Development of a Smartphone-Based mHealth Platform for Telerehabilitation

Wei-Ting Martin Lin, Bor-Shing Lin, *Senior Member, IEEE*, I-Jung Lee, and Si-Huei Lee

***Abstract*—Telerehabilitation is becoming increasingly valuable as a method for expanding medical services. The smartphone-based mHealth platform (SMPT) has been developed to provide high-quality remote rehabilitation through a smartphone and inertial measurement units. The SMPT uses smartphone as a main platform with connection to medical backend server to provide telerehabilitation. Patients would be referred to therapists to receive a tutorial of exercise technique prior to conducting their home exercise. Once patients begin their home exercises, they can report any problems instantly through the SMPT. The medical staff can adjust the exercise program according to patient feedback and the data collected by the SMPT. After completing the exercise program, patients visit their clinician for re-evaluation. A Service User Technology Acceptability Questionnaire from both medical professional and public perspective revealed a high level of agreement on enhanced care, increased accessibility, and satisfaction and a moderate level of agreement on the use of this platform as a substitute for traditional rehabilitation. Concerns about privacy and discomfort were low in the medical professional and public groups. Concerns about care personnel were also significantly different between the two groups. The SMPT is a promising system for providing telerehabilitation as an adjunct to traditional rehabilitation, which may result in improved outcomes compared with those achieved when using traditional rehabilitation alone.**

***Index Terms*—Telerehabilitation, smartphone, wearable device, therapeutic exercise, remote rehabilitation.**

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I. Introduction

TELEMEDICINE can be defined as the adoption of telecommunication technologies to provide medical information and services [1]. The focus on telemedicine is increasing because of the possibilities it offers for expanding the coverage of medical services. Telerehabilitation is an extension of telemedicine that involves delivering rehabilitation services remotely for certain medical conditions [2]. With the spread of COVID-19 worldwide, the importance of this technology has increased [3]. The traditional rehabilitation service is an outpatient treatment provided by certified therapists in the clinic. This treatment has several inherent limitations, including the length of time of the clinical visit, long periods of waiting between sessions, a lack of therapists, low accessibility for people with disabilities, and the lack of continuity in the rehabilitation after the patient returns home [4], [5]. Through the remote delivery of telerehabilitation, these limitations can be mostly overcome, and several studies have achieved positive results when using telerehabilitation to treat different diseases that limit patient physical function [6], [7], [8], [9], [10]. Consequently, telerehabilitation is being increasingly considered a valuable tool by medical providers and the wider society. The estimated global market size for this technology has been reported to be over $160 billion, and this market is expanding exponentially [9].

We developed a smartphone-based mHealth platform (SMPT) utilizing inertial measurement units (IMUs) to provide telerehabilitation acted as an adjunct to traditional rehabilitation. The aim of the SMPT is to extend the high-quality rehabilitation from hospital to home setting. Telerehabilitation can be delivered through several methods, including computer-based [12], [13], [14], [15], set-top-box-based [7], [16], [17], [18], and smartphone-based systems [11], [19], [20], [21]. Computer-based and set-top-box-based systems allow patients to access rehabilitation at home. Furthermore, these systems can meet patients' needs by providing different exercise programs with visual or audio instructions. However, computer-based and set-top-box-based telerehabilitation systems require additional equipment [20], [21], which is neither easily available nor portable. Although telecommunications applications, such as Skype and Teams, provide the other solution for telerehabilitation, the patients in need of rehabilitation are mainly the elderly, who exhibit a low likelihood of using the aforementioned technologies because of a lack of familiarity with them, the treatment effect of telerehabilitation might be attenuated [13]. As a result, we chose smartphone-based systems because smartphone-based systems allow patients to access rehabilitation at home without the aforementioned limitations. Smartphone ownership in 2020 was estimated to be 5.645 billion worldwide, and smartphone ownership is continuously increasing in developing countries [24]. The wide coverage of smartphones provides a potentially effective method to deliver telerehabilitation. Moreover, the availability, portability, and cost-effectiveness of smartphones, which do not require the purchase of additional equipment, contribute to their high acceptability among patients. Del Rosario *et al.* demonstrated the effectiveness of smartphone-based cardiac rehabilitation in conjunction with traditional rehabilitation for enhancing patient attendance [19]. A higher percentage of patients who received a smartphone-based intervention in addition to a traditional cardiac rehabilitation program completed half the training sessions compared with the patients in the control group. In a systemic review on the use of smartphone-based rehabilitation, an inertial measurement unit (IMU), which is primarily designed for posture monitoring, was the most frequently used technology [11]. The validity of IMUs for detecting human posture has been demonstrated in previous studies [25]. Hence, IMUs were the main monitoring tool for the SMPT.

