-confusion-matrix-d1c0f8feda5 (accessed Sep. 19, 2023).

[51] "Confusion Matrix - an overview | ScienceDirect Topics." https://www.sciencedirect.com/topics/engineering/confusion-matrix (accessed Sep. 19, 2023).

[52] "What is the k-nearest neighbors algorithm? | IBM." https://www.ibm.com/topics/knn (accessed Sep. 19, 2023).

[53] "What is the k-nearest neighbors algorithm? | IBM." https://www.ibm.com/topics/knn (accessed Sep. 19, 2023).

[54] A. Mehta, "What is Accuracy, Precision, Recall, and F1 score? What is its significance in Machine Learning?," *Medium*, Sep. 18, 2020. https://ai.plainenglish.io/what-is-accuracy-precision- recall-and-f1-score-what-is-its-significance-in-machine-learning-77d262952287 (accessed Sep. 19, 2023).

[55] "K-Fold Cross Validation Technique and its Essentials - Analytics Vidhya." https://www.analyticsvidhya.com/blog/2022/02/k-fold-cross-validation-technique-and-its-essentials/ (accessed Sep. 19, 2023).

[56] A. Dehghani, T. Glatard, and E. Shihab, "Subject Cross Validation in Human Activity Recognition." arXiv, Apr. 09, 2019. Accessed: Sep. 19, 2023. [Online]. Available: http://arxiv.org/abs/1904.02666

[57] "Rehab My Patient," *App Store*, Nov. 18, 2020. https://apps.apple.com/sa/app/rehab-my- patient/id623812937

(accessed Sep. 19, 2023).

[58] R. M. Patient, “Exercise prescription software for therapist | Rehab My Patient.” https://www.rehabmypatient.com// (accessed Sep. 19, 2023).

[59] “TRAINFES - التطبيقات على Google Play.” https://play.google.com/store/apps/details?id=com.trainfes.trainfesapp&hl=ar (accessed Sep. 19, 2023).

[60] "Home english," *TRAINFES*. https://www.trainfes.com/en/ (accessed Sep. 19, 2023).

[61] "Track Rehab - التطبيقات على Google Play."
https://play.google.com/store/apps/details?id=com.trackrehab&hl=ar (accessed Sep. 19, 2023).

[62] "About | Track Rehab." https://trackrehab.com/about (accessed Sep. 19, 2023).

[63] "My Rehab Pro," *App Store*, May 31, 2021. https://apps.apple.com/us/app/my-rehab-pro/id663296117 (accessed Sep. 19, 2023).

[64] "HOME," *My Rehab Pro*. https://www.myrehabpro.com/ (accessed Sep. 19, 2023).

[65] "re.flex - التطبيقات على Google Play."
https://play.google.com/store/apps/details?id=com.kinetotech.reflex.app (accessed Sep. 19, 2023).

[66] "re.flex," *App Store*, Sep. 13, 2023. https://apps.apple.com/us/app/re-flex/id1308263322 (accessed Sep. 19, 2023).

[67] "Rehab Guru Pro - التطبيقات على Google Play."
https://play.google.com/store/apps/details?id=com.rehabguru.rehabguru (accessed Sep. 19, 2023).

[68] "Exercise Prescription Software for professionals, physiotherapy and patients."
https://www.rehabguru.com/ (accessed Sep. 19, 2023).

[69] "Client-server architecture | Definition, Characteristics, & Advantages | Britannica."
https://www.britannica.com/technology/client-server-architecture (accessed Sep. 20, 2023).

[70] Mayuresh, "What Is Client Server Architecture? An Overview," *UNext*, Dec. 30, 2020.
https://u-next.com/blogs/cyber-security/what-is-client-server-architecture/ (accessed Sep. 20, 2023).

[71] J. Frost, "Using Moving Averages to Smooth Time Series Data," Statistics By Jim. Accessed: Dec. 02, 2023. [Online]. Available: https://statisticsbyjim.com/time-series/moving-averages-smoothing/

[72] I. Pernek, G. Kurillo, G. Stiglic, and R. Bajcsy, "Recognizing the intensity of strength training exercises with wearable sensors," *J. Biomed. Inform.*, vol. 58, pp. 145–155, Dec. 2015, doi: 10.1016/j.jbi.2015.09.020.

