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PATIENT FACING SYSTEMS

KinoHaptics: An Automated, Wearable, Haptic Assisted, Physio-therapeutic System for Post-surgery Rehabilitation and Self-care

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Abstract A carefully planned, structured, and supervised physiotherapy program, following a surgery, is crucial for the successful diagnosis of physical injuries. Nearly 50 % of the surgeries fail due to unsupervised, and erroneous physiotherapy. The demand for a physiotherapist for an extended period is expensive to afford, and sometimes inaccessible. Researchers have tried to leverage the advancements in wearable sensors and motion tracking by building affordable, automated, physio-therapeutic systems that direct a physiotherapy session by providing audio-visual feedback on patient's performance. There are many aspects of automated physiotherapy program which are yet to be addressed by the existing systems: a wide classification of patients' physiological conditions to be diagnosed, multiple demographics of the patients (blind, deaf, etc.), and the need to pursue patients to adopt the system for an extended period for self-care. In our research, we have tried to address these aspects by building a health behavior change support system called **KinoHaptics**, for post-surgery rehabilitation. *KinoHaptics* is an automated, wearable, haptic assisted, physio-therapeutic system that can be used by a wide variety of demographics and for various physiological conditions of the patients. The system provides rich and accurate vibro-haptic feedback that can be felt by the user, irrespective of the physiological limitations. *KinoHaptics* is built to ensure that no injuries are induced during the rehabilitation period. The persuasive nature of the system allows for personal goal-setting, progress tracking, and most importantly life-style compatibility. The system was evaluated under laboratory conditions, involving 14 users. Results show that *KinoHaptics* is highly convenient to use, and the vibro-haptic feedback is intuitive, accurate, and has shown to prevent accidental injuries. Also, results show that *KinoHaptics* is persuasive in nature as it supports behavior change and habit building. The successful acceptance of *KinoHaptics*, an automated, wearable, haptic assisted, physio-therapeutic system proves the need and future-scope of automated physio-therapeutic systems for self-care and behavior change. It also proves that such systems incorporated with vibro-haptic feedback encourage strong adherence to the physiotherapy program; can have profound impact on the physiotherapy experience resulting in higher acceptance rate.

This article is part of the Topical Collection on *Patient Facing Systems*

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Introduction

A major surgery is usually followed by an extended rehabilitation program for about one to six months [1]. The success of a surgery depends on two things: 1) how well the rehabilitation program is planned by a physiotherapist, and 2) how strictly a patient adheres to the physiotherapy program [2]. Due the nature of rehabilitation programs, which require a physiotherapist for an extend period of time, it is becoming increasingly difficult to afford and have constant access to a physiotherapist. The need for having a constant access to a physiotherapist becomes significantly concerning if the patient is residing in a rural or suburban area.

For a patient residing in rural area, he/she faces two main problems: 1) constant travel to a closest city to have access to a physiotherapist, and 2) increased strain and cost. Most importantly, it is advised by doctors that patients should not constantly travel, for at least a few months, following a major surgery. Extensive travelling puts a patient at the risk of injuring the site of operation or loosening the internal threads due to possible sudden jerks.

Researchers have extensively used advancements in motion tracking sensors to build automated physiotherapeutic systems. These systems reduce dependency on physiotherapists, and aim to provide customizable and an entertaining physiotherapy program for patients [3–6]. Currently available physio-therapeutic systems use audio-visual feedback, this kind of feedback may not have a significant impact on patients with physiological limitations. For example, a blind or deaf patient cannot use an automated physio-therapeutic system with audio-visual feedback.

In our research, we have addressed the limitations of existing automated physio-therapeutic systems by incorporating haptics assisted, ubiquitous, non-intrusive feedback mechanism. The system monitors a patient's physiotherapy session through a Kinect sensor, while specifically watching for the movements of selected joints, and feedback on patient's performance is provided through vibro-haptic pulses delivered via an armband.

The armband has an embedded array of vibratory motors, and via Bluetooth connection, the armband connects to *KinoHaptics* framework running on a computer [7–9]. In addition, the system also provides visual feedback on a computer monitor. Feedback on user's performance by the *KinoHaptics* system is based on an exercise program created by a physiotherapist, which is loaded as a configuration file by the *KinoHaptics* system. *KinoHaptics* generates vibro-haptic feedback whenever a user reaches the preset angle of elevation for a specified joint (body-part), during a physiotherapy session. This feedback prevents users from overdoing an exercise and hence prevents related injuries. Conversely, the feedback also ensures that a user is not under performing the suggested exercises.