Musculoskeletal diseases place a high socioeconomic and health burden on the elderly population, among whom the prevalence of these diseases is more than 80% [26]. Levels of physical activity and the range of motion are key factors in managing musculoskeletal diseases [27], [28]. IMUs are an effective tool for monitoring the joint position which is crucial for the rehabilitation process and quality of movement. On the other hand, the instant feedback features of IMUs allowed the in-time adjustment of the rehabilitation protocol. Many smartphone-based rehabilitation systems have exhibited positive results [29], [30], [31]. However, these systems only perform telerehabilitation for a single disease and are not designed to increase the number of sensors on the user, add new treatments, or adapt the rehabilitation exercise program [32], [33]. The SMPT can easily connect numerous sensors through Bluetooth and provide new exercise modules through a cloud server. This platform uses musculoskeletal diseases and adhesive capsulitis in musculoskeletal diseases as an implementation case due to its high prevalence in the general population [34]. But in the future, the system can extend to other diseases. Conventionally, ROM exercise is one of a common exercise treatment which would be prescribed to patients with adhesive capsulitis. Via the SMPT platform utilizing the IMUs, the medical professions could monitor and adjust the exercise in real time. Based on the similar concept, the SMPT can also be extended to other diseases. The SMPT has the following features: (1) a validated commercially available and affordable IMU with a smartphone-based platform; (2) an evolving therapeutic exercise database with multiple engaging exercises designed by certified therapists; (3) a monitoring and reporting system to allow medical providers to design and modify customized rehabilitation exercises, monitor patient progression, and receive patient feedback in real time; (4) a reward system to optimize patient motivation and enjoyment during the rehabilitation and maximize compliance; (5) a data analysis system for the evaluation of the effects of rehabilitation.

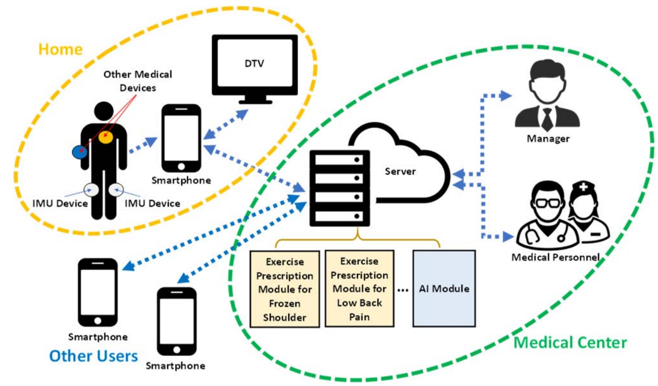

Fig. 1. Overview of the developed system.

II. METHODS

A. System Overview

The proposed SMPT for telerehabilitation consists of a smartphone, two IMUs, a digital television (DTV), and a server, as illustrated in Fig. 1. When a user wishes to perform a rehabilitation exercise, they first use the smartphone application (app) to connect to the IMUs through a Bluetooth interface and to the DTV through a high-definition multimedia interface or Wi-Fi. After the smartphone has successfully connected to the server in a hospital through Wi-Fi or a 4G or 5G network, the telerehabilitation program can be initiated. Besides the IMU device, other medical devices with Bluetooth interface could also be connected, for example, the sphygmomanometer. The senior physician who has higher authority in the medical center would be the system manager to help maintain the accounts of the system. The system is available to other users, patients using the same system, but each patient will have their own account. The patient can only access to their personal information on the system. Therefore, there is no ethical consideration of the system.

The software architecture of SMPT is presented in Fig. 2. The software contains the application on the smartphone and the backend program on the server. The functions of the application include Login Screen, My Tasks, Practice Mode, My Reward, My Devices, and IMU Power and Status Display. The functions of the backend program include Case Management, Personnel Management, Questionnaire Question Bank Management, IMU Location Management, Task Template Management, Rehabilitation Module Management, and Exercise Management and Classification.

B. Wearable Device

The SMPT uses two IMUs (MetaMotionR, MBIENTLAB, San Francisco, CA, USA) for movement detection, especially in relation to the range of motion of the target joint. The IMUs have a Velcro strap that can be easily attached to any part of the limbs and a small bag on the strap that can

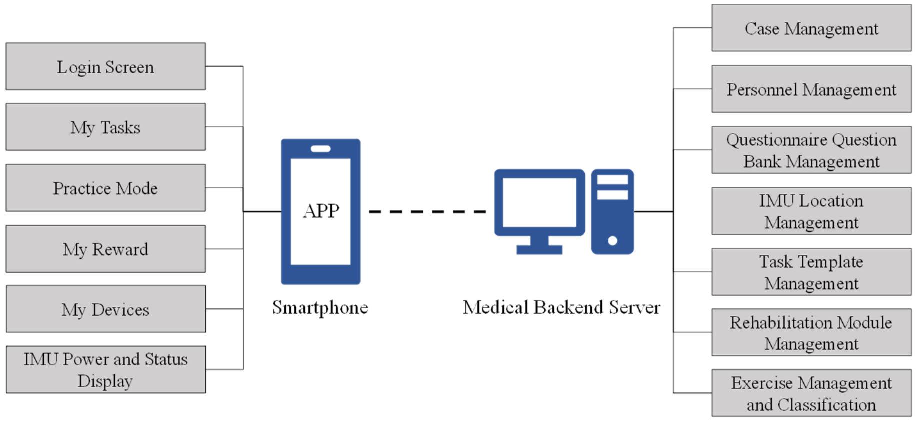

Fig. 2. Software architecture of the SMPT.

