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Research Article

Tele-DM: development of a mobile health technology for non-invasive type-2 diabetes mellitus patients with assistive physical activities and vital signs monitoring

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Abstract
Health experts have identified tailored physical activity (PA) and heart rate measurement as critical components in assisting type-2 diabetes (T2D) patients in improving their health. When performing PA, heart rate monitoring can be useful in figuring out the right intensity level for diabetic patients, helping them to benefit from the non-invasive treatment. Previous research has shown that mobile health (mhealth) applications have emerged as a viable option for enhancing health outcomes during the rehabilitation process. Regrettably, the current mhealth applications have constraints in facilitating a bidirectional interaction between the healthcare provider (HPC) and the patient. Moreover, the majority of mhealth applications designed for T2D treatment cannot directly capture real-time heart rate data from smartwatches or medical wearable devices. As a result, users are compelled to manually input this data into the applications. Thus, in this study, a Tele-diabetes mellitus management (Tele-DM), a remote monitoring system consisting of a mobile application and a smartwatch is developed to address these challenges by using the Flutter framework, Nodejs, Express, Heroku, and database management system (DBMS) MongoDB. A feature has been implemented to provide healthcare professionals (HCPs) with an interactive feedback page. This page allows HCPs to review and comment on the progress of their patients, facilitating more effective remote monitoring. In addition, through the utilisation of a multi-platform approach, the heart rate can be obtained in real-time from commercially available smartwatches and subsequently synchronised with the Tele-Dm apps following PA. The HCPs can monitor the performance and progress of the patients in real-time using this method. Functionality tests of this app have shown a remarkable success rate of almost 100%. From the user acceptance rating, it received an average of 4.03 rating for a user-friendly mhealth application. Ultimately, the Tele-DM system is an innovative solution for tackling the difficulties associated with diabetes self-care. It provides personalised guidance and remote monitoring of heart rate during rehabilitation sessions.

Keywords
Mobile health technology, Type-2 diabetes mellitus, Rehabilitation, Remote monitoring, Diabetes management, Apps development.

1.Introduction
The fast evolution of mobile technology has become beneficial in health-related fields. Nowadays, there is a large number of mobile health (mHealth) applications that have been developed and have proven their usefulness in the treatment of type-2 diabetes (T2D) patients. With the increasing prevalence of diabetes and the growing need for self-management, mHealth apps have become an

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important tool in helping patients achieve better glycemic control [1, 2].

On top of that, incorporating tailored physical activity (PA) in the mHealth applications is considerably pivotal for healthcare professionals (HCPs) in diabetes treatment [3]. Recent studies have also shown that the heart rate measurement while performing the PA is also an important contributor to diabetes management [4].

Through the monitoring of heart rate, HCPs can determine the suitable intensity level for the patient's PA and ensure that they are attaining the most advantageous level of exertion for their specific requirements [5]. Furthermore, heart rate monitoring assists HCPs in monitoring patients with myocardial infarction [6]. Built-in sensors on smartwatches allow them to monitor physiological signs such as heart rate and blood pressure [7, 8]. Diabetes mellitus (DM) is classified into three types: Type-1 diabetes (T1D), T2D, and Gestational diabetes mellitus (GDM) [9]. However, the focus of this study is on the rehabilitation of T2D patients who have insulin resistance caused by metabolic syndrome rather than autoimmune loss of the pancreas' insulin-producing beta cells [10]. T2D is the most common type of diabetes, impacting 460 million people, and is estimated to reach 700 million during the next 22 years [11, 12]. T2D develops gradually over time, beginning at a young age, and adults account for the majority of identified cases [13]. Insulin secretion, hereditary components, obesity, incretins, increased glucose absorption, and circadian rhythm are among the factors that contribute to T2D [12, 14, 15, 16].

This study is motivated by the changing landscape of mHealth technology and its potential to revolutionise the management of T2D patients' health conditions. Recent improvements in mHealth have exhibited a paradigm change in healthcare by providing individualised solutions and real-time monitoring capabilities [17−19]. The integration of wearables, smart devices, and sophisticated software has enabled people to actively engage in their health management [20‒22]. These technology improvements not only facilitate effective health monitoring but also provide vital insights for HCPs. Acknowledging the potential of mHealth, there is a growing interest in investigating its applications for personalised rehabilitation programmes [23, 24]. Furthermore, the issues posed by the coronavirus disease of 2019 (COVID-19) pandemic, underline the critical need for remote healthcare solutions globally [4].

The development of a mobile application for T2D remote rehabilitation involves several challenges, including feasibility [25], technical complexities [26], ethical considerations [27], security [28], and the current need for remote healthcare solutions. Technical obstacles include providing seamless integration and data synchronisation between various platforms, as well as selecting appropriate technologies for front-end and back-end technologies for developing the mobile application [17]. Data security and the proper use of sensitive health data raise ethical concerns that present obstacles from both ethical and electrical/computer engineering perspectives [29‒31]. The key problem is to provide a user-friendly interface that delivers PA guidance for T2D rehabilitation [32, 33].

Real-time remote monitoring frequently requires the integration of mobile applications with wearable medical devices or smartwatches to enable health data updates [34]. Thus, the accompanying problem in this integration is the need to overcome several impediments, particularly from a technical and design standpoint [35]. Common issues include the cost implications of using expensive open-source smartwatches, the time constraint for developing a smartwatch, the lack of packages in the Flutter framework to achieve a direct connection between smartwatches and mobile applications, and the lack of integration of smartwatches in previously developed mHealth applications [36, 37]. On a technical level, maintaining seamless and reliable Bluetooth connectivity, as well as integration with cloud databases, presents inherent challenges [38]. These challenges highlight the necessity for an innovative and inclusive strategy for smartwatch integration, taking into account cost, compatibility, and the overall goal of improving the mobile application's functionality for optimal diabetes management [2].

Over the years, there has been continuous research into the usefulness of self-management diabetic mobile applications and their potential effects on diabetes patients' health [39]. Questions remain about whether these applications genuinely or aggravate diabetes. Previous studies also have implemented a programme to assess the efficacy of their mHealth. Some of the studies have effectively demonstrated favourable improvements in participants' weight and glycosylated hemoglobin (HbA1c) levels [1, 40], while others have failed to produce positive outcomes [23, 41]. Therefore, precisely assessing the impact of mHealth applications remains a critical challenge.

Thus, the goal of this study is to develop a mobile application for a T2D remote rehabilitation system that incorporates a low-cost, off-the-shelf smartwatch via a multi-platform implementation employing Bluetooth connectivity. This advancement not only enhances accessibility but also opens up new possibilities for the cost-effective and widespread adoption of remote rehabilitation technologies in managing and improving the outcomes of T2D patients.

The paper is organized by first introducing the previous works of the mHealth applications and discussing the technologies used in the app development. Then, methods used in this work in developing the Tele-diabetes mellitus management (Tele-DM) are elaborated by detailing the front-end and back-end development. Finally, the mobile application is analysed based on functionality tests and user feedback. This work is organised in the following manner: it starts with a thorough examination of current literature on mHealth therapies designed specifically for patients with T2D. Afterward, it describes the approach used in creating the Tele-DM platform, offering in-depth information about its main elements, such as the patient portal, admin portal, and HCP portal. Furthermore, the report outlines the technique employed to assess the performance of the Tele-DM system. Subsequently, the paper describes the results obtained from the implementation of the Tele-DM platform. Moreover, it provides a clear explanation of the features of the Tele-DM system and examines the user's experience when using it. Finally, the study finishes by providing a thorough assessment of the overall results of the Tele-DM platform, along with suggestions for future research and development.

2.Literature review

2.1Previous work on mHealth applications for T2D patients

Table 1 lists eleven mHealth applications developed by different researchers for T2D patients. The table shows the different types of PA, portals incorporated within each application, vital sign monitoring capabilities, and associated health outcomes for each mHealth solution. Nine of these programmes have a self-reported (SR) PA feature. Users can manually enter different sorts of PAs into the application without receiving step-by-step instructions. The applications employing SR for PA include diabetes lifestyle intervention using technology empowerment (D'LITE) [1], BlueStar [23], Time2Focus [36], Health2Sync [37], DiaSocial [39], GlycoLeap [40], LIBIT (Huraypositive Co) [41], Triabetes [42], and iCareD [43]. One application, named mDiab [2], provides guidance of PA for users, but only for brisk walking. Finally, the Diabetes self-management education and support (DSMES) application does not specify the inclusion of any particular PA [44]. The addition of an SR PA component to mHealth applications has both advantages and downsides in the healthcare arena. On the plus side, the SR feature gives users the ability to report different sorts of PAs, providing a comprehensive picture of their lifestyle. However, in the healthcare context, reliance on SR data brings potential flaws and subjective biases [45]. Users may mistakenly overestimate or underestimate their PA levels, resulting in less accurate information for HCPs. This constraint can impair the dependability of collected data for clinical decision-making and the efficacy of therapies customised to the patient's real activity levels.

Table 1 The available mHealth applications developed for T2D patients

Reference	mHealth Apps	Type of PA	Type of portal	Monitored vital signs
[1]	D'LITE	SR, walking	Patient	Monitor steps using the phone's pedometer
[2]	mDiab	Brisk walking	Patient	None
[23]	BlueStar	SR	Patient	None
[36]	Time2Focus	SR	Patient	None
[37]	Health2Sync	SR	Patient	None
[39]	DiaSocial	SR, walking	Patient	Monitor steps using the phone's pedometer
[40]	GlycoLeap	SR, walking	Patient	Monitor steps using the phone's pedometer
[41]	LIBIT	SR	Patient	None
[44]	DSMES	Not Available	Patient	None
[42]	Triabetes	SR	Patient	None
[43]	iCareD	SR	Patient	None

Furthermore, the portal architecture of the developed mHealth applications focuses entirely on patient portals. In other words, there are no specific portals for HCPs or administrators. This constraint causes a functional gap, especially in terms of remote monitoring capabilities. In a computer engineering setting, the presence of various portals for HCPs and administrators is critical for developing a comprehensive remote monitoring system [46]. These portals would provide secure access to patient data, allowing HCPs to monitor vital signs, manage treatment adherence, and make educated decisions from anywhere. Addressing this gap is critical to increasing the overall efficacy and utility of these mHealth applications in the healthcare arena.

It is worth noting that just three applications use the mobile device's pedometer to collect step data during walking activities, while the remaining applications lack the vital signs monitoring feature. Monitoring vital signs, such as step count, is essential for determining the degree of PA. Using a mobile device's pedometer guarantees a cost-effective and widely accessible means of collecting vital data, providing insights into the user's activity levels [47]. However, it's critical to note that the breadth of vital signs extends beyond step count and includes measures like heart rate, calories burned, blood pressure, and oxygen saturation [48]. Smartwatch integration into mHealth applications opens up new possibilities for monitoring vital indicators. Smartwatches with advanced sensors can gather a greater range of vital signs data, providing a more comprehensive view of the user's health status [49]. From a healthcare standpoint, this integration enables a more precise assessment of the intensity and impact of PA on a patient's well-being. Real-time monitoring of vital signs using smartwatches enables rapid interventions and changes to treatment strategies. In terms of technology, the seamless integration of smartwatch technology improves the overall capabilities of mHealth applications, allowing for a more dynamic approach to vital sign monitoring.

Furthermore, several applications recommend moderate-intensity PA for people with T2D. DiaSocial, D'LITE, LIBIT, iCareD, and mDiab are among the applications that support moderate PA, recognising its potential to improve engagement and weight loss in people with T2D. While multiple reviews on various mHealth applications for diabetic self-management indicate positive short-term outcomes, particularly in terms of HbA1c and weight loss, the influence on long-term conditions such as neuropathy, retinopathy, nephropathies, or hypertension remains uncertain [50]. This uncertainty is compounded by challenges such as a lack of training, difficulties in practicing a healthy lifestyle, and limited access to HCP [51]. Despite their variances, all of these mHealth apps have the same goal: to evaluate their app's usefulness in improving the health outcomes of T2D patients.