To exemplify the functioning of *KinoHaptics*, assume a case where a patient has recently undergone shoulder surgery, and needs to undergo a physiotherapy program for restoring shoulder movements. A physiotherapist develops a program for the patient by specifying the angle of elevation during the physiotherapy session, this information is saved as a configuration file. The configuration file is shared with the patient for use at home. When it is time for the patient to perform an at home physiotherapy session, the patient loads the configuration file in the system, and as the patient begins exercising, Kinect watches for the movement of joints (in this case, shoulder joints). Once the user has raised his shoulder to the required angle of elevation, the user is notified through a haptic feedback delivered via the armband, indicating that the required height is achieved, and to stop any further movements. On a computer monitor, the user also sees the visual animation of himself exercising, as well as the progress.

Approach

We conducted system evaluation under laboratory conditions involving 14 participants. All participants were university students. The participants were chosen to ensure that they fall under one of the three categories: 1) participants who suffered an injury, and had undergone an extended period of physiotherapy, 2) participants who had no prior injury, but had limited motion in their limbs, and 3) participants with no prior injury, and no limited motion of their limbs. Experiments with each participant involved a pre and post user-study survey. The diverse user group helped us understand various characteristics of *KinoHaptics*: a) user convenience, b) effectiveness of vibro-haptic feedback, and c) persuasive nature of the system in behavior change.

Contributions

In our research we found that, an automated, wearable, physio-therapeutic system with an extend feedback mechanism through haptics, supports user convenience, and hence encourages strong adherence to the physiotherapy program. The system is persuasive in influencing a user to adopt a physiotherapy program, over an extended period. In addition the system also assures that no accidental injuries occur during the rehabilitation period.

Literature review of related works confirmed the originality of *KinoHaptics*. We will further discuss these related works and the unique features of *KinoHaptics* in section “Prior work”. In sections “System design” and “Implementation” we describe the system design and implementation details respectively. Section “Experiments” covers our experimental protocol, evaluating the efficacy of the system. Results from our laboratory studies are provided in section “Results”, followed by a discussion section “Discussion” that interprets the results and presents inferences. The paper will be concluded with a conclusion section “Conclusion”, and a future work section “Future work” discussing the future of automated, wearable, physiotherapeutic systems.

Prior work

The Bureau of Labor and Statistics projects a near 40 % job growth by 2022 for physiotherapists [10]. This increasing demand for physiotherapists and the need to create automated, affordable, and patient friendly physio-therapy systems, necessitates advanced research in this field [5, 6]. Improved accuracy of motion tracking, affordable motion tracking sensors, and ability to create wearable sensors at low cost has expedited research in automated physiotherapeutic systems.

Most automated physiotherapy systems share a common theme: to make physical therapy fun and engaging through gamification. Two methods are employed for successful gamification of exercises: 1) Tracking body movement using motion tracking sensors, specifically with Microsoft Kinect, and 2) Video-Capture-Based Virtual Environment for rehabilitation. While there are numerous research works on automated rehabilitation systems for physiotherapy the most relevant works with research goals in alignment with the contributions of *KinoHaptics*, use kinect as the primary motion tracking device.

Kinect based physio-therapeutic systems

Automated physio-therapeutic systems based on Kinect have been studied in good detail by Chien-yen Chang et al. [11], Lange, B et al. [12], Yao-Jen Chang et al. [13], Antonio Bo et al. [14], Shih-Ching Yeh et al. [15], Kitsunezaki N et al. [16], etc. Chien-yen Chang et al. [11], developed a pervasive physical health rehabilitation system using Kinect; in addition the system also used OptiTrack devices to compare patients performance and cost, in the field of game-based rehabilitation.

