MoMiReS: Mobile Mixed Reality System for Physical & Occupational Therapies for hand and wrist ailments

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Abstract— **The MoMiReS is a mobile mixed reality system aimed at physical and occupational therapies. The goal of the system is to engage therapy patients by involving them in a fun to play 3D game environment through physical interactions with a wireless sensor glove. Our system offers a solution for rehabilitation of the hand, wrist originated problems with a smartphone based mobile mixed reality game that will be used in conjunction with traditional rehabilitation programs such as home treatment. The key factor in the success of the home treatment is compliance of patients to the given therapy instructions. However, therapists report that patients do not carry on their home-exercises and activities. The main reason is the lack of motivation and boredom for the given activities. These activities require patients to carry out set of repetitive movements. The lack of motivation in exercises causes discontinuity and increases the recovery time and eventually increases the cost of the treatment. Therefore, we propose a complete framework by reducing the drawbacks of the traditional therapy. Our framework has three components; hardware, smartphone game, and cloud for data storage and processing. A sensor glove was developed with plug and play motion sensors streamed in real-time to the mobile phone with Bluetooth connection. The glove is used for tracking finger pressures and motion of the fingers. The patient side smartphone based interactive game verifies compliance of the motions for assigned exercises by occupational/physical therapist. The cloud side aims at ensuring patients that the assigned exercises are carried out and also monitors patient in real-time. Cloud application keeps the record of the patients' progresses for further analysis by therapists. In order to understand the effectiveness of the proposed system, we developed games specifically for treatment of carpal tunnel syndrome. The usability and effectiveness of the systems are surveyed among the occupational therapy students. Survey results show that 92% approval rate of the system.**

Index Terms— **Mobile Computing, Wearable sensors, Cloud Computing, Occupational and Physical Therapy, Mobile Gaming**

I. INTRODUCTION

Physical therapy (PT) and Occupational Therapy (OT) are type of treatments of a patient with impairments, disabilities, mobility or functional ability problems. Both try to promote quality of life and movement potential through examination, evaluation, diagnosis and physical intervention carried out by therapists. Occupational therapy; however, is the use of treatments developed in physical therapists to recover, or maintain the daily living and work skills of patients with a physical, mental or developmental conditions. The developed MoMiReS is mobile mixed reality framework aims at complementing conventional therapy and assisting patient's recovery for hand, wrist, and arm ailments with gaming.

The conventional PT or OT entails several drawbacks. One of the problems is the necessity of a therapy specialist's supervision throughout all the stages of therapy. This becomes problematic due to the lack of the sufficient specialist in the US and other countries [1]. In the US, 22% expected growth of PT specialist is unlikely to meet the demand in the next decade [2]. Scarcity of specialists limits the therapy services and also causes longer treatment due to long waiting on appointments. Underdeveloped states or rural places are further affected by inadequacy of specialists compared to developed states or regions of the same state. This drastically decreases patients' accessibility to specialist and interrupts continuity in treatment that is crucial for a complete and fast recovery.

The cost of the physical therapy is a limiting factor for uninsured and underinsured patients in conventional treatment. Considering the fact that 27% of the US population under 65 lacks proper health insurance [2]. As having basic health service becomes challenge, providing basic insurance coverage for the PT and OT service is unlikely even with recent health care law [3][2]. These treatments are considered as health services improving the quality of live rather than life-critical treatments. Therefore, patients who are not associated with any insurance have no alternative treatment. Unfortunately, these patients may never get appropriate treatments. With the new health care plan, it is expected to have majority of the population hold some type of health insurance coverage. Thus, it is inevitable to see higher demand to specialists. This demand will not be fulfilled with the current increase rates of the number of physical therapy specialists and current therapy treatment methodologies. Cost and time associated to patients' work force loss due to lacking physical therapy treatment will induce additional cost on patients and the nation. Therefore, there is upcoming necessity to increase home therapy regimes and their effectiveness.