[73] J. Quiroz, A. Banerjee, S. Dascalu, and S. L. Lau, "Feature Selection for Activity Recognition from Smartphone Accelerometer Data," *Intell. Autom. Soft Comput.*, pp. 1–9, Jul. 2017, doi: 10.1080/10798587.2017.1342400.

[74] M. B. Dehkordi, A. Zaraki, and R. Setchi, "Feature extraction and feature selection in smartphone-based activity recognition," Procedia Comput. Sci., vol. 176, pp. 2655–2664, Jan. 2020, doi: 10.1016/j.procs.2020.09.301.

[75] H. Dai et al., “Considerable effects of imaging sequences, feature extraction, feature selection, and classifiers on radiomics-based prediction of microvascular invasion in hepatocellular carcinoma using magnetic resonance imaging,” Quant. Imaging Med. Surg., vol. 11, no. 5, pp. 1836853–1831853, May 2021, doi: 10.21037/qims-20-218.

[76] H. Najeh, C. Lohr, and B. Leduc, “Considering the mutual information criterion for sensor configuration selection in human activity recognition in smart homes,” presented at the Building Simulation 2023, in Building Simulation, vol. 18. IBPSA, 2023, pp. 469–476. doi: 10.26868/25222708.2023.1194.

[77] “Optimizing Performance: SelectKBest for Efficient Feature Selection in Machine Learning | by Kavya D | Medium.” Accessed: Dec. 03, 2023. [Online]. Available: https://medium.com/@Kavya2099/optimizing-performance-selectkbest-for-efficient-feature-selection-in-machine-learning-3b635905ed48

[78] “Feature Selection Techniques in Machine Learning (Updated 2023).” Accessed: Dec. 03, 2023. [Online]. Available: https://www.analyticsvidhya.com/blog/2020/10/feature-selection- techniques-in-machine-learning/

[79] “Health Sector Transformation Program.” Accessed: Dec. 03, 2023. [Online]. Available: http://www.vision2030.gov.sa/en/vision-2030/vrp/health-sector-transformation-program/

5 Appendix

5.3 Appendix A: Interview forms

Interviewee: Rahaf aldossary	**Date:** 9/8/2023
Question 1: How much have you been working in the physical therapy field?	**Answer:** almost 4 years
Question 2: Do you consider Spinal Cord Injuries need specialized care? Why?	**Answer:** Of course, there are many types of SCI, each one needs special care depending on the severity of the injury.
Question 3: What are the challenges you face while evaluating a patients' rehab programs?	**Answer:** The problem is that some patients don't follow the prescribed program. And we can't know if they have done it or not.
Question 4: What are the current methods of rehab evaluation? Are they enough?	**Answer:** Currently, we use an application to track patient performance, the patient is responsible to mark the exercise as done, However, it depends on patient credibility, so we can't assure that the patient really did the exercise or not.
Question 5: How do you find a qualified therapist to get advice or discuss ideas?	**Answer:** I ask the other therapists at the health center and for complicated cases I contact expert therapists on social media, but they are not available all the time.
Question 6: If the prescribed patient's rehab program fails, how would you know the reason for the failure, if it is due to the patient's low commitment or the wrong choice of the program?	**Answer:** There is no way to know the reason of failure. If the prescribed patient's rehab program fails, I just try a different program. If it also fails, I will conclude that the failure was because of the patient's low commitment.
Question 7: Is there any thing you want us to consider?	**Answer:** try to make adjustments to your goal to become that you are trying to measure the muscles contraction rather than monitoring the patient, because some patients don't like to be monitored. good luck!