Lange, B et al. [12], created a low cost, game-based, balance rehabilitation tool using Kinect. Yao-Jen Chang et al. [13], exclusively focused on young adults with motor disabilities, and their rehabilitation using a Kinect based system. Antonio Bo et al. [14], used both Kinect and Inertial sensor to improve the joint angle estimation for rehabilitation. Shih-Ching Yeh et al. [15], used Kinect to create game based rehabilitation exercises to create bring about an interactive experience using motion tracking on voice commands. Kitsunezaki N et al. [16], used Kinect to give real-time feedback and measurements in rehabilitation.

These systems identically employ visual and audio feedback while lacking haptic feedback. This method is distracting as visual or audio feedback requires users’ attention. When a user’s attention is shared between physiotherapy and attentively watching video feedback, there are chances of re-injury, and hence, this method of feedback is not intuitive and safe.

Video capture based physio-therapeutic systems

Video Capture based Physio-therapeutic systems have been researched by Patrice L Weiss et al. [17], Rachel Kizony et al. [18], and Heidi Sveistrup et al. [19]. These researchers similarly used video capture based system to create a virtual reality environment to perform various physio-therapeutic treatments. In each of these systems, real-time images recorded by a video capture system is imported into a virtual reality environment and displayed on a screen. Users can interact with the virtual environment by moving parts of their body. These virtual reality systems create an experience similar to the ones found in a real life environment.

Weiss, Kizony and Sveistrup also focused on using video capture and virtual reality based systems to treat specific injuries during rehabilitation. Patrice L Weiss et al. [17], applied a virtual reality environment for rehabilitation involving motor and cognitive process. Rachel Kizony et al. [18], focused on creating a system for patients with paraplegic spinal cord injuries by creating a virtual environment where a patient is tasked with catching objects as they appear on a screen. Heidi Sveistrup et al. [19], directed the system to users going through motor rehabilitation. These users were tasked with navigating through a virtual environment to exercise their motor skills. These systems neither use Kinect for motion tracking nor provide haptic feedback. The absence of vibro haptic feedback makes patients with physiological limitations unable to use such systems.

Physio-therapeutic systems with haptic feedback

There has been limited primary work on automated physiotherapeutic systems with haptic feedback. Works include, Uri Feintuch et al. [20], Guevara et al. [21], RF Boian et al. [22], D Sadihov et al. [23], etc.

Uri Feintuch et al. [20], integrated haptic-tactile feedback into a video-capture-based virutual environment for rehabilitation. The system uses a GX VR system, where a user can interact with a two dimensional virtual environment. Haptic feedback based on user's interaction in virtual environment is delivered through haptic gloves worn by the user. Guevara et al. [21], created robotic exoskeleton, which is controlled by Kinect; the system uses a single haptic sensor to retrieve the mechanical force needed to move a specific limb during physiotherapy. This information will help the therapist to sense the resistance of the patient.

RF Boian et al. [22], created a haptic feedback system specifically for podiatric rehabilitation. The system stimulates walking in a virtual environment. Also, this work summarizes different approaches to foot interaction.

D Sadihov et al. [23], created upper-limb rehabilitation system, which is enhanced with motion based tactile feedback. The system is built with the main focus on rehabilitation of stroke patients. Kinect is used for upper limb tracking and a haptic glove for providing feedback through interactive vibration pattern for an immersive experience.

These systems are limited in their ability to support physiotherapy of any other part of the body rather just the limb. The limitations of these systems stem from the fact that they use haptic gloves for feedback. KinoHaptics, unlike these systems uses a vibro-haptic armband that communicates with kinect wirelessly; it can be worn on any part of the body for physiotherapy.

The prior works discussed are constrained by one or more limitations with feedback mechanism, motion tracking, flexibility, or the way haptic feedback is delivered. *KinoHaptic* address all these issues by using Kinect for motion tracking, and a wireless armband for vibro-haptic feedback; the armband can be worn on any part of the body. Lastly, KinoHaptics provides a well-designed, easy to use, and a live feedback patient client interface for additional visual feedback.

System design

KinoHaptics is an ubiquitous, intelligent, multi-agent system that uses state of the art technologies, sensors, and devices from motion tracking and haptics domains [7–9]. The system aims at providing unobtrusive and natural feedback via haptic vibrations. Hence, we have created an armband that is easily customizable and can be worn around any part of the patient's body, undergoing physiotherapy. For tracking the motions of a patient's body, as precisely as possible, we use Kinect 2.0 that is higher in precision when compared to its previous versions, and has biometric capabilities. The interface of the system is designed to be user-friendly and intuitive to operate by both the patient and the physiotherapist. *KinoHaptics'* user interface is developed using unity3d game development framework.[1] The interface consists of two modules: 1) Patient's interface, and 2) Physiotherapist's interface. A pictorial depiction of the system design is as shown in Fig. 1.