Considering the problems of health care system and current limitations, the PT/OT with home exercises become vital in

the treatment [4]. In OT and PT literature, it is known fact that the home therapy is effective and has become an integral part of the long term treatment [5]. The key factor in the success of the home treatment is compliance of patients to the given therapy instructions. However, therapists report that patients do not carry on their home-exercises and activities and thus their treatment remains incomplete. The main reason is the lack of motivation and boredom for the given activities [6] [7]. These activities require patients to carry out set of repetitive movements. The lack of motivation in exercises causes discontinuity and increases the recovery time and eventually increases the cost of the treatment. Besides, this lack of motivation restrains compliance with the given treatment. Therefore, the success of the treatment solely depends on the self-motivation and discipline of the patients.

Our proposed approach aims at complementing the traditional treatment and offers a quantitative, accessible and portable therapy treatment system that can be used anytime, anywhere in conjunction with the conventional methods. The therapy treatments for hand generally fold in two groups; one group of exercises tries to increase the range of motion and the other groups try to increase the muscle strength. Both exercises are traditionally first performed in a specialist's supervision and later the patients themselves are expected to continue on the given exercises. These exercises for muscle improvements include several set of movements; stretching, contractions or combination of both. These exercises enforce patients to gain the expected movements. The muscle improvement exercises follow range of motions that aim at fully recovering the motion of the hand and wrist. Both of these groups of exercises are covered by the MoMiReS system.

Our proposed aim is to develop a portable system to facilitate the treatment at home for the patients and eventually reduce number of appointments for patients. The system tries to motivate therapy patients by attracting with a mobile game. The goal is to increase the compliance of the patients by integrating the fun in exercises.

Our system is a low cost, portable and accessible therapy system related to recovery of hand ailments or impairments. The system has three integral parts; Glove hardware, patient side mobile game and cloud storage/computing side. The entire system provides affordable and robust solution, real-time monitoring for therapy diverges from other solutions in regards to glove and overall system functionality [8][9][10][11] [12][13] [14][15] [16]. Competing solutions in hand therapy domain have limited use due to its high cost. On the contrary, our glove is developed with low-cost, off-the-shelf sensors that cost less than hundred dollars. Moreover, the system only requires a mobile device (or tablet or PCs) that entices wide use and reachability. This makes our proposed solutions independent of any specific hardware/software platform.

The conventional therapy system provides no means of quantitative progress of the patient and any information about compliance to the given therapy [17][18]. On the other hand, our approach offers real-time feedback to the patient. As our system records patient's hand movements, it could easily detect if patients fail to fulfill the given therapy regimen. This monitoring aspect gives artificial supervision over the patients and expected to increase the patient commitment to the system. Whereas other systems lack of real-time monitoring or assessment which require patients own dedication or caregiver's supervision. In traditional methods, this may impose pressure on patients and caregivers [19]. This decreases the effectiveness of the recovery by increasing the recovery time which is a common problem for many enrolled at-home therapy programs [20][21].

II. MoMiReS System framework

The MoMiReS system is a complete hand, wrist, and arm therapy system that consists of both custom hardware and software. The system offers therapy anytime, anywhere and also makes it fun. The goal of the system is to meet the needs of physical and occupational therapists by providing remote, real-time, quantitative progress monitoring of a patient with automated scoring, recording, and assessment capabilities meanwhile reaching patients who lack the means or interest to engage in a traditional therapy. The broader impact of the MoMiReS system stems from the goal of reducing the level of non-compliance, and enhancing the possibility of achieving the desired healthcare outcomes through real-time therapy data collection, recording, and assessment in a cloud environment for hand, wrist and arm therapies.

MoMiReS sensor glove and mobile game are mainly used by the patients. The glove is made with different sizes that are fused with multiple sensors to detect the hand and finger pressure and also motion of the fingers. The finger joint movements and pressure sensors are used to assess the patient range of motion and hand and finger muscle strength while they are playing the game. The glove is composed of several internal components such as; Bluetooth module for wireless communication, microcontroller for reading the sensory information and controlling the Bluetooth communication, software filtering and circuits that perform hardware level filtering. The whole system is powered with tiny polymer lithium ion battery. The circuits and sensors are attached on the glove layer which is also covered with additional non-conducting fabric. This is also needed to eliminate any failure or noise in data due to wire or cable snag. As the wire and cables do not have any direct contact with hand, it eliminates any problems that may arise due moisture or other skin characteristics of hand. The internal design of the sensor glove without the outer fabric is illustrated in Fig.1.