2.2 Technologies used in remote monitoring applications

Table 2 shows nine mobile applications developed for remote monitoring, each having numerous portals within their system. This table provides an overview of various technologies for constructing a remote monitoring system, including front-end, server, and database components. The incorporation of several portals inside these apps demonstrates their ability to cater to various user interfaces (UIs) and capabilities, resulting in increased user engagement and flexibility. Furthermore, this table sheds light on the complex technological decisions made by developers to improve the performance and usefulness of various remote monitoring programmes.

Table 2 Technologies used for remote monitoring in developed mobile applications

Reference	Applications name	Front end development	Type of server	Database
[31]	Clinical Consultation	Java (Mobile)	Django, Anaconda	MySQL
[30]	Frame	Xamarin (mobile) and C# (Web)	RESTful API, Microsoft Azure	Azure hosted MSSQL
[52]	College App	Flutter (Mobile and Web)	Firebase	Firebase
[53]	Know Your Ride	Flutter (Mobile) and hypertext markup language (HTML) / cascading style sheets (CSS) (Web)	Firebase (Mobile) and Python, Django (Web)	Firebase
[54]	Ride Sharing	Flutter (Mobile and Web)	Node.js	MongoDB
[55]	Attendance	PhoneGap - Apache Cordova	Apache Tomcat	MySQL
[56]	Smart Learning and Attendance Management System	Java	.NET	SQL Server 2012

Reference	Applications name	Front end development	Type of server	Database
[57]	Android Personal Safety	Java (Mobile) and HTML/CSS (Web)	Python	MySQL
[58]	Campus News	Flutter (Mobile)	Python Flask and Heroku	PostgreSQL

Front-end technologies vary across platforms, including mobile, web, and desktop. Developers frequently choose cross-platform frameworks for efficient development, generating several applications with a single code base[59, 60]. Popular frameworks include Xamarin, React Native, Ionic, Apache Cordova, and Flutter [61]. Notably, as indicated in *Table 2*, Java is not intrinsically cross-platform, highlighting the importance of aligning technology with project goals and a wide range of end-user devices. Using cross-platform frameworks enables developers to optimise audience exposure while maintaining a single codebase for platforms such as Android, iOS, and web applications. Aside from well-known frameworks like Xamarin and React Native, there are others such as Unity 3D, Cocos 2D, Titanium, and others [62]. Flutter is the most popular cross-platform framework, with 42% of global developers utilising it in 2021. Its advantages include a big community actively upgrading the framework [63]. On top of that, Flutter has been highlighted to be exceptional in time execution in processing sensor data [64]. Another study comparing Flutter and React Native with different frameworks reveals excellent results in various performance parameters [65]. As a result, the Flutter framework was used in this work due to its efficiency, popularity, and cross-platform adaptability, as well as leveraging a unified codebase for streamlined development and prospective community assistance.

A database management system (DBMS) stores data either locally or in the cloud, accessible from anywhere with an internet connection [66]. Databases facilitate create, read, update, delete (CRUD), and various types exist, including hierarchical, network, relational, object-oriented, graph, entity-relationship (ER) model, document, and NoSQL databases [67]. For mobile app development, both relational and NoSQL databases are suitable [68, 69]. *Table 2* shows examples of remote monitoring applications using databases compatible with Flutter, such as Firebase, MongoDB, and PostgreSQL, all falling under the NoSQL category [70]. NoSQL databases, supporting javascript object notation (JSON) documents, offer flexibility compared to rigid row-column formats, especially for schema changes [71, 72]. While studies highlight MySQL's compatibility with Flutter for remote monitoring [73, 74], there's no universal best database for mobile apps. Considering plans for a web application, MongoDB is favored in this work for its compatibility and popularity in the tech landscape, aligning with the project's broader goals.

With Flutter for the front-end and MongoDB for the database, the server-side technology possibilities become clearer. According to *Table 2*, only the Ride Sharing app uses the same technology for both the front and back ends, namely Node.js. This shows Node.js' interoperability with Flutter and MongoDB for remote monitoring. MongoDB supports a variety of server-side technologies, including Python, Java, .NET, Ruby, PHP, Express.js, AWS Mobile, Parse, Django, and Firebase [75]. Developers can choose the server-side technology that best meets their needs. Node.js was chosen because it is widely used and supports complicated CRUD operations required for remote monitoring. Node.js' popularity and abundance of tutorials further support its decision [76–78]. For web applications, MERN and MEAN stacks, utilizing MongoDB and Node.js, are popular [79, 80]. While MERN and MEAN employ React and Angular.js for the front-end, Flutter is used in this project, which presents a hurdle in connecting the server and database. Heroku services were used to install the server side (Node.js and Express), resulting in a hypertext transport protocol (HTTP) application programming interface (API) compatible with Flutter for seamless communication.

This literature review presents a comprehensive assessment of mHealth applications for T2D patients, which provides useful insights into the current landscape of technology-assisted distant rehabilitation. The study focuses on the design and functionality of a Tele-DM programme, emphasising its potential influence on healthcare. The bulk of existing mHealth applications for T2D patients include SR of PA characteristics. While such tools allow users to enter various PAs manually, the study correctly highlights the potential downsides, such as inaccuracy and subjective biases in reported data. The investigation also indicates a significant gap in the portal architecture of existing apps, with a concentration primarily on patient portals and no dedicated portals for HCPs or administrators. This constraint reduces remote monitoring capabilities, which are critical for a comprehensive healthcare system. The study correctly underlines the importance of including portals for healthcare workers, which provide secure access to patient data and enable remote monitoring, which is critical for good healthcare management. Furthermore, the research dives into the technological aspects of remote monitoring applications, including information on the various front-end development tools, server kinds, and databases used in these systems. Cross-platform frameworks, such as Flutter, are becoming increasingly popular for efficient development across multiple platforms. The topic of DBMS, which includes NoSQL databases such as Firebase, MongoDB, and PostgreSQL, provides useful information for developers looking to optimise data storage and retrieval in mHealth applications. The use of Flutter as a front-end framework in Tele-DM application development is justified by its efficiency, popularity, and cross-platform flexibility. The choice of MongoDB for the database is consistent with the project's objectives, emphasising flexibility and compatibility for dynamic data management. Node.js's popularity, comprehensive tutorials, and compatibility with Flutter all contribute to its integration on the server side, enabling seamless communication in the proposed Tele-DM application.

3.Methodology

Tele-DM application development is iterative, with the application divided into segments. The Tele-DM application's iterative development method can be described as incremental releases, repetition of actions, and feedback. During incremental releases, the Tele-DM project is broken into smaller increments, each representing a working and tested version of the application. Instead of waiting until the entire application is complete, incremental releases enable the delivery of certain features or modules at regular intervals. Then, in the repetition of activities, each iteration of the Tele-DM development cycle repeats core activities such as planning, design, implementation, testing, and evaluation. Comprehensive testing is performed to guarantee that newly implemented features in Tele-DM work as intended and do not introduce mistakes.

It entails analysing the results of the iteration, identifying lessons learned, and making improvements for future iterations. Following each release, feedback from T2D patients and HCPs is actively solicited. Users' experiences and insights are critical in shaping the usability of Tele-DM and ensuring it meets the needs of T2D patient's rehabilitation. Feedback from each cycle is used to adjust and improve the application. This could include bug corrections, feature upgrades, or changes to the overall design depending on user feedback. This process is repeated till the entire and final product is produced.

3.1Tele-DM development framework

Developing a full-stack system for a Tele-DM mobile application requires suitable technologies. The framework used for Tele-DM development is shown in *Figure 1*. It consists of a front-end and a back-end development. The front-end system for Tele-DM involves creating a mobile application on Android devices using the cross-platform framework, Flutter. The DBMS utilises MongoDB, a non-relational database known as NoSQL. Furthermore, the Tele-DM is equipped with dedicated PAs tailored by health experts, specifically for T2D patients [4] as shown in *Table 3*. It aims to help diabetes patients lower their blood glucose levels and promote an active lifestyle by guiding them to get out of sedentary behaviour through this app. Their vital signs, such as calories, steps, and heart rate, are captured from their smartwatch using the integrated API while executing the PAs. Different users can use the apps, namely, the T2D patients, the HCPs, and the administration personnel, for effective and sustainable remote monitoring for DM non-invasive treatment. In this study, an economical smartwatch, namely, Xiaomi Band 7 has been used for the vital signs data collection during these PAs.

Table 3 Description of PAs in Tele-DM

PA	Description
Aerobic exercise	Perform warm-up, dynamic stretching (10 types), brisk walking, cool-down, and static stretching (9 exercises).
Resistance exercise	It contains repetitions and sets for the main activity. Perform warm-up, dynamic stretching (10 exercises), resistance exercise (6 exercises), cool-down, and static stretching (9 exercises).

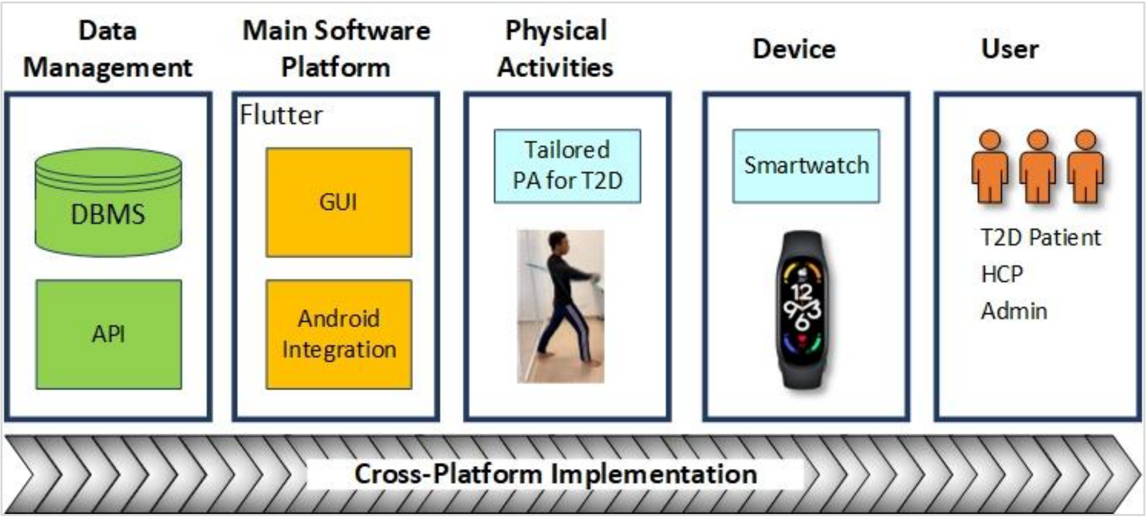


Figure 1 The framework used in the development of Tele-DM

3.2Tele-DM system architecture

Figure 2 represents the system architecture of the Tele-DM system. This system's two critical parts are the front-end and the back-end systems. The front-end is the Android devices for the end users, which are T2D patients, HCPs, and admin. The back-end development includes a DBMS MongoDB database uniform resource identifier (URI) and a REST API. The REST API development involved NodeJS and Express technologies using visual studio code with a specific file structure, essential libraries, and dependencies as well as key server files to enable CRUD operations and database connection. It was then deployed to Heroku for accessibility in the front-end system. The deployed REST API on Heroku ensures seamless connectivity between the front-end and back-end. Finally, the Tele-DM mobile application requires an internet connection to access the API and perform CRUD operations. This connectivity enables users to interact with the back-end system, retrieve and manipulate data, and experience the full functionality of the application.