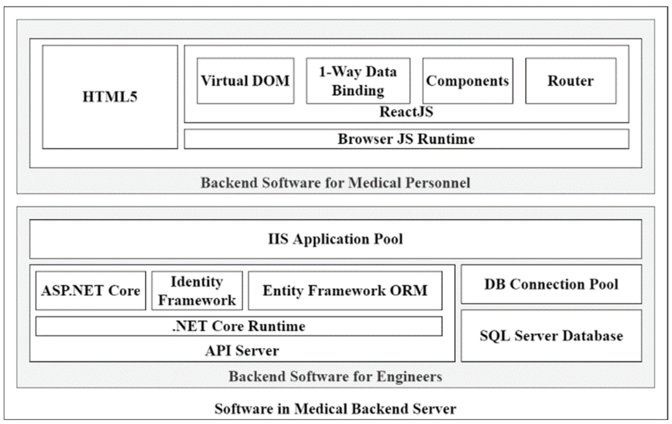

Fig. 3. Software architecture for the medical backend server.

stably cover them and prevent them from slipping off the user. When operating the app, the patient must pair an IMU with the Bluetooth interface. Through the continuous return of the posture signal from the IMU through Bluetooth, the IMU can judge whether the movement is achieved and the exercise completed. Bel *et al*. proved the validity of using two IMUs in three classic knee rehabilitation exercises: heel slides, short-arc quadricep contractions, and sit to stand [25]. Therefore, in the SMPT, two IMUs are used to sense body movements in therapeutic exercises. The IMUs can be worn on the subjects' different positions depending on different activities to measure the angle and acceleration during the movement. In the future, depending on task requirements, the number of IMUs can be increased, or other physiological signal acquisition devices, for example heart rate and blood pressure monitor, that use Bluetooth can be adopted. The IMUs can also be extended to provide the velocity and time of the movement by using algorithm. Moreover, the muscle strength can also be measured by using the weight and joint angle of the user.

C. Software Design for the Medical Backend Server

All backend software is executed through Windows Server IIS and can be divided into backend software for medical personnel and backend software for engineers. The software architecture is presented in Fig. 3. The backend software for medical personnel is used primarily to manage cases (patients) and exercise distribution. This backend software is implemented using ReactJS technology and runs in a browser environment. The backend software for engineers is maintained and managed by engineering-related personnel. The system's backend data are interfaced in the application programming interface (API) mode, and the backend API server is implemented using.NET Core technology and the following technical solutions: (1) Entity Framework as the data capture layer; (2) Identity Framework for controlling the authority mechanism; (3) the IIS application pool and database connection pool for optimizing resource utilization; and (4) the Microsoft SQL Server as the database engine.

A key program executed in the backend server is the backend software for medical personnel, which is presented and operated on a Web interface. A general description of the backend software for medical personnel is presented in the following text.

1) Case Management: The primary function of case management is to manage the user's personal data, including case list queries, new cases, case modification, password modification, and a detailed page view for a single case.

2) Personnel Management: Personnel management involves adding and modifying information on back-office personnel (medical personnel). When adding personnel, the ID (account) number, password, name, personnel role, and administrator authority must be entered. Passwords can also be reset.

3) Questionnaire Question Bank Management: To collect feedback after completing exercises, any validated scales can be used when appropriate. When creating a questionnaire question bank, the name of the question bank and a list of questions must be entered. After creating the questionnaire database, the exercise management page can be accessed to confirm the actions.

4) IMU Location Management: IMU location management involves providing IMU location options for adding and modifying actions. When creating a location, the name of the location must be entered. After creating the location options, the action management page can be accessed to confirm the actions.

5) Exercise Management and Classification: The function of exercise management and classification is used to query the exercise list and add, edit, and delete exercises. When creating an exercise, the exercise name, classification, exercise images, demonstration videos (including the exercise start time and the support start and end times in the video), exercise video subtitle file, and, if required, the questionnaire question bank for use after completing the exercises must be entered. To set the IMU location, medical personnel must set the number of IMUs as well as the measurement position, rotation axis, rotation direction, starting angle, maximum displacement angle, and preset target angle interval of each IMU. Details of the exercise design are discussed in section E.

6) Task Template Management: To allow medical personnel to set an exercise task for clinical practice, they can use the function of task template management to create in advance a task template that includes several exercises for the same purpose. A message can be embedded in a task, and this message is automatically brought into the note field of the task when the task is dispatched, which prevents the repeating of messages. The task template can also be shared publicly, thereby allowing other medical personnel to use it.