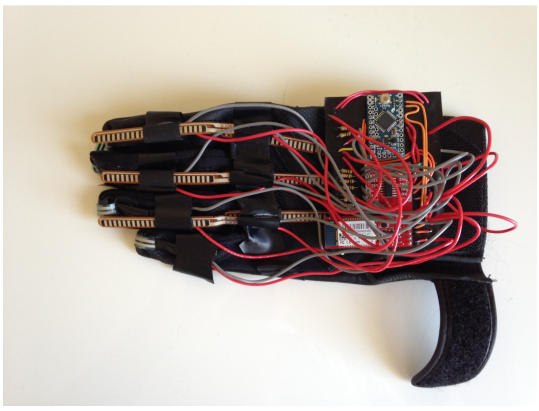

Fig. 1 Sensor glove top view

Our designed glove with its sensors communicates with a mobile platform with Bluetooth module RN-42. The module is capable of communication with any device that supports Bluetooth version 2.0. The support of Bluetooth makes the glove wireless that eliminates any unnecessary cabling. Therefore, hardware is adaptable with any future devices for any human body regions unlike other solutions [22][15]. Its self-powered and light weight feature increases its convenience and its transferability. Therefore, the patience can carry our system and practice given exercises no matter his/her physical location. This allows treatment outside the home unlike other approaches.

The sensors on the glove are wired to the microcontroller for real-time data reading. The circuits are integrated with multiple multiplexers to read from channels more than the microcontroller input supports. At present, open hardware Arduino-pro microcontroller is used to read sensor information. Arduino pro is a light weight and tiny microcontroller that minimizes footprint of circuitry. Pressure sensors are FSR 400 that has accuracy with minimum 0.1N and 10N. The pressure sensors are fixed at the finger tips. The bend sensors are linear spectra symbol flex sensors that are capable of detecting the angular-displacement motion. The bend sensors are fixed for each finger joint to detect the finger motion. The kinematics of the bend end point locations is derived to accurately compute the finger movements. As the sensors and circuitry characteristically have noise, we embedded hardware level low-pass filtering. These low pass filters serve for suppressing the fluctuations at sensor level. Additional filtering is also implemented at the microcontroller level to have more robust readings from the sensor. This additional software filter is also integrated to adjust thresholds in the calibration step. Prior to the therapy, patient needs to complete calibration process for bend and pressure sensors. For this, the game first pairs with glove over the Bluetooth. For bend sensors, the game will ask patients to complete pre-set trivial motions. For pressure sensors, patients will be asked to use pre-determined weights that need to be placed for each sensor calibration. After the semi-automatic calibration process, the application becomes ready to receive patient hand and finger motions in real-time.

The sensory information is collected in real-time. The sensors data is then transmitted over the Bluetooth communication with baud rate 115200 bits/sec to the game. All sensors information are sent to the game application and kept in the internal buffers to eliminate any lag originated from I/O. The game loop uses the information for navigating the game character.

The software side is a mobile game designed towards to execute the hand/wrist therapy exercises. The game component works on the smartphones and tablets. Multiple games are developed for various hand exercises. All game specific goals comply with the therapy regiment and aim at reiterating the exercises as much as possible. The game design encourages the exercises by scoring mechanism. As one of the examples, for carpal tunnel syndrome, the tendon gliding exercises are accepted as therapy regimen. In these exercises, patient needs to put hand and fingers in straight positions and then in hook position, then fingers in table top position where fingers are positioned at ninety degrees with the palm. As hand movements can be tracked with our glove, avatar in the game will need to perform these movements. The avatar needs to carry out these movements to escape from its enemies in a constricted game play area as seen in the Fig. 2. Indeed, the enemies compels patient to perform those motions. As seen in Fig.2, the avatar which is the orange spaceship in the game play, can only escape from its enemies by dodging. This will require moving all fingers down. This is just an exemplary game play setting which can easily be adapted any other hand therapy regiments.