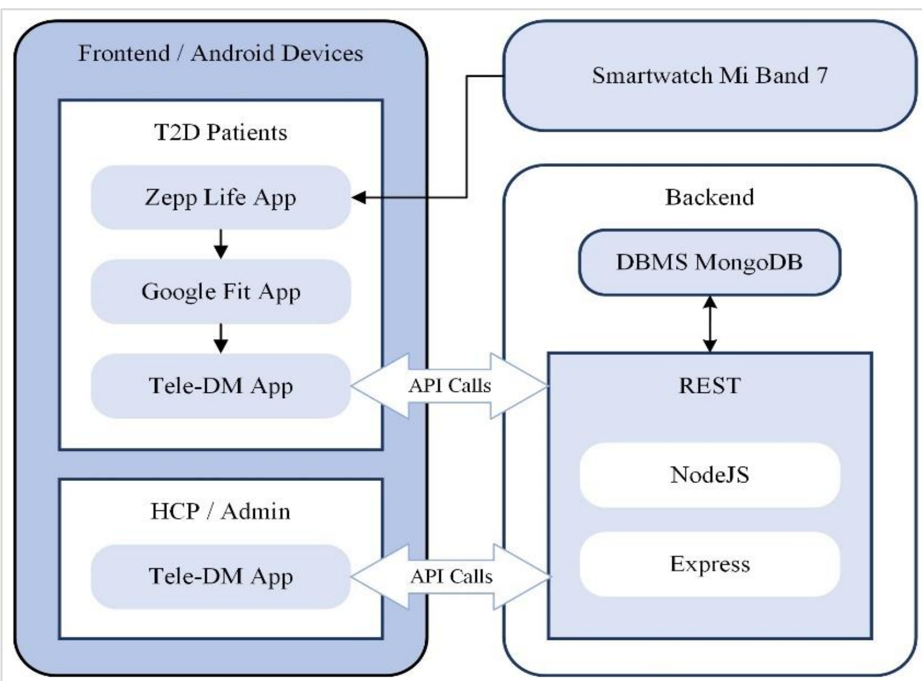


Figure 2 The system architecture of Tele-DM consists of front-end and back-end systems

3.3Fetching vital signs from a smartwatch to Tele-DM mobile applications

The Xiaomi Band 7, a smartwatch with enhanced functionality, is essential for monitoring a patient's heart rate while exercising. Unfortunately, Flutter primarily focuses on providing a framework for building user UIs for mobile, web, and desktop applications. Integrating with a smartwatch involves considerations beyond the Flutter framework, such as the capabilities and APIs provided by the smartwatch platform. As a result, to effortlessly incorporate this heart rate data into the Tele-DM programme, the Zepp Life and Google Fit apps must be installed on the smartphone. Zepp Life is one of the officially sanctioned applications for acquiring and presenting data from this smartwatch. The data retrieved from these apps is synchronised with the Google Fit Apps via the Google cloud console. Tele-DM then updates the vital signs data in its applications by retrieving the stored data from the Google Cloud. Due to the scarcity of open-source smartwatch implementations, data is retrieved across many platforms. *Figure 3* shows the data transfer from the smartwatch to the Tele-DM application via multi-platform implementation.

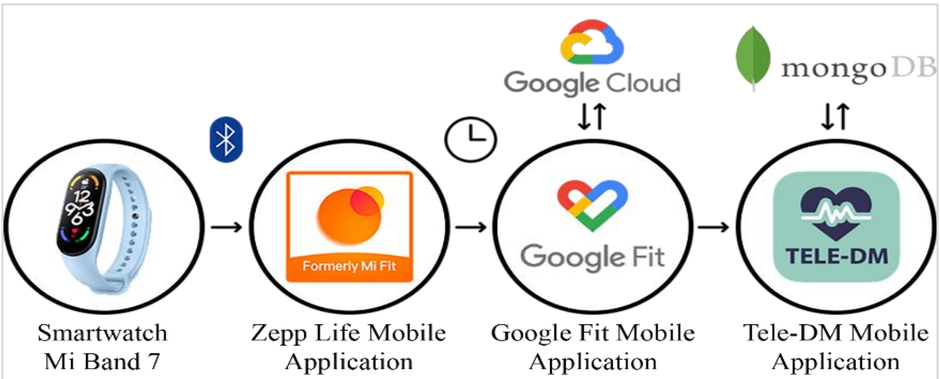


Figure 3 The data transfer from the smartwatch to the Tele-DM application via multi-platform implementation

3.4User Hierarchy and authorization level

Figure 4 and *Figure 5* comprehensively illustrate the Tele-DM mobile application's user hierarchy and system architecture. The central system of Tele-DM is meticulously segmented into three distinct subsystems: (1) the patient subsystem, (2) the HCP subsystem, and (3) the admin subsystem. *Figure 4* and *5* elucidate how users gain access to specific systems based on their designated roles, as depicted in *Figure 3*. The security features adopted in this application are by using passwords and usernames. In a position of authority, the administrator has unrestricted access to all user-related data, encompassing personal and identification information. Conversely, HCPs possess limited access, confining them solely to the information and progress of the patients they are assigned to oversee. This limitation is in place to safeguard patient privacy while enabling effective monitoring of exercise and reporting activities. Meanwhile, patients are granted access solely to the patient system, catering to their individual needs and engagement within the application. The Splash screen is used as the opening page in the Tele-DM mobile application as it contains the main logo of this app.

The splash screen of the Tele-DM mobile application serves two purposes. First, it provides a consistent user experience by accessing cached login information from the device's local storage. It eliminates the need for users to log in to the system each time they visit the app, resulting in greater ease and efficiency. *Figure 6* depicts the unified modeling language (UML) of the splash screen. When the Tele-DM mobile application is launched, the system checks for the presence of the user's login information, which is saved as a unique identification (ID) in local storage utilising shared preferences. Assume the user is using the programme for the first time, and the unique ID is set to empty by default. In that situation, the system redirects the user to the login page, requesting them to enter the required information. When the Tele-DM mobile application detects an existing user based on a unique ID stored in the shared preferences, the system verifies the user's role, which is also saved in shared preferences. The system retrieves the user's information from the database and stores it in the state management system, namely within the Provider. Following that, based on the user's position, the system directs the user to the appropriate system within the programme, personalising their experience to their specific access privileges and duties. It is vital to remember that when the user closes the Tele-DM mobile application, it instantly logs them out. However, the system keeps the user's unique ID and role information, allowing for smooth login during subsequent app usage by effectively obtaining the user's data from the database.

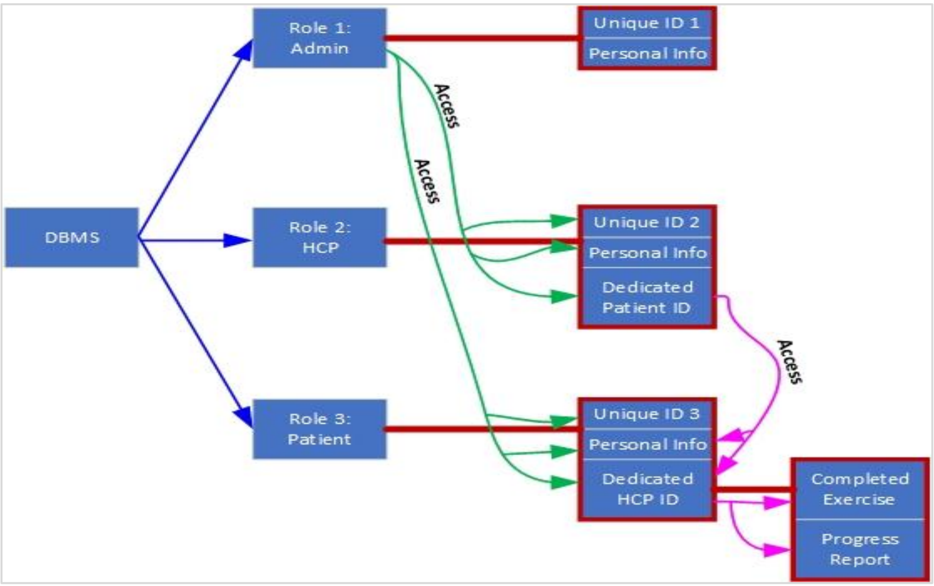


Figure 4 Authorised access for different user roles in Tele-DM to the controlled information

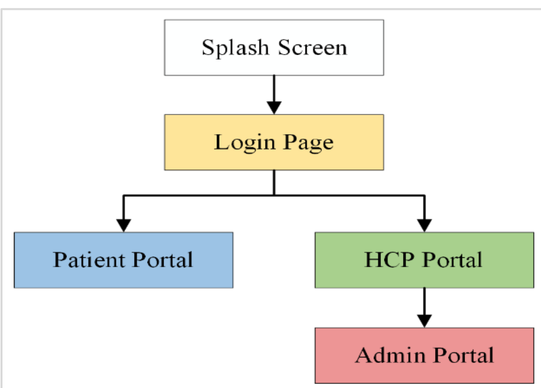


Figure 5 The portals available in the Tele-DM

In conclusion, the splash screen of the Tele-DM mobile application plays a pivotal role in enhancing user convenience and system efficiency by intelligently managing login credentials and directing users to their designated systems based on their roles within the application.

3.5Tele-DM main portals

Figure 7 illustrates the UML activity diagram for the 'Login' page. The process begins with users entering their name, identification card (IC) number, and role. Subsequently, the system searches for the user in the database. As depicted in the diagram, the login process differs between the student and HCP portals. In the patient portal, users are prompted to grant necessary permissions and to sync their Google account with the mobile application. These steps are essential for vital signs data collection. Finally, both portals save the users' data fetched from the database into the state management, Provider, before transitioning to the respective portal. This ensures that the user's data is readily accessible and available within the application for seamless usage and interaction.

3.5.1The patient portal

Due to its central role, the patient subsystem emerges as the most intricate component within the Tele-DM application, with patients constituting the primary user group. This subsystem entails a multitude of intricacies as patients engage in tailored PA, log their progress, input vital signs, and provide feedback to their HCPs. *Figure 8* visually illustrates the patient system's meticulously organised and interconnected navigation structure in the Tele-DM mobile application, presenting a comprehensive view of its functional layout and interactions. The patient subsystem comprises three primary pages: the home page, the rehabilitation page, and the account page. Each page serves distinct functions to cater to the diverse needs of patients within the Tele-DM application. The home page is a comprehensive repository of crucial health data, including the patient's HbA1C levels, height, weight, and exercise schedule, all conveniently displayed on a calendar. Meanwhile, the rehabilitation page provides various resources to facilitate assisted PA. Patients can access instructional videos and assessments tailored to their rehabilitation journey.