7) Rehabilitation Module Management: The function of rehabilitation module management is used to query the module list and add, edit, and delete modules. When creating a rehabilitation module, medical personnel must enter the name of the module, which can be combined into a new rehabilitation module from existing tasks.

D. Design of the Smartphone Application

The SMPT app supports the iOS and Android smartphone platforms. It can be downloaded by patients and installed on their smartphones. The SMPT app is mainly used to receive exercise tasks from the backend and perform them. When operating the app, the patient must pair the IMUs through a Bluetooth interface, and the attitude data continuously returned by the IMUs are used to determine whether the movement has been achieved and the rehabilitation task has been completed. The general description of the app software is provided in the following text.

1) Login Screen: The patient can log in into the app by entering their ID (account) number and password or by scanning a QR code.

2) My Tasks: After logging in, the patient can click on "My Tasks" to view the list of tasks from the previous 2 weeks, the tasks for the day, and all future tasks. Only tasks listed for a day that have not been completed can be clicked on and performed. After clicking on the task of the day, a list of exercises is displayed, and the patient can select an exercise to begin the task.

3) Practice Mode: The "Practice Mode" is similar to the "My Tasks" screen. The patient can see the tasks sent; however, these tasks are for practice only and do not count toward the official results. Each task can only be practiced once.

4) My Reward: The patient can view the reward badges obtained using the "My Reward" function.

5) My Devices: Each patient can pair two IMU devices through the "My Devices" function. After the IMUs are paired, this function can be used to check whether they are connected correctly. Paired IMU devices can also be clicked on to disconnect them from the aforementioned function.

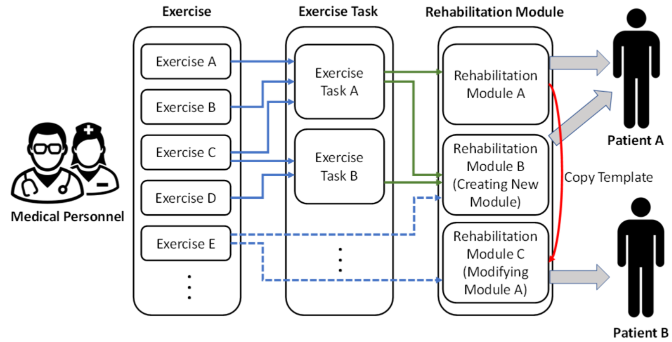

Fig. 4. Map of the exercise database.

6) IMU Power and Status Display: The current connection status of the two IMUs and their real-time battery use are displayed at the bottom of the login screen. When the battery is excessively low, a conspicuous warning message appears on the screen, which prompts the user to recharge the battery.

E. Exercise Database Design

The exercise database was designed by certified therapists in Taiwan on the basis of their experience and the existing literature [35], [36], [37]. The SMPT is unique and has a high level of expandability. New therapeutic exercise protocols can be easily added through the medical personnel backend server. The main protocols in the current system include stretching exercises, range-of-motion exercises, and endurance and strength training. To develop an exercise program, the medical personnel must enter relevant information, including the number of repetitions and sets for each exercise, the resting time between each set, the duration and time limit of each exercise, and the target angle interval measured by the IMUs. The therapist can add several exercises to generate an exercise task, and each exercise task can be added to a rehabilitation module. For example, in the case of adhesive capsulitis, a stretch-based exercise to increase the range of motion in the shoulder joint, which is a key exercise for this disorder, can be included in a muscle strengthening program. The therapist can select pre-existing shoulder range-of-motion and muscle strength exercises and combine them to create an adhesive capsulitis rehabilitation module. Fig. 4 illustrates the relationship among exercises, exercise tasks, and rehabilitation modules. A new exercise task can be modified from the existing exercise task template or created using several exercises. All exercise programs, tasks, and rehabilitation modules can be shared with other medical personnel and modified, as required, in the backend server, thereby allowing the clinical practitioner to develop appropriate rehabilitation modules promptly.

III. Results

A. System Implementation for Medical Personnel

In the developed SMPT for telerehabilitation, the software is divided into a medical backend server and a smartphone app for patients. To better accommodate to the clinical setting, several combine discussion meetings including the engineers and medical professions were held to discuss the exercise in

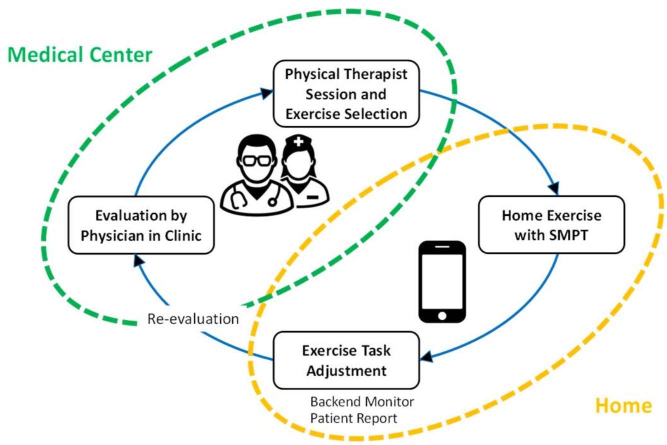

Fig. 5. Implementation of the SMPT.

the system and the operation of the medical backend server. The software in the backend server is operated by medical personnel through a Web browser. After a patient has been evaluated by a clinician and therapist, the medical personnel can create a profile for the patient and design a personalized therapeutic exercise protocol.