Armband

Armband, a wearable wristband, is responsible for directing a patient and providing feedback on the performance during a physiotherapy session. The vibro-haptic feedback not only have a utilitarian value, but it assimilates richer immersive experience into the physiotherapy program [7–9]. The ability of vibro-haptic feedback to sway between patient's periphery and center of attention creates a calm experience as the patient is notified only when the task goal is accomplished; each task expects a patient to lift the body-part to the required angle of elevation.

The vibro-haptic feedback mechanism also simulates a real time experience of having a physiotherapist during the session. Each distinct vibro-haptic feedback generated by the armband is an encoded message from the *KinoHaptics* framework; the intensity, duration, and number of haptic pulses delivered can be configured by the physiotherapist.

Kinect

KinoHaptics uses Kinect 2.0[2] for motion tracking of a patient's body during a physiotherapy session. For each physiotherapy program, a configuration file is created by a physiotherapist that is then read by the *Patient Client*. Before beginning a physiotherapy session, Kinect interfaces with the *Patient Client*, and retrieves all information specific to the physiotherapy session.

A configuration file for a physiotherapy session has various details: a) number of exercises in that session, b) exercise name, c) body part, d) angle of elevation, and e) number of repetitions. Once a physiotherapy session begins, Kinect watches for the specified body part, and the angle of elevation. After the patient raises the body part to a required angle of elevation, kinect sends a message to the armband to generate a vibro-haptic feedback, and this completes one repetition. The same process continues for the number of repetitions mentioned in the physiotherapy configuration file.

Bluetooth modem

Bluetooth Adapter communicates messages between the *Armband* and *Patient Client*. *KinoHaptics* uses a Bluetooth

[1] www.unity3d.com

[2] www.microsoft.com/en-us/kinectforwindows/meetkinect/default.aspx

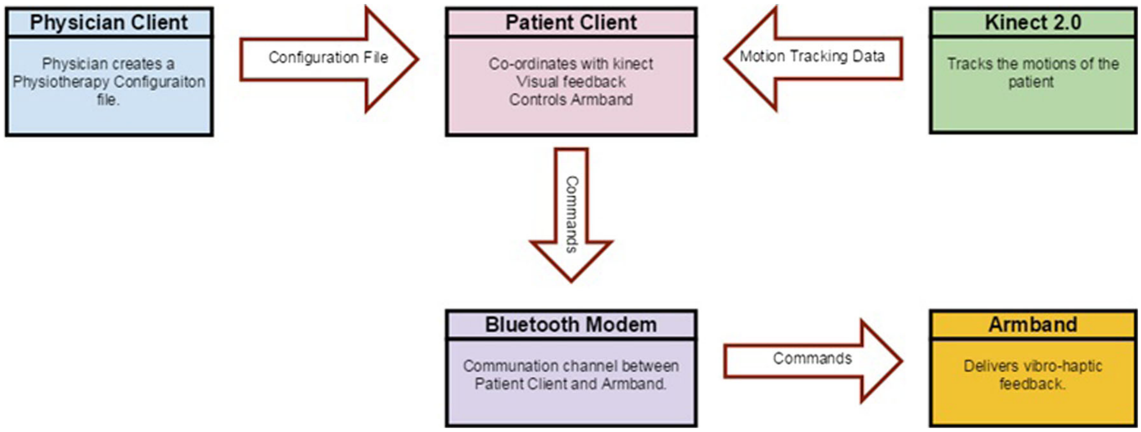


Fig. 1 KinoHaptics - System Architecture

Modem (BlueSMiRF) by SparkFun Electronics.[3] Bluetooth Modem enables unconstrained movement of body-parts and user convenience as there are no fixed cables. All control instructions to the armband during a physiotherapy session are sent via Bluetooth Modem; each control instruction has an encoded meaning. All messages received from the *Patient Client* are delivered to the Teensy Microcontroller on the armband. *KinoHaptics* uses Teensy++ 2.0 Microcontroller, an Arduino Software Compatible, USB Development Board produced by PJRC.[4] The microcontroller controls the functioning of vibration motors by decoding the instructions received from Bluetooth Modem.