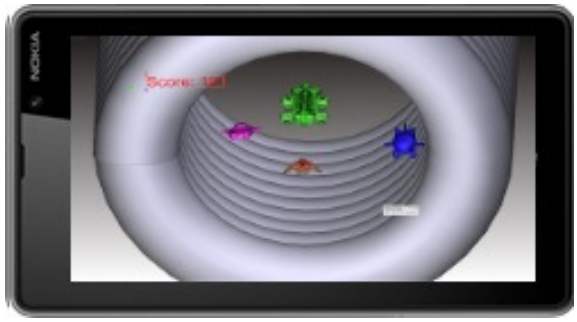

Fig. 2 one MoMiReS Game play on smartphone, the orange spaceship in the middle is the avatar that is manipulated by a patient who wears our glove.

The game encourages the patients on the physical therapy [6][23]. The more score patient makes in the game the more progress will be gained. The fun ingredient in the activity will more likely increase the patients' engagement with the game [24]. This directly increases the patient loyalty to the game and the therapy in that game internally executes therapy regimen other than other approaches that enforces the same strict, tedious exercises only in digital environment [25] .

The cloud side of our system, also the back end side, is responsible for collecting and analyzing all therapy related information in the cloud storage. This includes but not limited to the raw sensor data, patient scores, time spent with the game, correct movements complied with therapy. The raw sensor data is stored to replicate the game play if needed. The patients' time and scores will give feedback about the progress to both patients and also to the specialists. No other patient specific or any personal information is collected other than their progress

information. Even such information stored in de-identified and encrypted fashion.

The cloud storage and computing support allows us not only keeping the record of the current progress but also tracking of the past treatment and exercises of the same patient. The back log of the patient activity grants the quantitatively assessing of the patient progress over the time. The quantitative feedback such as the motion of the fingers, the score obtained from game, range of motion, time spent with the game, are also sent to the associated specialist to assess the patient's current condition. Therefore, the specialists can oversee the entire progress and assign new therapy regiments if needed. The specialist can intervene and change scoring scheme in the game and give weights to certain movements (which believed to be more important than others) more than others. The specialists can update the current regimen in the case of fast or slow progress of the patient. This update to the game can be done anytime and online through the cloud. Online modification on the game scenario allows patient specific therapy, which normally cannot be done in conventional treatment unless patients see the therapist in their next appointment. The overall schematic of our MoMiRes architecture can be seen in Fig. 3.