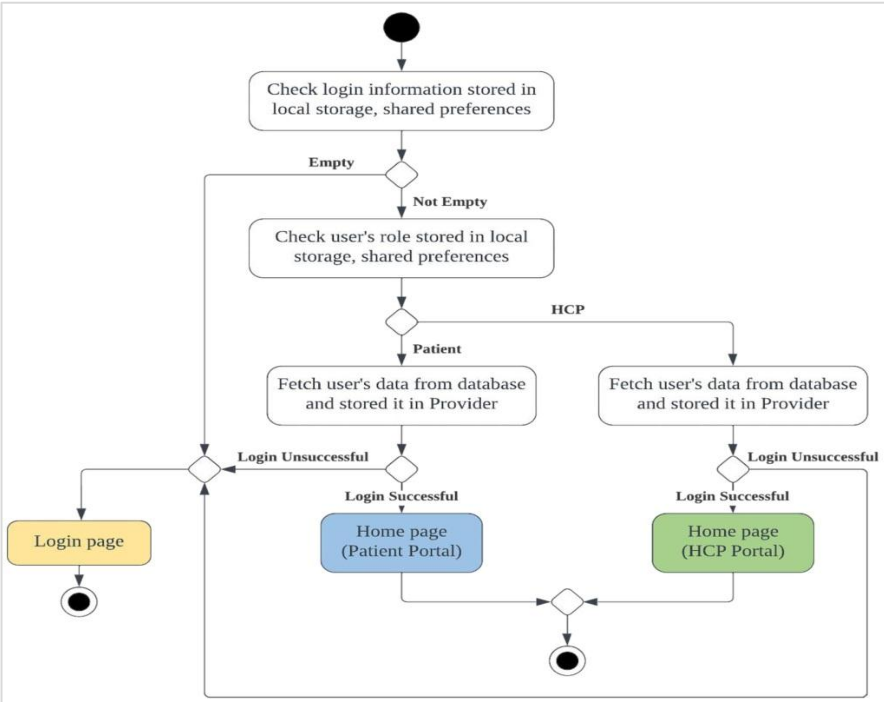


Figure 6 UML activity diagram for splash screen

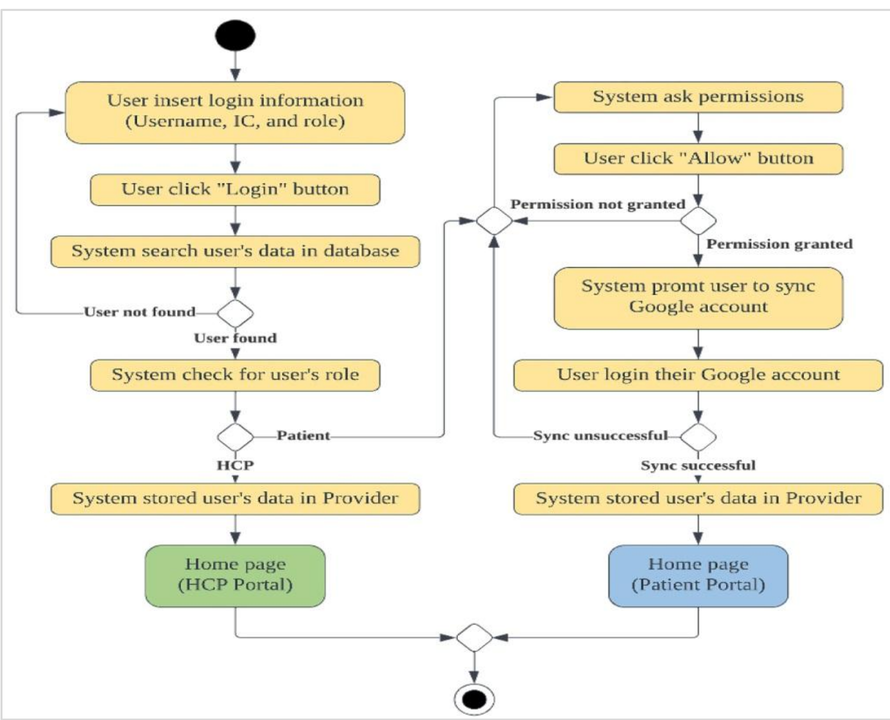


Figure 7 The UML activity on the login page

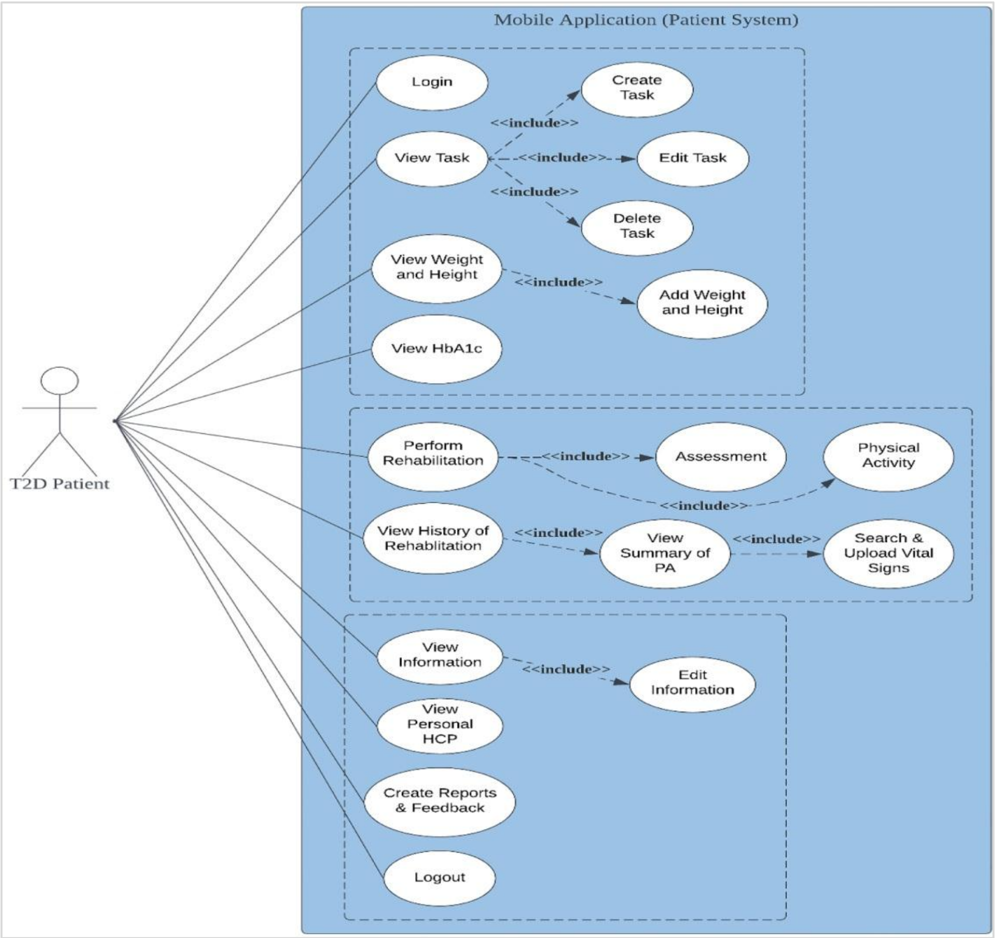


Figure 8 UML activity for patient portal

Additionally, this page houses a repository of the patient's rehabilitation history. It offers a dedicated section for the patient and the HCPs to document feedback and progress summaries. Lastly, the account page is a central hub for personalisation and administrative features. Patients can manage page settings, access information about their appointed HCP, view login details, and provide feedback on their experience with Tele-DM. Collectively, these three pages form an integral part of the patient subsystem, empowering patients with valuable health insights, rehabilitative resources, and convenient account management capabilities within the Tele-DM application.

3.5.2The admin and HCP portals

In contrast to the patient subsystem, the HCP, and admin portals exhibit relatively lower complexity. *Figure 9* shows the UML activity for the admin portal. The admin's role is limited to login authorisation and access to non-sensitive information related to HCPs and patients. However, in the event of unintended data corruption affecting sensitive information concerning HCPs and patients, the admin can access the database system for resolution and recovery. Additionally, the administrator can create new users for HCPs. By clicking the logout button, the actor can return to the HCP portal.

In *Figure 10*, the UML use case diagram for the HCP portal is depicted. The primary actors in the diagram are the HCPs or administrators. In the portal, the actor can monitor the list of HCP's assigned patients. Next, by clicking the name of the patient displayed on the list, the system opens the "Patient Home" page. Here, the actor can access detailed information about the patient, encompassing rehabilitation history, task, height, weight progress, HbA1c progress, reports, and feedback.

3.6Performance analysis

The final purpose of this study is to assess the performance of a mobile app for T2D therapy. This section describes a comprehensive testing strategy for assessing the application's performance. The study consists of two tests: apps functionality test and user acceptability test. Firstly, functionality testing analyses the system's ability to perform CRUD actions and features. Initially, the functionality test the performance of the data fecthing from the smartwatch. The test involved the oparation of transferring vital signs data from smartwatches to the mobile application, using intermediary apps like Zepp Life and Google Fit. Then, the functionality testing is continued to evaluate the app's performance across various operations and features. The features that were tested are the data flow analysis and data analysis as well as performance. In the former, the study examined the data flow between the front-end and back-end systems, specifically looking at the interaction between the database, Heroku server, and the Tele-DM mobile application. Test cases were designed for create(), read(), update(), and delete() operations. While the latter, the goal was to understand the coherence and consistency of data transfer across these components, assessing system integrity and its performance. Secondly, user acceptance testing comprises soliciting feedback from users via online surveys. A variety of surveys were produced, with one set of questionnaires designed for T2D patients to get their feedback on utilising the Tele-DM as part of their remote rehabilitation. The second set was designed to collect feedback from the HCP while performing remote rehabilitation with this app. For this test, 14 respondents have been chosen to fill the survey form. The respondents are the T2D patients and HCPs involved in this study. This testing aimed to assess various aspects of the app's usability, functionality, and effectiveness from the user's perspective. The key areas that have been tested are the app stability, the opening speed of the app, the speed of the PA video playback, the usability of the remote rehabilitation program, the functionality of the HPC portal and the remote monitoring of patient during activity feature. In this survey, the participants were asked to rate various features and aspects of the app on a scale (e.g., 1 to 5 stars), providing quantitative data on user satisfaction. In addition to ratings, participants likely had the opportunity to provide open-ended feedback on their experiences, offering qualitative insights into the app's performance and areas for improvement.