The SMPT provides clear instructions for the patient to perform the exercises. The current system is dynamic, with high flexibility to accommodate the patient's condition. The implementation of the SMPT involves four steps, as depicted in Fig. 5. First, the patient is evaluated by a clinician to determine whether they are suitable for the SMPT and then referred to a therapist. Second, the therapist designs a personalized therapeutic exercise program with six training sessions to educate the patient on not only how to use the SMPT but also the correct method to perform the selected exercises. Third, the patient begins the exercises and can provide feedback through a questionnaire after each exercise. The therapist can also monitor the quality of movement through the data presented in the medical backend server. If the exercises require adjustments, the therapist can modify the tasks instantly to suit the patient's condition or invite the patient to the clinic for a further assessment. Fourth, when the patient has completed the task or requires an additional medical visit, they can return to the clinic for re-evaluation or a further medical intervention.

When therapists design a personalized therapeutic exercise, the exercise can be easily allocated to the patient by selecting and dragging the exercise from the database, as illustrated in Fig. 6.

In general, the information on the prescribed exercise should include at least the frequency, intensity, time, and type of exercise [38]. By adjusting the frequency, intensity, and time of an exercise, it can be modified to best meet the needs of a patient. Information on each exercise should include the numbers of repetitions and sets, the resting time between sets, the time limitation for each set, the time for which the target angle should be held for, and the target angle of the exercise. The system interface for observing the detailed parameters of an exercise is displayed in Fig. 7. By selecting the target angle and hold time, stretching and stability exercises can be tailored effectively.

Moreover, medical personnel can view the task performance in the backend server to evaluate the quality of movement and decide whether to progress to the next stage of rehabilitation. The backend server would generate the report of the complete rate of the exercise. Take shoulder exercise as an example, the target angle of shoulder flexion is 120 degrees, and the actual angle performed by the patient would be shown in the post exercise report to justify the complete rate of the patient. On the other hand, the number of the task being done could be seen from the backend server allowing the medical personnel to evaluate the compliance of the patient. The patient's feedback can also be viewed through the platform, thereby providing further input for subjective measurements such as rate of perceived exertion or pain scale, if required. The system interface for medical personnel operation is depicted in Fig. 8. An artificial intelligence module can be added to the designed system in the future to improve how the collected data are used and to assist a clinician in creating effective therapeutic exercise protocols.

B. System Implementation for Patients

Patients can download the app to their smartphone and begin exercises by their own at home after completing training sessions with a therapist. The SMPT is not designed for a single musculoskeletal disorder but is an evolving exercise database that can provide specific exercise protocols for different diseases. Therefore, switching to a new platform or app for different musculoskeletal problems is unnecessary. Moreover, our system can connect to other Bluetooth sensors apart from the IMUs, which can provide additional information to the patient. For example, the system can be combined with the sphygmomanometer with Bluetooth interface, which can provide the blood pressure and heart rate of the patient to the system. Medical personnel provide the patient with an account and a password, and the designed system also supports log in through a QR code. After the first log in, the patient is logged in automatically. The smartphone operating screen is illustrated in Fig. 9. The welcome screen contains four windows: "My Tasks," "Practice Mode," "My Reward," and "My Devices." By clicking "My Tasks," the patient enters the exercise window and begins the rehabilitation session. Clicking on "Practice Mode" enables the patient to practice different exercises from the database with the permission of medical personnel; clicking on "My Reward" allows the patient to view their rewards for completing exercises; and clicking on "My Devices" enables the patient to check the connection to the IMUs. Under the "My Tasks" option, the patient can initiate their personalized therapeutic exercise program according to the schedule designed by a medical professional. Although a training session prior to commencing the home exercise program is provided in the hospital, a short video tutorial is provided at the beginning of each exercise to ensure that the patient performs the exercise accurately. Captions are provided in Mandarin and English because the patient's primary caregiver may not be a native Mandarin speaker (Fig. 10).