Figure 62: First Interview Answers

Interviewee: Fahad Algarni	**Date:** 9/8/2023
Question 1: How much have you been working in the physical therapy field?	**Answer:** 20 years
Question 2: Do you consider Spinal Cord Injuries need specialized care? Why?	**Answer:** Depending on the patient's condition. Whether he can or she can sit or cannot sit , because if he or she cannot sit , he/she need support , It will also affect the patient's exercises.
Question 3: What are the challenges you face while evaluating a patients' rehab programs?	**Answer:** We first determine the strength of the muscle and work on strengthening it He enters a program according to the patient's recovery period, but the problem we have is that the sensor tells us that the limb is moving, but it does not tell us that the limb is moving correctly or not.
Question 4: What are the current methods of rehab evaluation? Are they enough?	**Answer:** No, it's not enough It will be sufficient when the sensor tells me that the patient has moved the limb correctly while doing the exercise
Question 5: How do you find a qualified therapist to get advice or discuss ideas?	**Answer:** All fresh graduates are not qualified enough to deal with spinal cord injury patients. there will be in job training for a year or more to learn all the important things related to spinal cord injury.
Question 6: If the prescribed patient's rehab program fails, how would you know the reason for the failure, if it is due to the patient's low commitment or the wrong choice of the program?	**Answer:** There is no complete failure, but instead there are multiple factors that affect the progress of the rehab program. Including patients low-commitment and not showing off in sessions. As a result, these factors could slow down the progress pace and lengthen it by months. However, the biopsychosocial model is a good evaluation method that determines the success of the rehab program. In addition, we test patients if they can do certain moves, like going from bed to wheelchair.

Figure 63: Second Interview Answers

Interviewee: khalid Almuhareb	**Date:** 7/9/2023
Question 1: How much have you been working in the physical therapy field?	**Answer:** I have been working in physio therapy since 1414H (1993 m) 30 years
Question 2: Do you consider Spinal Cord Injuries need specialized care? Why?	**Answer:** Yes I do, because injuries are vary sensitive to care as specialized care. also it's neurological cases needs more caring and safety.
Question 3: What are the challenges you face while evaluating a patients' rehab programs?	**Answer:** There are some obsticals and challenges when evaluate these patients due to: • Co-operation's patient to give that information as what he complain and feel . • using accurate testing to give a good evaluation form that used about-now I am not agreed
Question 4: What are the current methods of rehab evaluation? Are they enough?	**Answer:** We can find that by refreshing exams according rehabilitation physiotherapist .it's done every year to make improvement.
Question 5: How do you find a qualified therapist to get advice or discuss ideas?	**Answer:** If that happens I may contact the patient co-ordinal or to the knowledges therapists.
Question 6: If the prescribed patient's rehab program fails, how would you know the reason for the failure, if it is due to the patient's low commitment or the wrong choice of the program?	**Answer:** It maybe both reasons we can not know for sure.
Question 7: Is there any thing you want us to consider?	**Answer:**. I want to consider some notes: • the physiotheraipst must be refreshing the information about case and what is new to evaluate and rate. • more reading and researches flowing about rehabilitation programs. • Training programmes with a high-qualifed and specialized physiotheraipsts.

Figure 64: Third Interview Answers

Interviewee: Abdullah Alsuraybi	**Date:** 7/9/2023
Question 1: How much have you been working in the physical therapy field?	**Answer:** Since 2013 I am a lecturer on KSU univeristy,but I have been on the clinc for 1 year.
Question 2: Do you consider Spinal Cord Injuries need specialized care? Why?	**Answer:** Depending on the level of injury Whether it is a complete paralysis or incomplete. Also, the expected function of the patent depends on the type of injury.
Question 3: What are the challenges you face while evaluating a patients' rehab programs?	**Answer:** Setting the goals is the most challening.Due to patient's denial at the begining of the rehabiliation program, conflicts may happend. For example there was a patient that should take the program in 6 months, but it expanded to 1 year instae Because of the low-commitment of that patient. Also, The first 6 months is the most important ones because it eases the rehabiliation
Question 4: What are the current methods of rehab evaluation? Are they enough?	**Answer:** We mostly depend on some measures to know if the patient have been stick to the plan in home or not, it is not accurate all the time. Also, we can see his/her movement in the everyday activties. Self reported survey is another way however, it is rarely used.
Question 5: How do you find a qualified therapist to get advice or discuss ideas?	**Answer:** It was difficult to find a therapist who specializes in Saudi Arabia, especially since my class of 2013 is the first class in this major. Now, it is easier if you know them in person.
Question 6: If the prescribed patient's rehab program fails, how would you know the reason for the failure, if it is due to the patient's low commitment or the wrong choice of the program?	**Answer:** There is a weekly assessment for the patient to see if there is a progress in his/her rehabilition. if there is not we change the plan immeditaly. Hence, if there is no progress we ask them and it mostly due to the patients' low-commitment. Then, we give them a more intersting activites to commit.