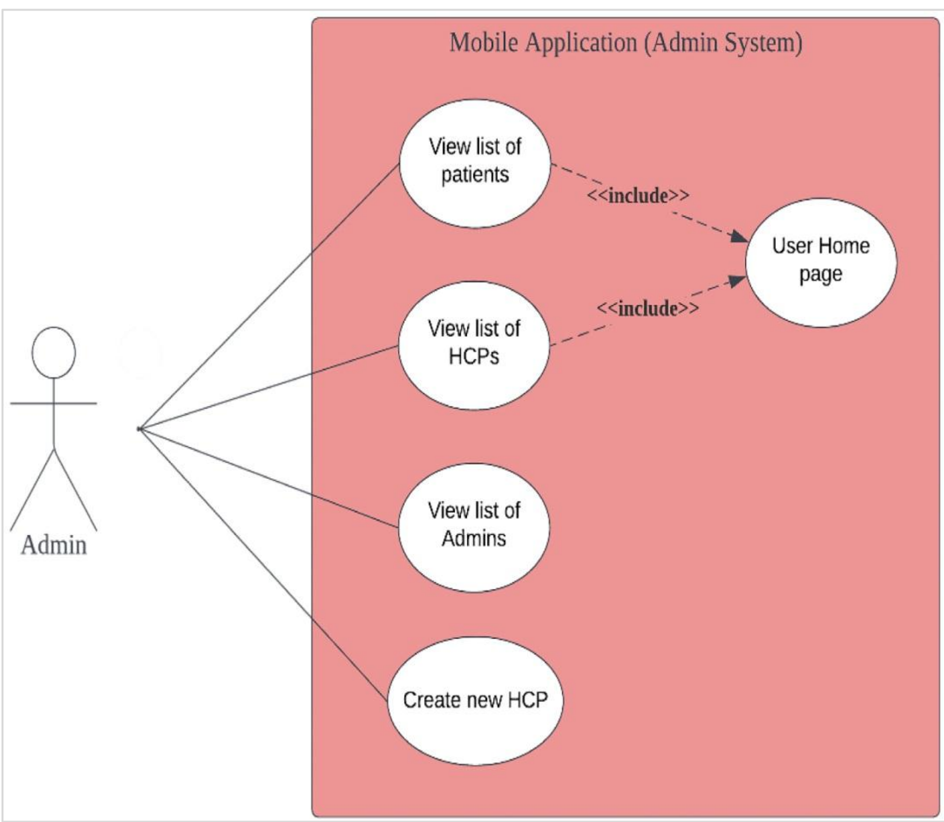


Figure 9 UML activity for admin portal

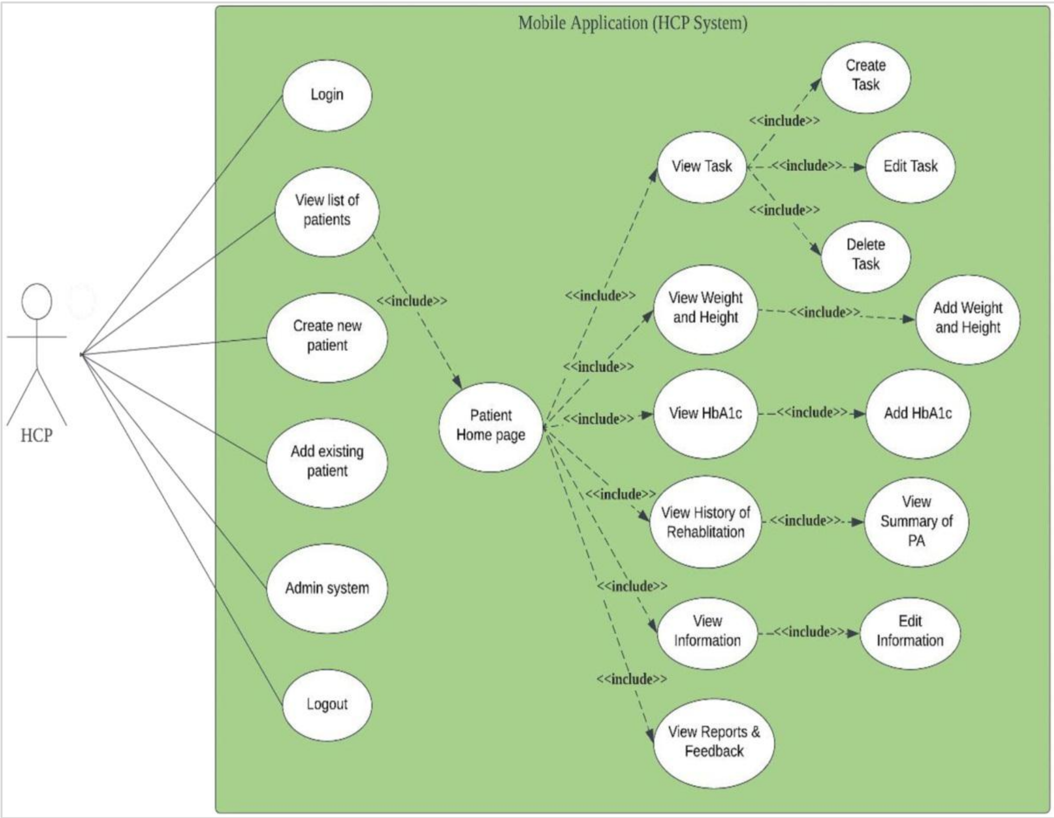


Figure 10 UML activity for HCP portal

4.Results

4.1Comparative analysis between Tele-DM and other mHealth applications for T2D patients

Table 4 presents a detailed comparison of the Tele-DM mobile application with other existing mHealth tools. It outlines the distinctive features and functions of Tele-DM in comparison to these similar tools. Tele-DM offers a comprehensive range of PA options, including aerobic (22 activities) and resistance (27 activities) exercises. This extensive variety may contribute to higher user engagement as it caters to diverse preferences and needs. In comparison with other mHealth tools, such as D'LITE, mDiab, BlueStar, and others, they are primarily focused on SR or specific types of physical activities like walking or brisk walking. Tele-DM's broader selection may enhance user engagement by providing more choices.

Table 4 Tele-DM versus previous mhealth

References	mHealth applications	PA	Available Portal	Vital signs monitoring	Other significant features
	Tele-DM	Aerobic (22 activity) and resistance (27 activity) exercise.	Patient, HCP, and administrator.	Monitor steps, calories burned, and heart rate during PA using the smartwatch.	SR weight and blood glucose, and daily tasks calendar.
[1]	D'LITE	SR, walking.	Patient.	Monitor steps using the phone's pedometer.	Blood glucose and weight monitoring, and chat function.
[2]	mDiab	Brisk walking.	Patient.	None.	Weight tracker.
[23]	BlueStar	SR.	Patient.	None.	Medication reminders, diabetes, and diet videos.
[36]	Time2Focus	SR.	Patient.	None.	Glucose monitoring, Education video on eating

References	mHealth applications	PA	Available Portal	Vital signs monitoring	Other significant features
					healthy.
[37]	Health2Sync	SR.	Patient.	None.	SR diet and medication.
[39]	DiaSocial	SR, walking.	Patient.	Monitor steps using the phone's pedometer.	SR food intake.
[40]	GlycoLeap	SR, walking.	Patient.	Monitor steps using the phone's pedometer.	Online health lesson, Blood glucose, and weight monitoring.
[41]	LIBIT	SR.	Patient.	None.	Blood glucose and weight monitoring.
[42]	Triabetes	SR.	Patient.	None.	Sets individual goals for blood glucose, weight, etc.
[43]	iCareD	SR.	Patient.	None.	Healthy diet videos.
[44]	DSMES	SR.	Patient.	None.	Medication reminders.

Furthermore, Tele-DM offers three distinct interfaces for patients, HCPs, and administrators. This multi-portal method proposes a comprehensive and collaborative system encompassing multiple stakeholders, which could lead to more successful T2D management. In contrast, some mHealth technologies, such as D'LITE, mDiab, and BlueStar, primarily provide patient portals. Tele-DM's portals for HCPs and administrators improve coordination and communication among the various parties involved in diabetes treatment. Tele-DM measures vital markers such as steps, calories burned, and heart rate during physical exercise using a smartwatch. This real-time monitoring feature adds a dynamic layer to T2D management, allowing users and healthcare practitioners to examine the immediate impact of PA on vital signs. Other apps, such as D'LITE, DiaSocial, and GlycoLeap, track steps using the phone's pedometer. However, the use of smartwatch technology for real-time vital sign monitoring distinguishes Tele-DM, potentially providing more accurate and timely information than current mHealth applications for T2D patients. In addition, Tele-DM contains SR weight and blood glucose levels, a daily task calendar, and a selection of aerobic and resistance exercises. This comprehensive strategy seeks to address several elements of T2D management, providing a more holistic and personalised experience than existing mHealth applications. The effectiveness of mHealth tools in managing T2D and satisfying users is determined by a variety of criteria, including tool usability, accessibility, and feature alignment with user demands. Because of this, Tele-DM's PA alternatives, real-time monitoring, and multi-portal approach may improve user engagement and satisfaction. The incorporation of educational information and daily task management reinforces a user-centered approach to T2D management. Thus, Tele-DM's strategy may contribute to a more engaging and satisfying user experience than other mHealth products with a narrower focus.

In summary, Tele-DM stands out for its extensive PA options, multi-portal approach, real-time vital signs monitoring, and a combination of features supporting holistic T2D management. While other mHealth tools may excel in specific features, Tele-DM's comprehensive design suggests a promising approach to user engagement, effectiveness in managing T2D, and overall user satisfaction. Further user studies and feedback collection will be essential to validate these observations and continuously improve Tele-DM based on user needs and preferences.

4.2Assessment of unauthorized login

When an incorrect password is entered in a Tele-DM mobile application, the ensuing outcome serves as a critical aspect of user authentication and security. The application's response to an erroneous login attempt as shown in *Figure 11* to enhance security measures and protect user accounts. Rather than allowing unlimited successive incorrect entries, the Tele-DM mobile application implements restrictions by temporarily locking the account from the authorized person. The display of specific authorization information, such as an error message, serves to inform the user about the nature of the mistake. This approach not only aids in preventing unauthorized access but also provides a user-friendly experience by guiding individuals on rectifying their login errors. Furthermore, the implementation of limitations on login attempts helps mitigate the risk of brute force attacks, where an attacker systematically tries various passwords to gain unauthorized access. Overall, the application's response to incorrect password inputs plays a crucial role in maintaining both security and user-friendly interaction.

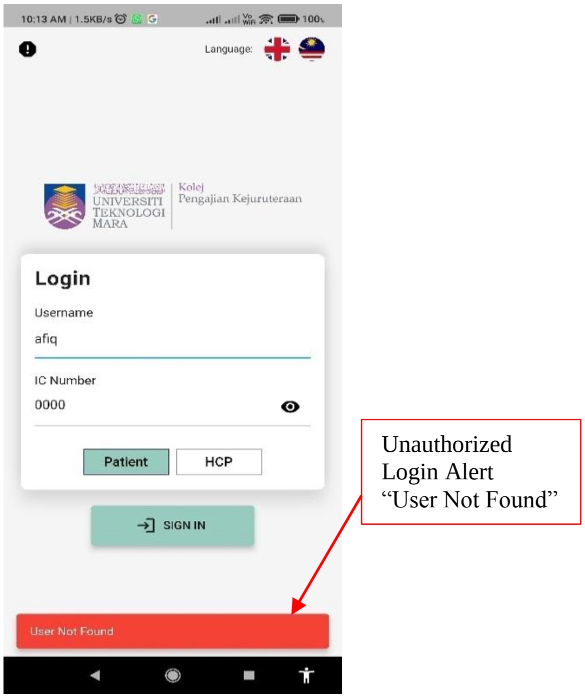


Figure 11 Unauthorized individuals are prevented from logging in by password protection

4.3The evaluation of data transfer between the front-end and back-end systems

This section compares data between the front and back-end systems, including a study of data flow via the database, Heroku server, and Tele-DM mobile app. The examination's goal is to provide a thorough understanding of the coherence and consistency of data between these critical components, revealing light on the overall system integrity and performance. *Figure 12* shows an example of user data saved in a MongoDB database. Here, the data is referred to as a document, with specific parameters such as rolePatient labeled as fields. The next step is to retrieve the document from the mobile application using the read (CRUD) operation, as shown in *Figure 13*, which displays the JSON output of the HTTP API endpoint using Postman software. These data are then stored in the Provider, the state management tool, and shown in the Tele-DM mobile application, as illustrated in *Figure 14*. As a result, using Provider enables accurate synchronisation between the mobile application and the database, resulting in consistently displayed information.

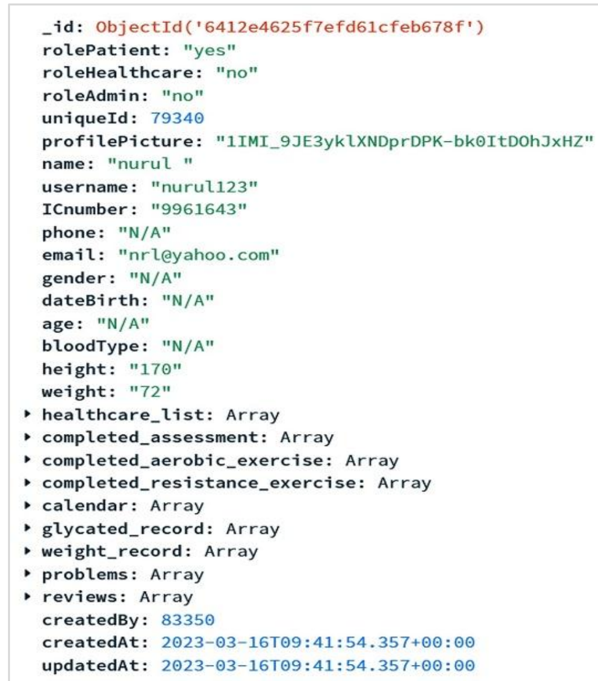


Figure 12 Example of data saved in MongoDB

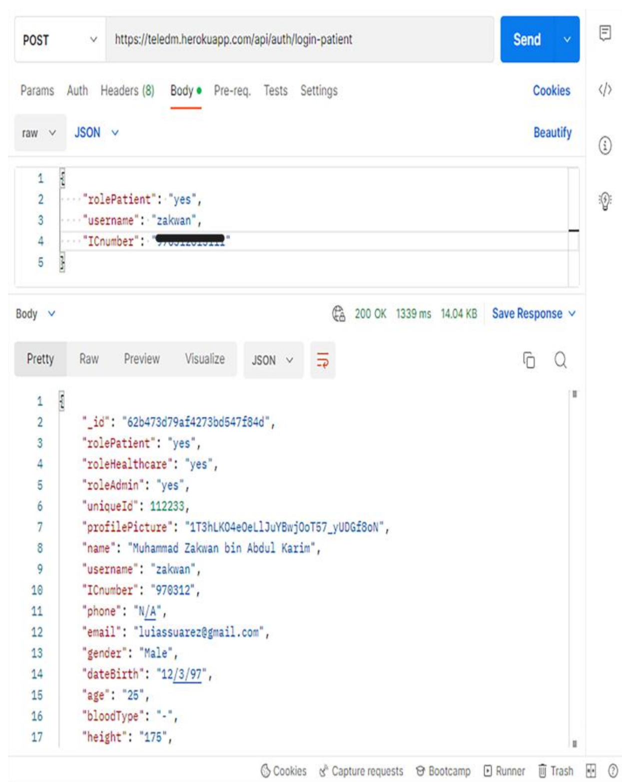


Figure 13 The JSON output of the HTTP API endpoint using postman software for CRUD operation