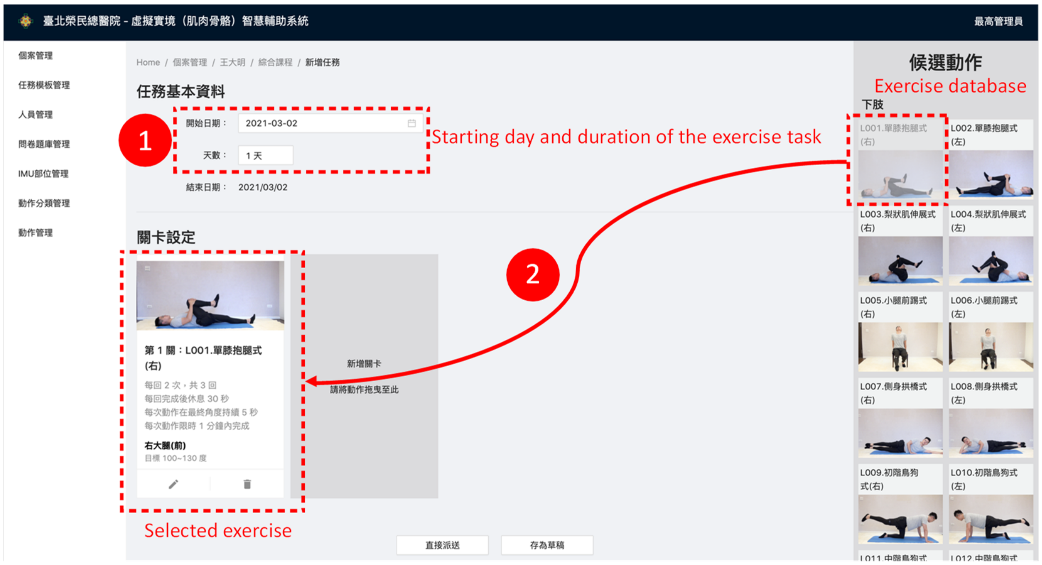

Fig. 6. Creating new therapeutic exercises (Step 1: enter the exercise start date; Step 2: select the exercise from the database).

Fig. 7. Detailed parameters of an exercise (Step 1: repetitions and sets; Step 2: resting time between sets; Step 3: hold time; Step 4: target angle; and Step 5: press OK to finish).

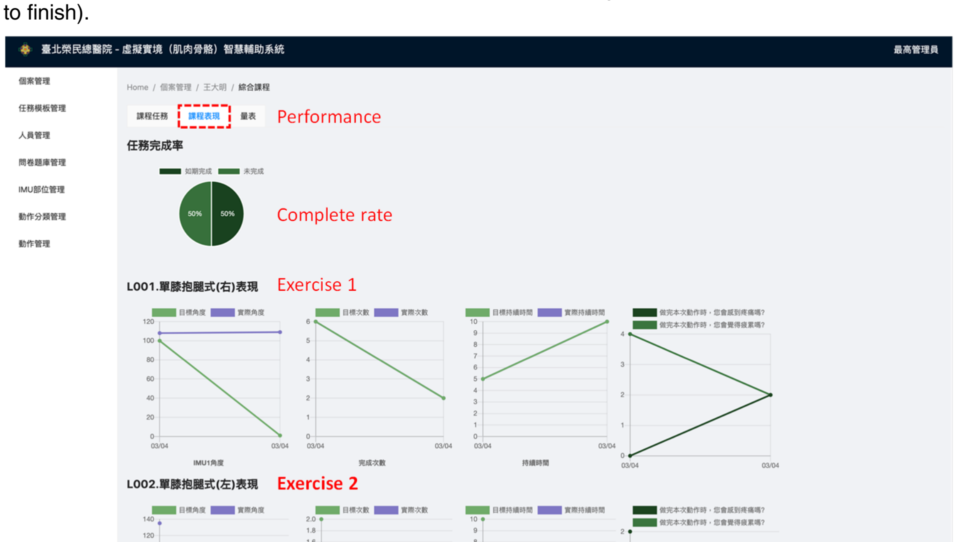

Fig. 8. System interface for medical personnel operation.

During the exercise session, the patient can observe the ideal position or angles measured by the IMUs and the remaining time or requirements for each training session, as shown in Fig. 11. After completing the training sessions, the patient can send feedback through a questionnaire, which can be observed in the medical backend server.

Fig. 9. Four windows on the SMPT welcome screen: “My Tasks,” “Practice Mode,” “My Reward,” and “My Devices.”

Fig. 10. Video tutorial before each training session. The tutorial is in both Mandarin and English and provides instructions on IMU placement and exercise steps.

Fig. 11. Exercise window. Information includes the angles measured by the IMUs, the hold time, the remaining sets, and the number of repetitions. A video demonstration is also provided to ensure that the patient performs the exercise correctly.

Patient feedback helps to modify exercises, if required, in real time.

The patient’s motivation and compliance are key to treatment outcomes [39]. Studies have revealed that adding playful elements to rehabilitation protocols is an effective method for enhancing these two aspects [40], [41]. After the completion of every training session, the patient receives a pet as a reward. Taking the idea from the famous comics, Pokémon, as more sessions being completed, the patient will either receives a new pet or the the existed pet will undergo an evolution and grow up. The patients could access to their pets through the “My Reward” window on the welcome screen. The additional enjoyment and sense of achievement provided by the system may deepen the engagement and participation of patients.