Figure 65: Fourth Interview Answer

Interviewee: Osamah keridis	**Date:** 7/8/2023
Question 1: How much have you been working in the physical therapy field?	**Answer:** 7 years
Question 2: Do you consider Spinal Cord Injuries need specialized care? Why?	**Answer:** Yes, they need specialized care because they are unable to do their daily activities. SCI patients need medical care and physical therapy, to help them become as independent as possible.
Question 3: What are the challenges you face while evaluating a patients' rehab programs?	**Answer:** The patient's fear of treatment and lack of awareness of the importance of the exercise, also some patients' families don't support them. These are many reasons that may affect the patient's commitment and therefore affect the evaluation process.
Question 4: What are the current methods of rehab evaluation? Are they enough?	**Answer:** I think it's not enough, However I can predict whether a patient has done his exercise or not by Measuring muscle stiffness. If the patient did not do the required exercise his muscles would be very stiff.
Question 5: How do you find a qualified therapist to get advice or discuss ideas?	**Answer:** I ask the therapists at the health center and for tough cases I contact expert therapists on social media but it is not an easy way to get help especially for emergencies.
Question 6: If the prescribed patient's rehab program fails, how would you know the reason for the failure, if it is due to the patient's low commitment or the wrong choice of the program?	**Answer:** The patient is asked to conduct a test that will help us to evaluate his condition. We try to use different programs until one of them works.
Question 7: Is there any thing you want us to consider?	**Answer:** No, I wish you all the pest in your project. thank you.

Figure 66: Fifth Interview Answers

Interviewee: Reem Alsubait	**Date:** 9/9/2023
Question 1: How much have you been working in the physical therapy field?	**Answer:** I'm experienced with occupational therapy and have been dealing with sci and stroke. I graduated in 2018, almost 5 years in my job.
Question 2: Do you consider Spinal Cord Injuries need specialized care? Why?	**Answer:** Yes, especially the period after the injury directly. Sometimes they need in-hospital rehab until they reach a level where they can go home, and then complete the rest of the program there with the given equipment.
Question 3: What are the challenges you face while evaluating a patients' rehab programs?	**Answer:** Some patients are not open to talk about their limits, they always pretend that everything is good. Hence, it needs multiple sessions to understand the patient's abilities and behavior.
Question 4: What are the current methods of rehab evaluation? Are they enough?	**Answer:** There is a report before a patient is discharged to home, it has the patient 's current state and the goal state. However, the questionnaire is not used alone, there is an OT evaluation form that assists the evaluation process. No practical technology is common in this field, so we usually test the patient's abilities to move while evaluation.
Question 5: How do you find a qualified therapist to get advice or discuss ideas?	**Answer:** We usually work together and we negotiate at a therapist's gym. This allows us to share our patient experiences and their faced difficulties. Hence, exploring different methods and techniques from other experts to help in patient progress.
Question 6: If the prescribed patient's rehab program fails, how would you know the reason for the failure, if it is due to the patient's low commitment or the wrong choice of the program?	**Answer:** There is no specific way to know this, but we usually understand the patients from their behavior and interactions in sessions. This then gives us an intuition of the patient's commitment to the rehab program.
Question 7: Is there any thing you want us to consider?	**Answer:** good luck!