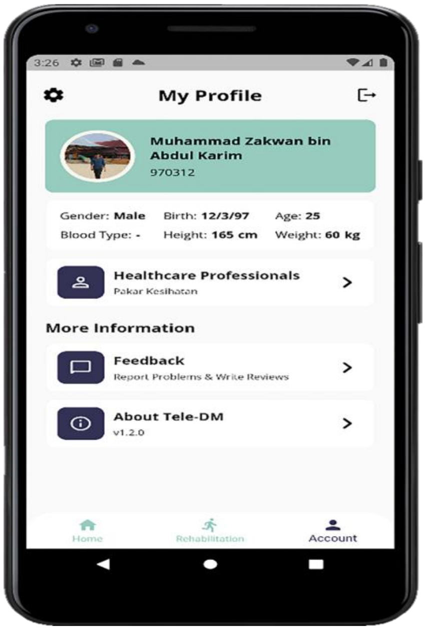
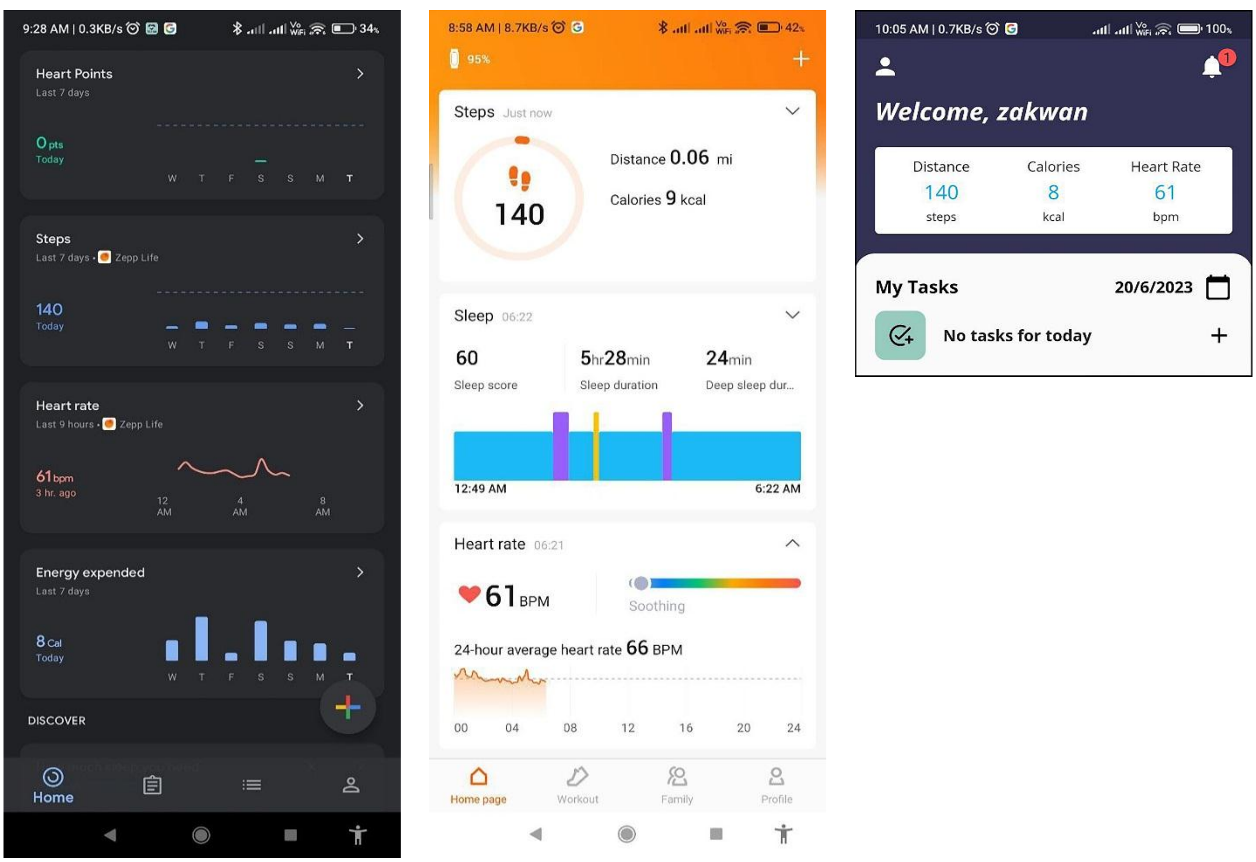


Figure 14 The retrieved data from the mongo DB is displayed in the Tele-DM mobile application

4.4 The evaluation of the data fetching from smartwatch to Tele-DM mobile application

Figure 15(c) depicts the vital signs shown on the developed mobile application, whereas *Figures 15(a)* and *15(b)* depict vital signs data from the Zepp Life and Google Fit smartphone applications, respectively. The Zepp Life mobile application displays vital sign data acquired straight from the smartwatch, indicating a total of 140 steps, 9 kcal expended, and the most recent heart rate of 61 bpm. These vital signs data are synchronised across all mobile applications. However, there is a tiny difference in the calories burned value between Zepp Life and Google Fit, with Google Fit showing 8 kcal rather than 9 kcal. This disparity can be traced to the rounding up of numbers between the two programmes. These findings demonstrate the successful transmission of vital sign data from the smartwatch to the built mobile application.



(a) (b) (c)

Figure 15 Vital Signs Data transfer from smartwatch directly to a) Zepp Life application via Bluetooth connection and then transferred to buffer application, b) Google Fit Application, and finally to (c) Tele-DM mobile application

4.5 The functionality test on Tele-DM applications

Table 5 shows the results of functionality analysis for CRUD operations, with an overall success rate of 23 out of 24 functions at 100%. However, the updateInformation() function had an 80% success rate. This reduced success rate is due to the function's responsibility for updating various user information, such as full name, username, email address, age, and so on. While some of these data are kept as strings in the MongoDB database, others are labeled as integers in the mobile application. The disparity resulted in problems when the mobile application attempted to convert strings to integers due to incorrect characters saved by users. Addressing this issue in the future entails incorporating conditions into the mobile application to detect and handle incorrect characters submitted by users. The remaining functionalities earned an amazing 100% success rate, highlighting the rigorous and thorough development approach. This result demonstrates the system's robust functionality, which ensures the consistent execution of CRUD operations across multiple components of the mobile application. Next, complete functionality testing for the mobile application's features was carried out, and the results are shown in *Table 6*. *Table 6* notably shows the elements that include the splash screen, the 'Login' page, and the three main portals: patient, HCP, and admin. The findings in the table show a remarkable 100 percent success rate across all aspects. The high success rate demonstrates the application's dependability and provides insights into its sturdy architecture and features.

Table 5 Functionality testing for CRUD operations in data management

S. No.	Operations	Result (%)	
		Success	**Failure**
	Create	-	-
1	*createPatient()*	100	0
2	*createHcp()*	100	0
3	*createAdmin()*	100	0
	Read	-	-
4	*displayUser()*	100	0
5	*loginPatientPortal()*	100	0
6	*loginHcpPortal()*	100	0
7	*loginAdminPortal()*	100	0
	Update	-	-
8	*updateInformation()*	80	20
9	*updateHeight()*	100	0
10	*updateWeight()*	100	0
11	*addHcpList()*	80	20
12	*removeHcpList()*	100	0
13	*createCalendar()*	100	0
14	*editCalendar()*	100	0
15	*deleteCalendar()*	100	0
16	*createGlycated()*	100	0
17	*createReview()*	100	0
18	*createProblem()*	100	0
19	*createAssessment()*	100	0
20	*createAerobic()*	100	0
21	*createHeartAerobic()*	100	0
22	*createResistance()*	100	0
23	*createHeartResistance()*	100	0
	Delete	-	-
24	*deleteUser()*	100	0

Table 6 Functionality testing for mobile application’s features

S. No.	Feature	Result (%)	
		Success	**Failure**
	Splash screen	-	-
1	“Login” page	100	0
2	Patient portal	100	0

S. No.	Feature	Result (%)	
		Success	Failure
3	HCP portal	100	0
	Login page	-	-
4	Text fields	100	0
5	Button language (MY)	100	0
6	Button language (EN)	100	0
7	Alert – When the user does not exist in the database	100	0
8	Dialog - Google sync	-	-
9	Dialog - Permissions	100	0
10	‘Patient’ button	100	0
11	‘HCP’ button	100	0
	Patient portal – ‘Home’ page	-	-
12	Daily vital signs	100	0
13	Daily tasks	100	0
14	‘Calendar’ button	100	0
15	‘Weight and Height’ button	100	0
	Patient portal – ‘Rehabilitation’ page	-	-
16	‘History’ button	100	0
17	‘Assessments’ button	100	0
18	‘Exercises’ button	100	0
	Patient portal – ‘Account’ page	-	-
19	‘Gear’ button	100	0
20	‘Sign Out’ button	100	0
21	‘HCP list’ button	100	0
22	‘Reports and Feedback’ button	100	0
23	‘About Apps’ button	100	0
	Patient portal – Sign Out	-	-
24	‘Sign out’ button	100	0
25	Dialog - Confirmation	100	0
	HCP portal – ‘Home’ page	-	-
26	Drawer button	100	0
27	Search field	100	0
28	‘Refresh’ button	100	0
29	‘Patient name’ button	100	0
	HCP portal – Drawer	-	-
30	‘Register new patient’ button	100	0
31	‘Add existing patient’ button	100	0
32	‘Admin Login’ button	100	0
33	‘Report problem’ button	100	0
34	‘Sign out’ button	100	0
35	‘Sign out’ button	100	0
36	Dialog - Confirmation	100	0
37	‘Continue’’ button	100	0
	Admin portal – ‘Home’ page	-	-
38	‘Back’ button	100	0
39	Tabs (Patient/HCP)	100	0
40	Drawer button	100	0
41	HCP portal – Drawer	100	0
42	‘Register new HCP’ button	100	0
43	‘View admin’ button	100	0

Figure 14 shows the comprehensive results of the testing, including the response time (RT), which indicates a direct relationship between the magnitude of the user's data and the time elapsed. The RT increases in proportion to the size of the user's data. The x-axis in this figure depicts the range of data sizes, from 1.50KB to 400.5KB, while the y-axis represents the RT measured in milliseconds, from 1332ms to 4509ms. In conclusion, the charts' trendlines confirm the idea of a positive association

between the magnitude of the user's data and the average RT. This suggests that higher data sizes necessitate a longer processing time when launching the mobile application. These findings help us analyse the performance of the mobile application's login function. Furthermore, it assists researchers or developers in implementing various types of methods in the login function of their mobile applications to avoid this issue. *Figure 16* shows the comprehensive results of the testing, including the RT, which indicates a direct relationship between the magnitude of the user's data and the time elapsed. The RT increases in proportion to the size of the user's data. The x-axis in this figure depicts the range of data sizes, from 1.50KB to 400.5KB, while the y-axis represents the RT measured in milliseconds, from 1332ms to 4509ms. In conclusion, the charts' trendlines confirm the idea of a positive association between the magnitude of the user's data and the average RT. This suggests that higher data sizes necessitate a longer processing time when launching the mobile application. These findings help us analyse the performance of the mobile application's login function. Furthermore, it assists researchers or developers in implementing various types of methods in the login function of their mobile applications to avoid this issue.