C. Quantitative Feedback

According to Hajesmaeel-Gohari *et al.*, the Telehealth Usability Questionnaire, Telemedicine Satisfaction Questionnaire, and Service User Technology Acceptability Questionnaire (SUTAQ) are the leading questionnaires for assessing the feasibility and satisfaction of telerehabilitation [42], [43], [44]. After reviewing these questionnaires, the SUTAQ was considered the most suitable for evaluating our platform [45]. A new questionnaire based on the SUTAQ was designed in this study, with different versions being designed for the public and medical professionals. Similar to the original SUTAQ, the questionnaire designed in this study contains six subscales:

TABLE I
BASELINE CHARACTERISTICS OF THE PARTICIPANTS

	Medical professions N=25	Publics N=12
Age	42.16 ± 11.76	57.83 ± 13.8
Gender (M/F)	11/14	5/7

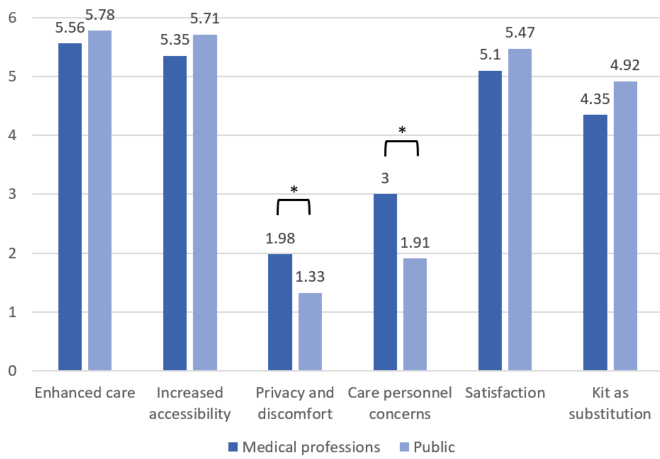

Fig. 12. Results obtained for the medical professionals and public. * indicates that $p < 0.05$.

enhanced care, increased accessibility, privacy and discomfort, care personnel concerns, satisfaction, and kit as a substitute.

The aim of the current study is to introduce and evaluate the feasibility of the SMPT system. As for the efficacy of SMPT is planned as the next step of our study. To assess the feasibility of SMPT, 37 volunteers were recruited from Taipei Veterans General Hospital. These volunteers consisted of 25 medical professionals (three consultants, four residents, nine occupational therapists, two physiotherapists, four nurses, and three personnel from other professions) and 12 members of the public randomly selected from the outpatient clinic. The procedure was approved by the Institutional Review Board of Taipei Veterans General Hospital (Code: 2020-09-009A), and each participant provided written informed consent before participating in the research project. A brief introduction to the designed system was provided by a research assistant, followed by a short live demonstration. The baseline characteristics of the participants are listed in Table I.

The statistical results of the questionnaire are outlined in Fig. 12. Each subscale was scored using a 6-point Likert scale (1 = strongly disagree, 6 = strongly agree), and the following average scores (medical professionals/public) were obtained: enhanced care = 5.56/5.78, increased accessibility = 5.35/5.71, privacy and discomfort = 1.98/1.33, care personnel concerns = 3/1.91, satisfaction = 5.10/5.47, and kit as a substitute = 4.35/4.92. The public and medical professional results for each subscale were similar, and no significant difference was identified. A high level of agreement was observed for enhanced care, increased accessibility, and satisfaction, and a moderate level of agreement was observed for kit as a substitute. A low level of agreement was identified for concerns about privacy and discomfort; however, a significant difference was noted in the results of the two groups for this subscale. The results for concerns about care personnel also exhibited a significant difference between groups, with a low level of agreement among members of the public and a moderate level of agreement among medical professionals.

IV. DISCUSSION

Telerehabilitation has been evolving through different platforms, including set-top-box-based, computer-based, and smartphone-based systems [15], [16], [17], [18], [19], [20]. Table II presents a comparison of relevant studies on the following indicators: platform used, sensor used, target disease, monitored body parts, portability, cost, real-time monitoring, reward system, automatic synchronization, device extensibility, and software extensibility. Only the system proposed by Bermejo-Gil *et al.* requires no sensors. However, although this system can provide guidance on the exercises, it cannot monitor patient movements. Moreover, most of the systems in the compared studies were developed for a specific disease. Only the SMPT can be used for multiple musculoskeletal diseases. With regard to monitored body parts, all the smartphone-based platforms can track a patient's whole-body movements, whereas the other systems can only track the movement of specific body parts. The data in Table II indicate that systems comprising smartphones and wearable devices are more portable than are the other systems and can be used without environmental limitations. Regarding system applications, only the SMPT can simultaneously provide the functions of real-time monitoring, a reward system, the automatic synchronization of exercises, and device and software extensibility. Moreover, the cost of the SMPT is relatively low. All the examined indicators suggest that the SMPT is superior to other similar systems.