Figure 67: Sixth Interview Answer

5.4 Appendix B: UAT Questionnaire

How effective was the search functionality in finding a specific patient? *

	1	2	3	4	5	
Very effective	○	○	○	○	○	Very ineffective

How easy was it to find the option for ranking patient performance? *

	1	2	3	4	5	
Very difficult	○	○	○	○	○	Very easy

How easy was it to navigate between weekly and monthly tabs and switch between text and chart views in the report? *

	1	2	3	4	5	
Very difficult	○	○	○	○	○	Very easy

TheraSense

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How satisfied are you with your overall experience using the app? *

	1	2	3	4	5	
Very dissatisfied	○	○	○	○	○	Very satisfied

TheraSense application has a user-friendly interface and is easy to navigate. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Were there any features or functionalities you found confusing or unclear? Please specify. *

Your answer

Did you encounter any technical issues while using the app? If yes, please describe. *

Your answer

Do you have any suggestions for future work? Please share your thoughts. *

Your answer

Which age group do you belong to? *

- 18-30 years old
- 31-45 years old
- 46-60 years old
- Over 60 years old

How would you rate your technical experience ? *

- Novice
- Intermediate
- Advanced

TheraSense Sign-in process was familiar to you. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

TheraSense

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TheraSense provides a sufficent details about the patient. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Add a therapy program for a patient was clear. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

How easy was it to update a therapy program for a patient? *

	1	2	3	4	5	
Very difficult	○	○	○	○	○	Very easy

How clear was the process of generating a report? *

	1	2	3	4	5	
very unclear	○	○	○	○	○	very clear

TheraSense

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TheraSense provides an important feature by allowing sending the report with patients *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The task to print a report was completed quickly. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

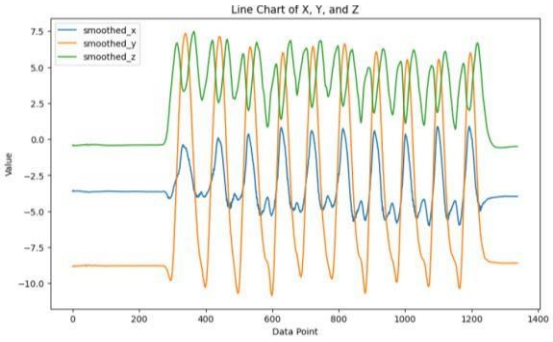
How would you rate the user-friendliness of the chatbot for FAQs and quizzes? *

- ○ Excellention
- ○ Good
- ○ Fair
- ○ Poor

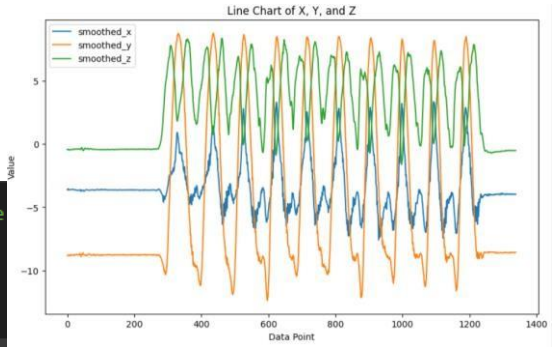
5.5 Appendix C: Data Preparation experiments

A. moving average filter experiments.

```
# Data smoothing using Exponential Moving Average
df['moving_Avg_x'] = df['X'].ewm(span=20).mean()
df['moving_Avg_y'] = df['Y'].ewm(span=20).mean()
df['moving_Avg_z'] = df['Z'].ewm(span=20).mean()
```




```
# Data smoothing using Exponential Moving Average
df['moving_Avg_x'] = df['X'].ewm(span=5).mean()
df['moving_Avg_y'] = df['Y'].ewm(span=5).mean()
df['moving_Avg_z'] = df['Z'].ewm(span=5).mean()
```




```
# Data smoothing using Exponential Moving Average
df['moving_Avg_x'] = df['X'].ewm(span=10).mean()
df['moving_Avg_y'] = df['Y'].ewm(span=10).mean()
df['moving_Avg_z'] = df['Z'].ewm(span=10).mean()
```