Patient client

Patient Client, is the patient's interface to KinoHaptics system that directs a patient, and provides visual feedback during a physiotherapy session. Patient client runs on a computer, and has a Kinect connected to it to track patient's movements. It reads physiotherapy configuration files to understand the goals of a physiotherapy session. Once the patient achieves the required angle of elevation during a physiotherapy session, the *Patient Client* sends a message to the *ArmBand* to notify the patient. The visual feedback system has an interface with a progress bar, and a circular dial to reflect the session progress and angle of elevation respectively.

Physician client

A physiotherapist uses the *Physician Client* to develop a physiotherapy program for a patient. Physician Client, a standalone desktop application, provides an interface for the physiotherapist to specify various attributes relevant to the physiotherapy program. The physician uses *Physician Client* interface to create a physiotherapy configuration file with a list of exercises, and values of four attributes for each exercise: 1) exercise name, 2) body part, 3) angle of elevation, 4) number of repetitions. The resulting physiotherapy configuration can be exported as an independent file. A patient loads the configuration file generated by a physiotherapist in *Patient Client* interface that directs the physiotherapy session.

Working model

Functioning of the system begins with a physician creating physiotherapy configuration file in the *Physician Client*. A configuration file contains details on all the exercises to be performed during a physiotherapy session. A patient loads the physiotherapy configuration file in the *Patient Client*. A Kinect sensor is connected to the *Patient Client*, which is responsible for motion tracking. *Patient Client* establishes communication with the armband via Bluetooth. Kinect tracks movements of the specified body part, once a patient begins a physiotherapy session. A vibro-haptic feedback is delivered to the patient, when Kinect detects desired angle of elevation of the body part. The patient restores to normal position after receiving a haptic feedback, and this completes once repetition.

Further, the patient repeats the same exercises for the number of repetitions specified in the configuration file. The patient can view the progress of the physiotherapy session, and the whole body motion tracking on his/her computer monitor. The physiotherapy session is concluded, once all the exercises specified in the configuration file are performed, for the specified number of repetitions. A pictorial depiction of the working model is shown in Figs. 2, 3, 4, 5, 6, 7 and 8.

[3] www.sparkfun.com/products/12577

[4] www.pjrc.com

Fig. 2 Wearable Armband On User's Shoulder

Movement model

The design of KinoHaptics allows for multiple configurations of physiotherapy programs. This flexibility of the system allows for tracking multiple movements of a body part under physiotherapy. The agility of the system is achieved by allowing a physician to design the complete physiotherapy program on a Physician Client system. The physician client allows for selecting various shoulder and leg joints on a human model, and specify the angle of elevation as described in section "Physician client". During a physiotherapy session, unless the angle of elevation of the body part moves outside of the range of angle specified, the system considers such movements as natural movements. However, all other movements, outside of the allowed angle range are identified as accidental movements. KinoHaptics instantly notifies the user in case of accidental movements through haptic feedback. The calculation of angle between the reference point and body part under physiotherapy is described in section "Angle calculation".

Implementation

Physician client

User interface of *Physician Client* is built on .NET framework using C# programming language; the GUI[5] components are created using Unity 3D engine[6] and related graphics libraries. The interface adopts a simplistic design by providing a minimal GUI for creating an exercise plan.

[5]Graphical User Interface

[6]www.unity3d.com

Fig. 3 Automated Physiotherapy Session

To select a part of the body for a therapy program, a physician selects the buttons positioned on various shoulder and leg joints of the human model displayed on screen. *Add Exercise* feature allows the physician to add an exercise to the physiotherapy program by specifying the exercise name, body part, angle of elevation, and the number of repetitions. Other features of the system allow the physician to update existing exercises and provide various file handling capabilities. A pictorial depiction of physician client is as shown in Fig. 9.