The results obtained using the SUTAQ indicated that the public and medical professionals viewed the SMPT positively. A high level of agreement was identified between the aforementioned groups in terms of increasing the accessibility of rehabilitation, enhancing the quality of rehabilitation, and satisfaction for this platform. Although the obtained scores did not support the SMPT being used as a substitute for traditional rehabilitation, its current design is intended to offer additional high-quality rehabilitation outside the hospital and not intended to replace current forms of treatment. Moreover, with regard to the privacy and discomfort and care personnel concerns subscales, a significant difference was identified between the scores of the public and medical professionals. In general, the medical professionals appeared to exhibit more conservative attitudes toward the SMPT than did the public.

Recommendations and feedback obtained using the questionnaire suggested that invasion of the professional privacy of medical personnel, interference in current practice, uncertainty over the effectiveness of the platform, uncertainty over patient ability to perform the exercises correctly, and inability to access patient conditions before the exercises (e.g., vital signs) were the main concerns of the medical personnel with the SMPT. To address these concerns, a comprehensive training program can be conducted for medical professionals to familiarize them with the designed platform. The goal of the SMPT is not to replace medical professionals but to provide

TABLE II
COMPARISON BETWEEN THE SMPT AND OTHER TELEREHABILITATION SYSTEMS

	Caroppo *et al.* [15]	Bhatia *et al*. [16]	Noveletto *et al.* [17]	Bermejo-Gil *et al.* [18]	Wei *et al.* [19]	Moreno-Gutierrez *et al.* [20]	SMPT
Year	2014	2021	2020	2021	2019	2021	2021
Platform	Set-top box	Computer	Laptop	Smartphone	Smartphone, computer	Smartphone	Smartphone
Sensors	Depth camera	Mechanical device	Mechanical device	None	Depth camera	Fitbit and ECG devices	IMUs
Applicable subjects	Alzheimer's disease	Neurological injuries	Stroke	Respiratory diseases	Parkinson's disease	Breast cancer	Multiple rehabilitation diseases
Monitored body parts	Upper-limb	Upper-limb	Lower-limb	Whole body	Whole body	Whole body	Whole body
Portability	Low	Low	Low	High	Low	High	High
Cost	High	High	High	Low	High	Low	Low
Real-time monitoring	Yes	No	No	No	Yes	Yes	Yes
Reward system	No	Yes	Yes	No	No	No	Yes
Automatic synchronization	Yes	No	No	Yes	Yes	Yes	Yes
Devices extensibility	No	No	No	No	No	No	Yes
Software extensibility	No	No	No	No	No	No	Yes

an extension to their clinical expertise to overcome potential barriers related to time and limitations. To ensure that patients have the ability to perform exercises correctly, a therapist must provide training before the beginning of the SMPT program. This training covers not only the exercises but also how to operate the system and safety during the exercise. In the future, a prospective randomized controlled trial should be conducted to evaluate the effectiveness of the SMPT in a clinical setting.

In addition to the aforementioned strengths and advantages, therapeutic exercise as a form of physical activity may provide considerable benefits for physical fitness not limited to the original musculoskeletal problem [46], [47], [48]. Thus, the SMPT may enhance physical activity in the wider population. The contributions of the SMPT are as follows. First, the exercise database is built by certified physical therapist and physician, but other mHealth solutions mainly operated by patients themselves or fitness trainers. Second, via the medical backend server, the medical personnel can monitor and adjust the exercise instantly to better fit the clinical condition of the patient. Last but not the least, the equipment of the current system is smartphone-based, which is highly available comparing to other systems which need additional devices. However, this study has some limitations. Because the SMPT is a smartphone-based platform, the patient must be familiar with a smartphone. This problem can be addressed by training the caregiver. The SMPT requires the patient to be cooperative; thus, patients with cognitive impairment may not be suitable candidates. Compensation during exercise cannot be fully avoided, and the IMUs are unable to detect this compensation. Consequently, suitable training should be provided before a patient begins their exercise program.

V. CONCLUSION

In this study, an SMPT with a medical backend server and smartphone app was developed and clinically evaluated. The SMPT contains an evolving therapeutic exercise database designed by medical professionals that comprises exercises suited to patients' conditions as well as validated and commercially available IMUs for monitoring the exercise quality. physical therapists can use the SMPT to create new exercises, individual tasks, and rehabilitation modules quickly for different rehabilitation treatments. Once an exercise program has been designed, the SMPT can be used immediately, and the patient can view the program content on their smartphone. The patient's smartphone is immediately updated if the physical therapist makes any adjustments to the exercises. An instant report system allows medical personnel to modify the customized rehabilitation tasks, monitor patient progression, and receive patient feedback in real time. The reward system may potentially maximize compliance by increasing motivation. In the future, artificial intelligence can be incorporated into the designed system for analyzing the collected data to assist medical personnel in designing suitable personalized exercise plans. We believe that using the SMPT as a treatment adjunct to traditional rehabilitation would result in superior outcomes to those achieved when using traditional rehabilitation alone.

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