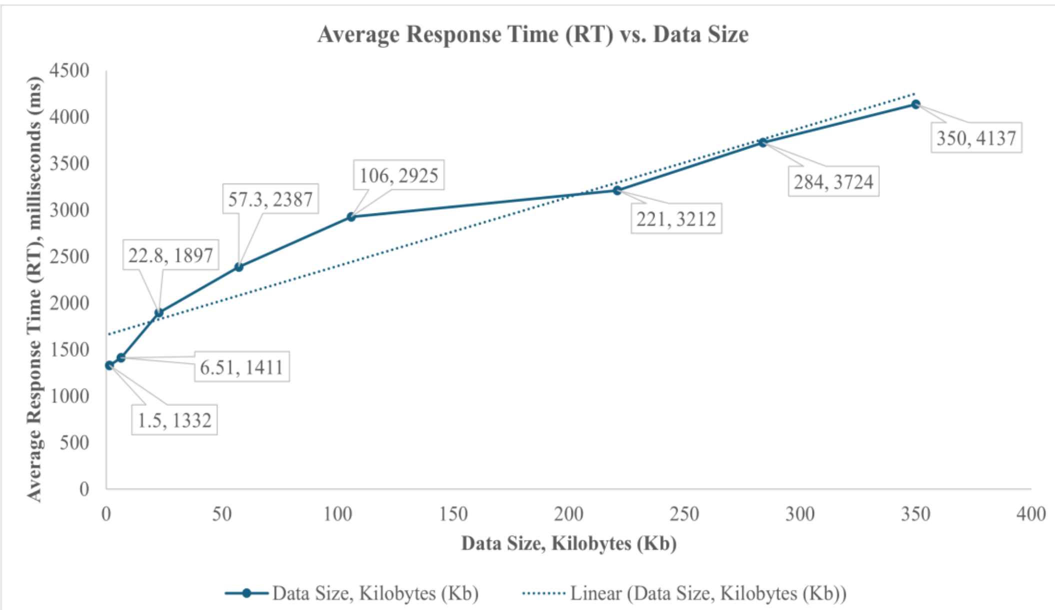


Figure 16 The correlation between the size of the data and its RT during the data retrieval operation

4.6 The result of the user acceptance test

Based on the responses in *Figure 17*, it appears that the mobile application has a good track record for app stability. Out of the 14 respondents, 13 reported that they had never experienced the application close itself for no apparent reason while they were using it. This suggests that the programme functions as planned and provides a consistent user experience. However, one respondent, who is also a participant in the effectiveness programme, reported instances of the application closing. The actual cause of this occurrence is unknown, although it is suspected that it is related to limited device storage on the patient's device. The majority of respondents were satisfied with the mobile application's opening speed, which is shown in *Figure 18*. Six of the fourteen respondents gave the application a five-star rating, indicating that they were highly pleased with its opening speed. Overall, the app's opening speed received an average rating of 3.8 stars out of 5. It is worth mentioning that one respondent, an early participant in the programme, gave the opening speed one star. The cause for the ranking is unknown, although it is likely that the respondent has a sluggish internet connection.

However, several customers expressed worry about the pace at which movies played on the Tele-DM mobile application. According to *Figure 19*, seven of the 14 respondents gave five stars, suggesting that they were extremely delighted with the speed with which any movie within the application could be played. The average rating for the speed of playing any video was 3.9 stars out of 5, which is a relatively high score. One possibility of the unsatisfactory rating is that the respondents' devices may affect the video playback performance. The responses from the 14 participants show that the majority of them found the rehabilitation programme straightforward to understand, with 8 giving it a 5-star rating as shown in *Figure 20*. The average rating given by the user on the distress level in following the rehabilitation program provided by the Tele-DM is 0.75, which is low. This shows that the programme could be well-designed and user-friendly. However, it would be beneficial to explore the feedback provided by individuals who gave lower ratings to find areas where improvements could be made to improve understanding and user engagement.

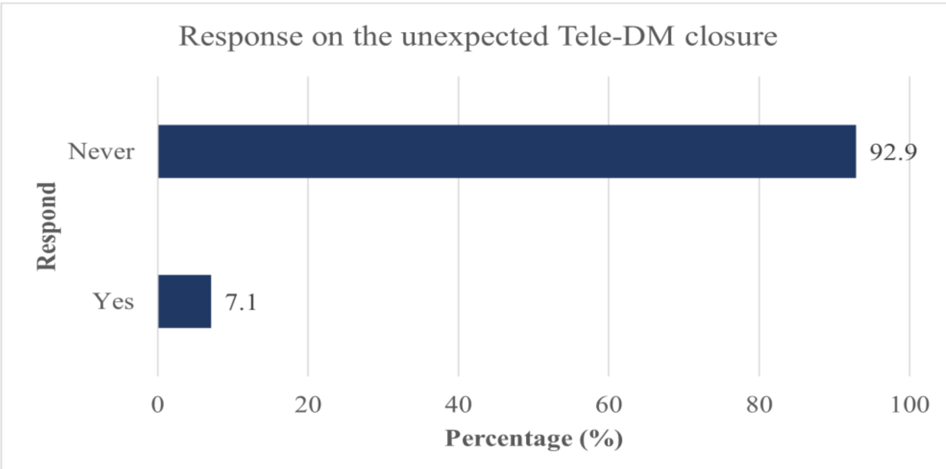


Figure 17 The user response to the unexpected Tele-DM closure problem

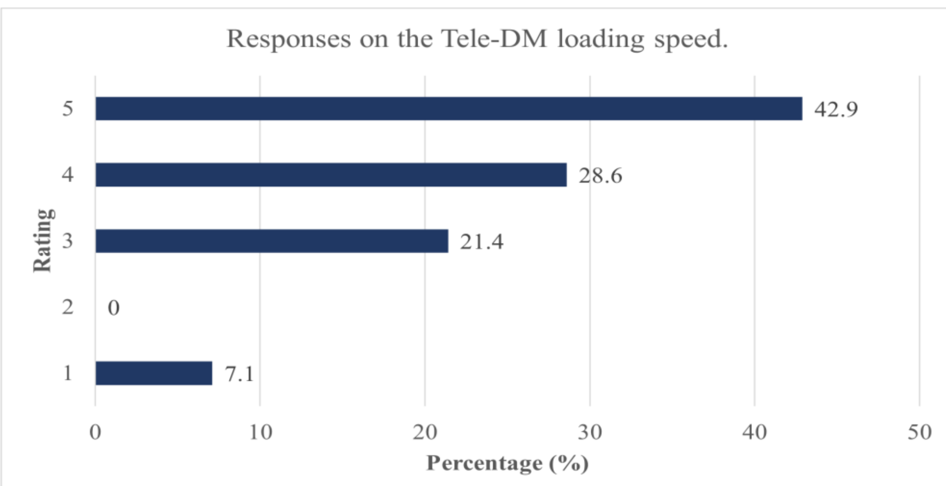


Figure 18 The user response on the Tele-DM application loading speed

Figure 21 depicts the responses to the difficulties of comprehending the "Search & Upload" feature for updating vital signs in the Tele-DM. It appears that most respondents found it difficult to utilise. Seven of the 14 respondents selected four stars, while one voted five. The average rating for this feature was 2.86 stars, indicating room for improvement. According to the feedback, consumers had difficulty navigating the functionality and would benefit from more precise instructions on how to utilise it.

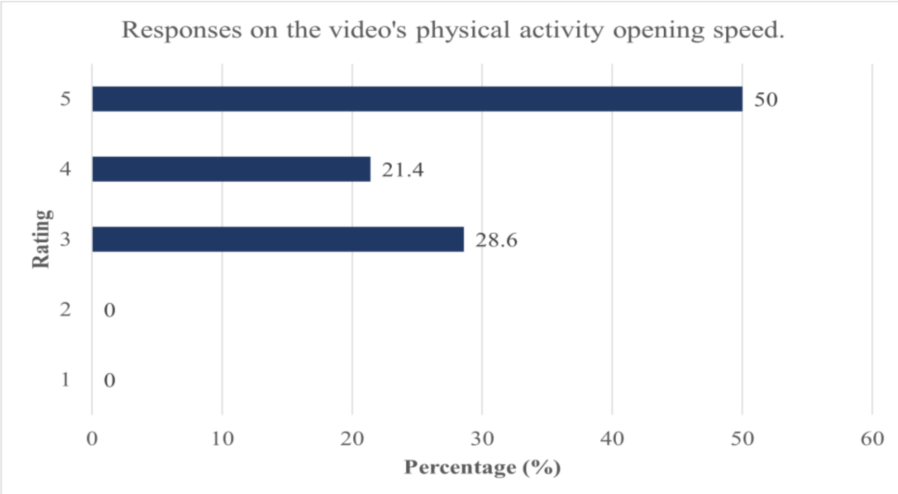


Figure 19 The user's reaction to the playback speed of the PA videos

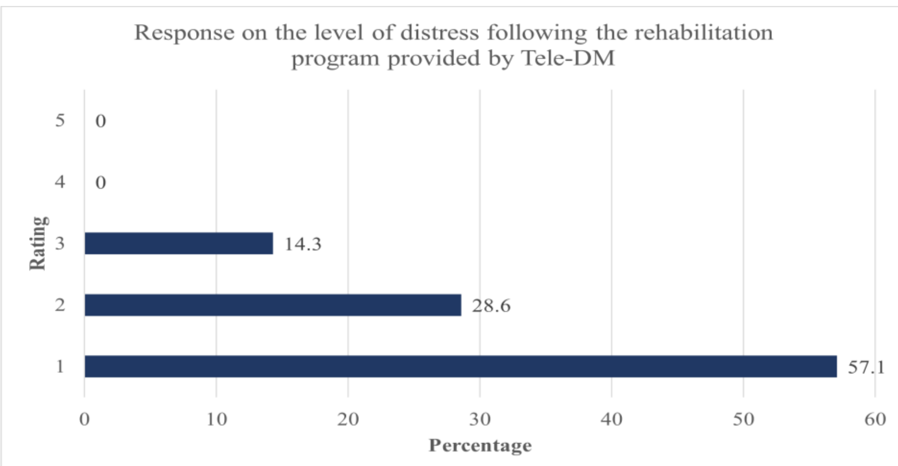


Figure 20 The user's feedback regarding the distress level while adhering to the provided rehabilitation program via the Tele-DM application

Nonetheless, respondents provided positive feedback on the 'Patient List' option of the HCP portal. *Figure 22* depicts a positive evaluation. Four out of seven respondents voted for five stars, while three voted for four. This suggests that the majority of respondents were quite pleased with the patient list dashboard's functionality and user experience. The "Patient List" tab has an average rating of 4.7 stars. The dashboard received high reviews, indicating that it is efficient, user-friendly, and fits the demands of HCPs. Respondents gave positive feedback on the Tele-DM application's bidirectional communication for monitoring patients during activity. Out of seven respondents, which are the HCPs, five voted for five stars and two voted for four stars, suggesting that the majority of respondents were quite satisfied with the process of monitoring patients during exercise, as shown in *Figure 23*. Monitoring patients' exercise levels is critical for HCPs to understand their patients' development and give appropriate care. The excellent ratings for the process indicate that the system is well-designed, user-friendly, and satisfies the demands of HCPs. The average rating for monitoring patients during exercise is 4.86 stars.