Patient client

Patient Client is the control center of *KinoHaptics* system. It is a platform that establishes connections between Kinect, Armband, and the Visual Feedback system. Similar to *Physician Client*, the user interface of *Patient Client* is

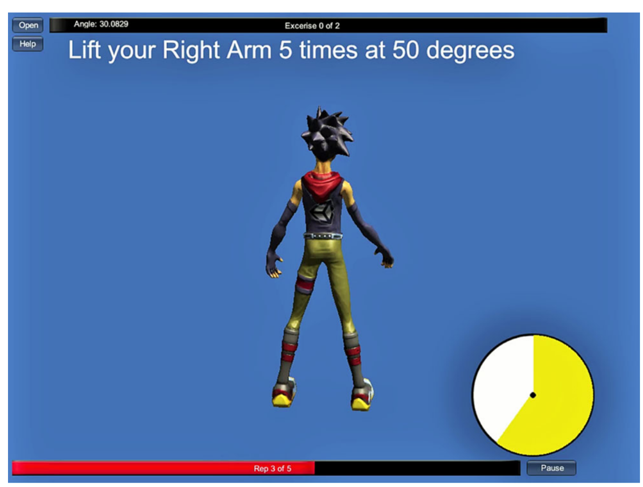


Fig. 4 Goal Partially Completed - Right Arm

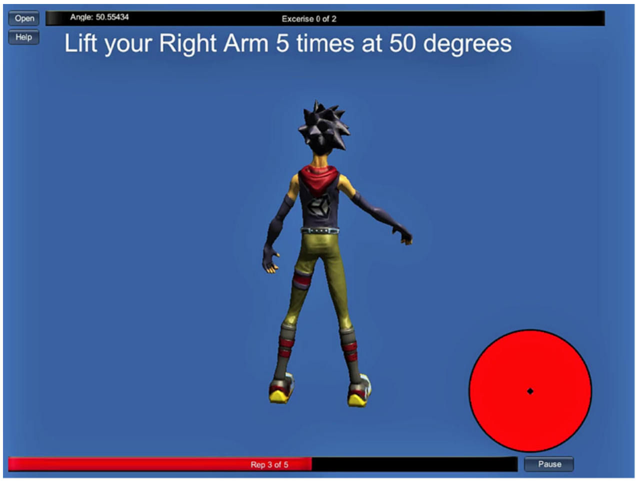


Fig. 5 Goal Completed - Right Arm

Fig. 6 User Started Exercise - Left Arm

built on Unity 3D engine[7] and related libraries. Bluetooth communication between the armband and patient client is implemented over *InTheHand.Net* Bluetooth libraries supported by 32feet.net.[8] Interface with Kinect is implemented on *Micorsoft.Kinect* library.[9] Patient client maintains a list of exercises supported by *KinoHaptics*; it also establishes an association with part of the body and corresponding exercise. A pictorial depiction of the physician client is shown in Fig. 10.

Angle calculation

We use data from Kinect sensor to calculate the angle of elevation of the body part during a physiotherapy session. Kinect tracks three points on the body-part selected for exercise. This data is transformed into two vectors (Fig. 11), and we find the angle between two vectors to find the angle between joints.

$$\text{Angle Between Joints} = \arccos \frac{a.b}{|a||b|}$$

Armband

Armband is one of the main components of *KinoHaptics*. The Armband is built indigenously by using three main electronic components: 1) Bluetooth modem, 2) Teensy microcontroller, and 3) Vibration motors. A pair of velcro straps secures the band onto a patient's body. A power pack made of four AA batteries powers the armband. There are several vibration motors positioned along the band, and two motors are specifically positioned at the center of the band for higher sensation. A pictorial depiction of the Armband is as shown in Fig. 12.

Armband circuitry

The band hosts five components: 1) A battery pack, 2) Bluetooth Modem, 3) Teensy Microcontroller, 4) Six vibration motors, and 5) A 10 Ohm resistor. The battery pack is made of four AA batteries and produces six Volts of power. The receive and send pins of the Bluetooth modem are connected to two output ports of the Teensy Microcontroller. A pictorial depiction of armband circuitry is shown in Fig. 13.