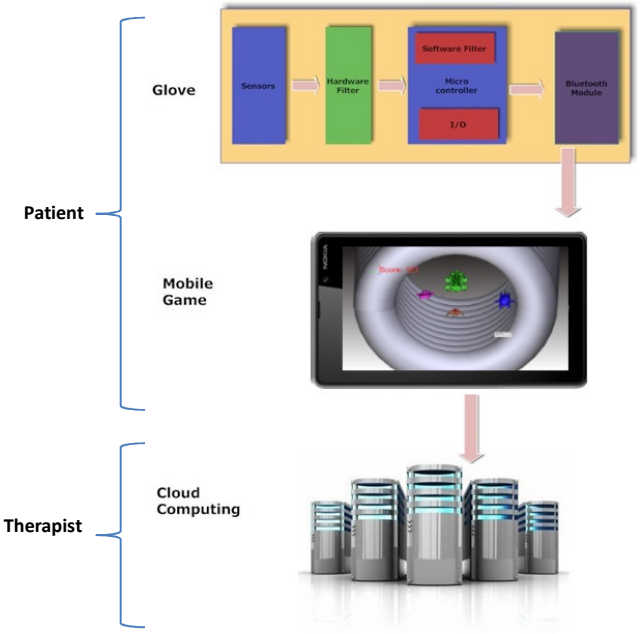

Fig. 3 The system architecture

III. RESULTS

We carried out questionnaire among the graduate level OT students to acquire the preliminary feedback for our proposed system. Total 46 students participated in the study. We demoed the system first and asked their opinions with several questions. The major questions given in Table 1. We asked them to rank their answers with 1-10 scale, where 1 indicates that if they totally disagree and 10 if they completely agree with the argument. First question, we would like to know if our proposed approach could be useful in home therapy. In the second question, our aim is to understand that whether our solution could be useful if they were the patients. This would also reveal their eagerness to accept the solution compared to home therapy treatment. Third question is to reveal effectiveness of our system in the compliance that is one of the primary goals in MoMiReS. The fourth question is to verify the significance of the compliance in home therapy treatment. Last question is to assess the importance of the tracking Range of Motion (ROM) and monitoring the patient's progress. As in the traditional treatment, progress of ROM can be measured only at therapy visits, which makes the continuous progress supervision not possible.

TABLE I SURVERY QUESTIONS

Question No	Questions
1	Compared to traditional home programs rate the glove on its usefulness as a therapy treatment aid?
2	If you were a patient needed therapy would be motivated to use the glove as part of a treatment plan?
3	Do you think that playing a game with hand movement controlling the game would aid in compliance with wearing the glove.
4	In your observation, is compliance to home programs important in therapy
5	Do you think tracking ROM through a smart phone app would be helpful to a therapist for monitoring progress?

The feedback of questionnaire is illustrated with box plots in Fig 4. The first question has average score 7.7 with median 8. All participants agree that the approach is beneficial with high percentile as the first quartile is around 7. In second question, majority of the participants agree to use our approach for their treatment. Only two did not want to use amongst 46. The average is noted as 7.59 with median 8. In the third question, the average is 8.11 with median 8. Except two people, all confirm that our system would be very effective in fulfilling the compliance. As indicated in the fourth question, the compliance is given high importance in home programs. Last question, has the highest rating among all other questions that ranks the effectiveness and usefulness of our solution with a mean of 8.83 and median 9.0. The minimum score noted with one person with 5.0. All the questions except 4, are directly linked to the overall acceptance of our system. The percentage of the scores greater than 5, which favors the system effectiveness and usefulness, that is around 93%.

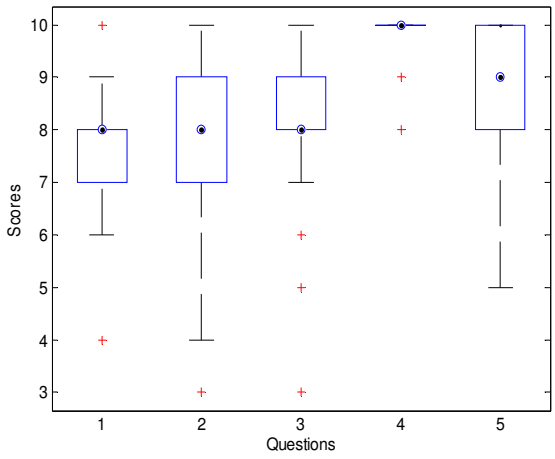

Fig. 4 Box Plot for the questionnaire. The median is indicated black dot in a circle

IV. Conclusion

We developed MoMiRES that is mobile mixed reality based game play environment with using glove with various sensors such as bend, pressure. The system aim is to motivate OT/PT patients with game play and assist them in given therapy regiments under the supervision of their therapists. The solution is low-cost, portable and accessible for both patients and therapists. The therapy can be monitored by the therapist and patients' progress can be overseen in real-time. The system has three components; wearable glove integrated with sensors for finger motions and pressure that are received and transmitted it to mobile game, a mobile game that uses sensor data used in game play for manipulation of avatar, and cloud data where all logged sensor information is transmitted to cloud storage for later use by therapists to assess the patient progress over the time. We also carried out initial questionnaire to assess the MoMiRES expediency in treatment. Based on the results, we have noted over 92% acceptance. As a future work, we plan to increase the therapy regiments in the game play and also will imitate the preliminary clinical studies.

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