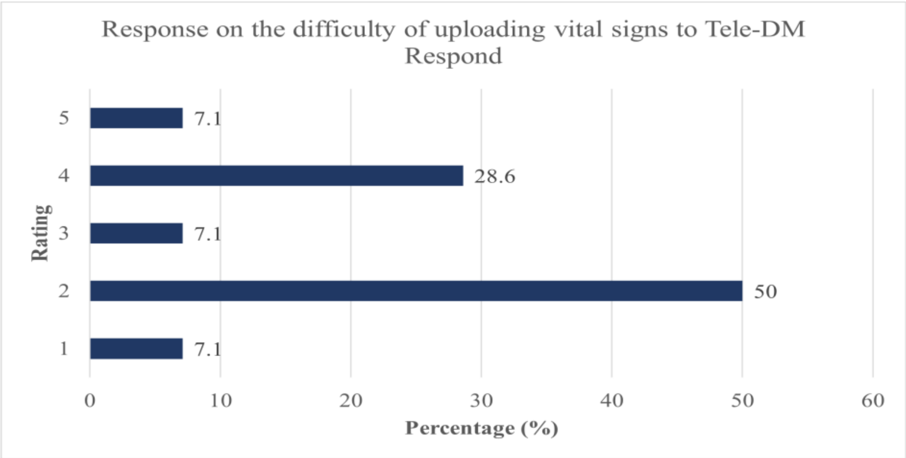


Figure 21 The user response on the difficulty in understanding the vital signs upload method in Tele-DM

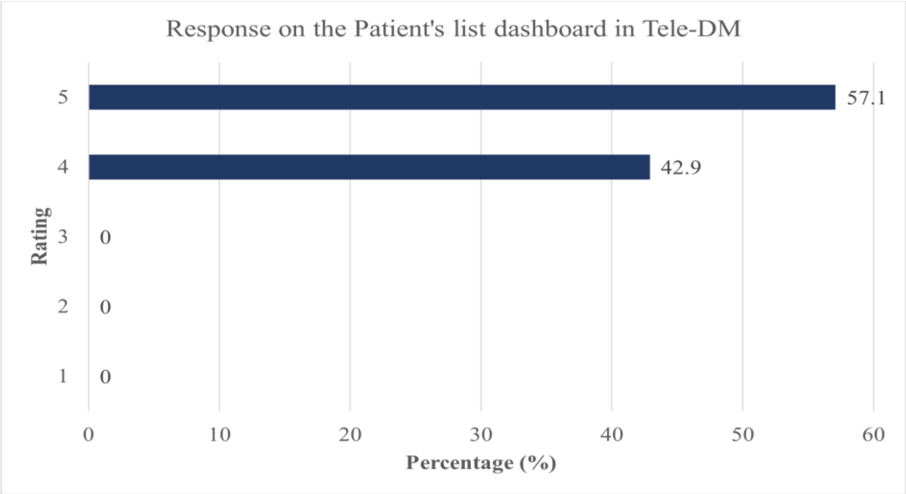


Figure 22 The user response on the Patient's list dashboard in the HCP portal

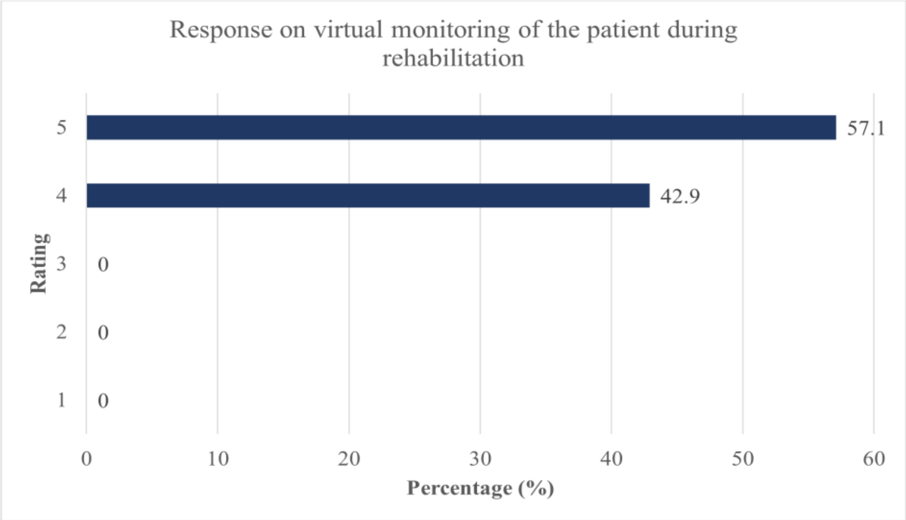


Figure 23 The HCPs' feedback on monitoring patients virtually during rehabilitation through the Tele-DM application

These findings lend credence to the built Tele-DM mobile application by providing favourable user feedback and demonstrating its capacity to meet its objectives efficiently. While there are several areas for improvement, such as UIs, opening speed, navigation ease, and specific functionality, feedback indicates that the mobile application has the potential to be a user-friendly platform for T2D self-management. By addressing these areas for improvement and expanding on the good features identified by respondents, the mobile application can continue to improve user satisfaction and serve as a valuable tool for diabetes care in the future. In conclusion, the overall rating received from the user responses for Tele-DM applications is 4.03.

In summary, Tele-DM stands out from other mHealth applications due to its complete features, which promote user engagement, effectiveness in managing T2D, and user happiness. The application provides a wide range of physical activities, including aerobic and resistance exercises, giving users a variety of alternatives that may help to increase participation. Notably, Tele-DM highlights access to three unique portals for patients, HCPs, and administrators, enabling collaboration and communication among diverse stakeholders involved in T2D management. The addition of real-time vital sign monitoring via a smartwatch distinguishes Tele-DM, allowing users and HCPs to examine the immediate impact of PA on metrics such as steps, calories burned, and heart rate. The application also includes features like SR weight and blood glucose monitoring, a daily task calendar, and a variety of exercises, providing a comprehensive and personalised approach to T2D management. While various mHealth solutions may excel in individual areas, Tele-comprehensive DM's architecture indicates a possible avenue for improving user engagement, T2D management effectiveness, and overall user happiness.

5.Discussion

The comparative analysis between Tele-DM and other mHealth applications for T2D patients highlights several key features that set Tele-DM apart from its counterparts. Notably, Tele-DM offers a comprehensive range of PA options, including both aerobic and resistance exercises, which cater to diverse user preferences and needs. This extensive variety of PA options may contribute to higher user engagement and adherence to exercise regimens, ultimately promoting better management of T2D. In contrast, many existing mHealth tools focus primarily on specific types of PA or SR data, which may limit their effectiveness in engaging users and addressing the multifaceted aspects of T2D management. Furthermore, Tele-DM's multi-portal approach, which includes interfaces for patients, HCPs, and administrators, facilitates collaborative care and communication among stakeholders involved in T2D management. This comprehensive and inclusive system may enhance coordination, decision-making, and overall patient outcomes by ensuring that relevant information is accessible to all parties involved in the care process. In contrast, some mHealth applications only provide patient portals, which may hinder effective communication and collaboration between patients and their HCPs. The incorporation of real-time vital sign monitoring using smartwatch technology is another distinguishing feature of Tele-DM. By tracking metrics such as steps, calories burned, and heart rate during PA. Tele-DM allows users and HCPs to assess the immediate impact of PA on their health and adjust their behavior accordingly. This dynamic feedback mechanism may motivate users to engage in regular exercise and make informed decisions about their lifestyle choices, thereby contributing to improved T2D management outcomes. In contrast, many existing mHealth tools rely on SR data or basic monitoring devices, which may lack the accuracy and timeliness of real-time vital sign monitoring. Additionally, Tele-DM's comprehensive approach to T2D management, which includes features such as SR weight and blood glucose monitoring, daily task calendars, and a variety of educational resources, provides users with a holistic and personalized experience. By addressing multiple aspects of T2D management in a single platform, Tele-DM aims to empower users to take control of their health and make informed decisions about their care. This integrated approach may enhance user satisfaction and adherence to treatment regimens, ultimately leading to improved health outcomes for individuals managing T2D.

While Tele-DM demonstrates several innovative features and potential benefits for T2D management, there are also limitations and areas for improvement that should be considered. Firstly, the effectiveness of Tele-DM in improving health outcomes and user satisfaction should be validated through rigorous empirical studies, including randomized controlled trials and longitudinal studies. While the results of user acceptance tests are promising, they may be subject to bias and may not accurately reflect the experiences of a broader population of T2D patients. Secondly, the usability and accessibility of Tele-DM for diverse user populations, including older adults and individuals with limited technological literacy, should be carefully evaluated. While the application's features may be appealing to tech-savvy users, it is essential to ensure that it remains accessible and user-friendly for all individuals managing T2D. This may require iterative design improvements and user feedback collection to address usability issues and optimize the user experience. Then, the security and privacy of user data within Tele-DM should be prioritized to maintain user trust and compliance with data protection regulations. While the implementation of restrictions on unauthorized login attempts is a positive step towards enhancing security measures, ongoing vigilance and updates are necessary to mitigate emerging cybersecurity threats and vulnerabilities. Additionally, clear policies and procedures for data handling, storage, and sharing should be established to protect user privacy and confidentiality. Finally, the scalability and sustainability of Tele-DM as a long-term solution for T2D management should be considered. As the user base grows and evolves, the application may need to accommodate increasing data volumes, user interactions, and feature requests. This may require ongoing investments in infrastructure, technology, and personnel to ensure that Tele-DM remains effective, reliable, and up-to-date in meeting the evolving needs of T2D patients and HCPs.

While Tele-DM shows promise as an innovative and comprehensive solution for T2D management, further research and development are needed to validate its effectiveness, improve usability, enhance security and privacy, and ensure long-term sustainability. By addressing these challenges and limitations, Tele-DM has the potential to revolutionize T2D care delivery and improve health outcomes for individuals living with this chronic condition.

A complete list of abbreviations is summarized in *Appendix I.*

6.Conclusion and future work

The Tele-DM mobile application provides a variety of functions, including thorough and precise instructions for personalised PAs. Furthermore, the application's smooth interface with smartwatches makes it easier to retrieve and analyse heart rate data during PA sessions. The primary purpose of the tailored PA component is to encourage patients to overcome sedentary tendencies and promote optimal diabetic self-management. Tele-DM allows HCPs to remotely monitor and evaluate the rehabilitation progress of people with T2D, providing a substantial benefit. The incorporation of remote monitoring into healthcare systems increases the effectiveness and accessibility of healthcare delivery, supporting more efficient and patient-centered treatment. In the future, there is an opportunity to improve the mobile application's UI, with a focus on fulfilling the needs and preferences of people with T2D, particularly the elderly. The rigorous collection of patient input will be critical in identifying potential features for the mobile application. This will improve the overall patient experience and expedite the rehabilitation process. The method of actively soliciting and implementing patient feedback iteratively can improve and optimise the application over time. This method ensures that the programme adapts to the changing demands and preferences of its users.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

This investigation employed two distinct datasets. The initial dataset was procured for the purpose of evaluating the efficacy of Tele-Diabetes Management (Tele-DM) applications, obtained from the Rehabilitation Center at the International Islamic University Malaysia (IIUM), Malaysia. This dataset comprised information from T2D patients who were enrolled in a three-month rehabilitation regimen utilizing the applications, as selected by HCPs. The availability of this dataset is restricted. The second dataset was collected to assess the acceptability of the Tele-DM applications among T2D patients and HCPs through a survey methodology. Similar to the first, this dataset is not available for public access, however, it may be obtained from the corresponding author upon submission of a reasonable request.

Author’s contributions statement

Muhammad Zakwan Abd Karim: Writing – original draft, synthesizing the research findings, literature review, theoretical framework, research findings, methodology, discussion points, and conclusions. **Norashikin M. Thamrin**: Supervision, offering guidance on study design, methodology, and data analysis, writing – review and editing. **Ruhizan Liza Ahmad Shauri**: Supervision, methodology, and data analysis, writing – review and editing. **Rozita Jailani**: Supervision, methodology, and data analysis, writing – review and editing. **Mohd Haidzir Abd Manaf**: Funding for the research project, Supervision, methodology, and data analysis, writing – review and editing. **Nurul Amirah Mustapa**: Data collection phase involving T2D patients, Writing – original draft, synthesizing the research findings, literature review, theoretical framework and research findings.

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Appendix I

S. No.	Abbreviation	Description
1	API	Application Programming Interface
2	COVID-19	Coronavirus Disease of 2019
3	CRUD	Create, Read, Update, Delete
4	CSS	Cascading Style Sheets
5	DBMS	Database Management System
6	D'LITE	Diabetes Lifestyle Intervention Using Technology Empowerment
7	DM	Diabetes Mellitus
8	ER	Entity-Relationship
9	GDM	Gestational Diabetes Mellitus
10	GUI	Graphical User Interface
11	HbA1c	Glycosylated Hemoglobin
12	HCPs	Healthcare Professionals
13	HTML	Hypertext Markup Language
14	HTTP	Hypertext Transport Protocol
15	IC	Identification Card
16	ID	Unique Identification
17	JSON	JavaScript Object Notation
18	mHealth	Mobile Health
19	PA	Physical Activity
20	RT	Response Time
21	SR	Self-Reported
22	T1D	Type-1 Diabetes
23	T2D	Type-2 Diabetes
24	Tele-DM	Tele-Diabetes Mellitus Management
25	UI	User Interface
26	UML	Unified Modeling Language
27	URI	Uniform Resource Identifier