The Teensy microcontroller has logic that allows for several different settings of vibrations to be set. A command of "d###" (e.g., d500) is used to set the delay in milliseconds between pulses of motors; delay values in the range of 001

Fig. 7 Goal Almost Completed - Left Arm

[7] www.unity3d.com
[8] http://32feet.codeplex.com/
[9] https://msdn.microsoft.com/en-us/library/microsoft.kinect.aspx

Fig. 8 KinoHaptics - Goal Completed - Left Arm

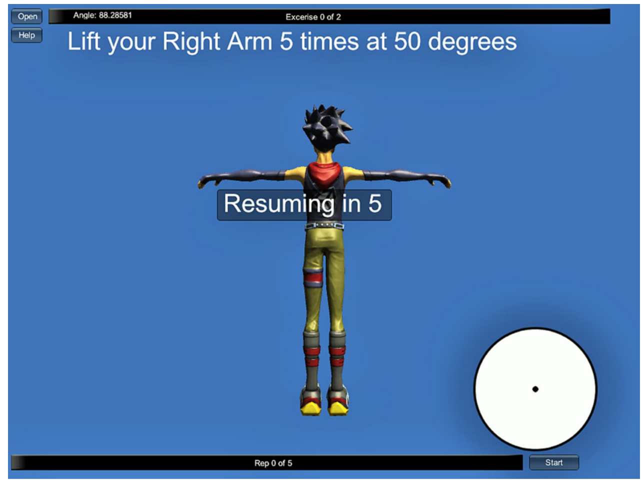


Fig. 10 KinoHaptics - Patient Client

to 999 are valid. A command of "p#" (e.g., p7) is used to set the total number of pulses to be delivered for each "on" command; pulses in the range of 1 to 9 are valid. A pulse value of '0' sets the motor permanently to "on" state. A command of "lvl#" (e.g., lvl6) is used to set the strength of vibration; but this command was not fully implemented, and hence, is always set to "lvl9".

A command of "on" is used to turn the motors "on", and the motors will pulse for the delay set, then pause for the delay set, and then pulse. The pulse-pause cycle repeats for number of repetitions set using command "p#". A command of "onc" functions similarly to an "on" command, but permanently turns the motors on. A command of "off" is used after the "onc" or "on" with "p0" commands. This command turns the motors from permanently "on" to "off" state. Teensy has a single output port that sends voltage to the motors. This output port is routed throughout the band and supplies power to all the motors, a possible future expansion of this would be to individually wire each motor to a separate port. This would allow for various motors to be turned on or off at different times. The band is made of a soft felt-like material. This material dampens the motor vibrations, without this material, the strong vibrations of the motor are inconvenient to users. This material also feels comfortable against the user's skin, while being easy to sew together. These features combined made it the ideal material to use for the creation of armband.

Experiments

In evaluation of *KinoHaptics*, we wanted to explore four main aspects: 1) Convenience of the system for self-care, 2) Intuitiveness of vibro-haptic feedback over audio-visual feedback, 3) Accuracy of the system in generating timely feedback, and 4) System's ability to pursue a user for behavior change and habit building. The user study was conducted under laboratory conditions. The study involved 14 participants (2 female and 12 male) between the ages 20 to 23,

Fig. 9 KinoHaptics - Physician Client

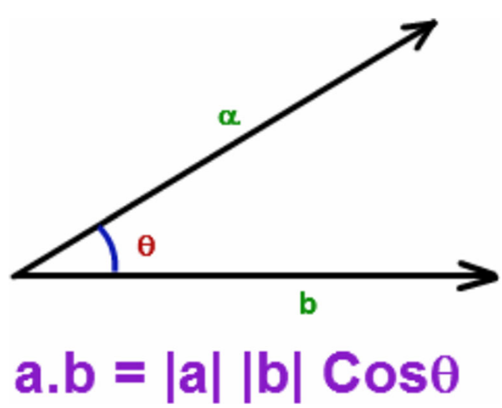


Fig. 11 KinoHaptics - Angle Calculation

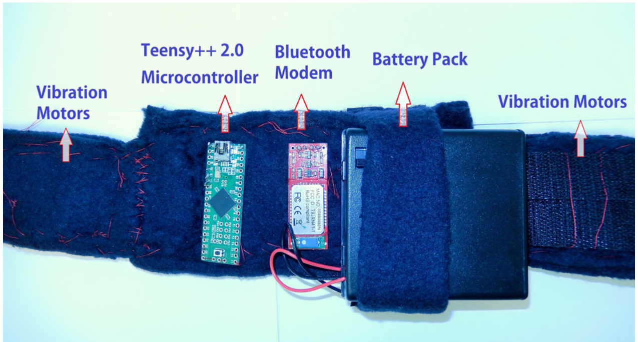


Fig. 12 KinoHaptics - Vibro-haptic Armband

while 22 being the average age. All participants were university students. 3 of the 14 participants had suffered an injury earlier, and had undergone an extended physiotherapy program. Feedback from each of these three participants are significant to our study, as they could compare and contrast *KinoHaptics* with their experience of physiotherapy sessions under the supervision of a physiotherapist.

During the user-study participants performed two activities: 1) Raise the right arm five times to 50 degrees, and 2) Raise the left arm seven times to 80 degrees. Participants had the freedom to fix the armband anywhere on their shoulder, in accordance with their convenience. The two kinds of tests (left arm and right arm) were performed one after the other, and there was no delay in between. Before every test began, each user was given brief instructions on system functionality and how to use graphical interface of the system. In addition, every user completed a pre and post user study questionnaire. Pre-user-study questionnaire had both qualitative and qualitative questions regarding user's background, medical conditions, and history of injury. The post-user-study questionnaire had only qualitative questions that are focused toward exploring the above listed four goals of the user study.

Results

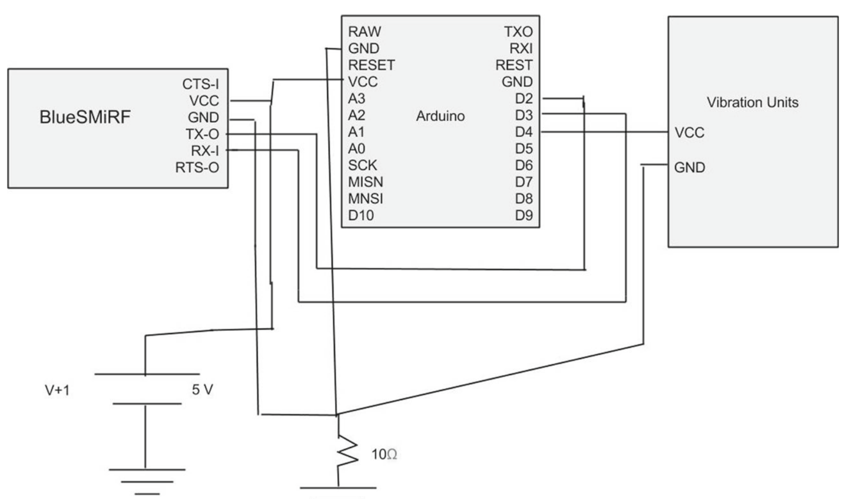
Each user filled a post user study survey, and was interviewed. Ninety-three percent of the participants reported that the user interface is simple and easy to use. Participants found the animation of a human model mirroring user's actions in real-time highly engaging. The progress bar for an overall session, and a circular progress bar for live feedback on exercises were features the participants found highly informative and easily interpretable. Few participants reported that font size for the interface could have been bigger, and suggested to use numbers on the progress bar and more contrasting colors.

One hundred percent of the users reported that the design of the Armband and vibro-haptic feedback are appropriate and they could easily feel the notifications. However, we received two requests for improvements with the armband: 1) Armband feels bulky for a person with small stature, and 2) Use a belt in place of the velcro for a tighter fit. Aside from these two comments, most of the users found it convenient to use the armband either around the shoulder or thigh.

One hundred percent of the users reported perfect timing of the haptic feedback. They received the feedback in time when the selected body part was raised to the required angle of elevation during a physiotherapy session. Also, no case of false positive or false negative haptic feedback was reported. Two users reported that users should be able to set the vibration level on the armband to feel the vibrations even when wearing thick clothing.

When the users were asked what kind of features they would like to add, users made the following suggestions, which are mostly cosmetic changes: a) a tutorial, b)

Fig. 13 KinoHaptics - Armband Circuitry



repositioning a few UI controls, and c) a different color scheme. A prominent feedback received for this question is to incorporate the ability to save data from a physiotherapy session, and share it with the doctor for feedback.

Discussion

Results of the user study indicate that *KinoHaptics* conclusively answers three out of four research questions set for the system evaluation: 1) User convenience, 2) Intuitiveness of the haptic feedback and 3) Accuracy of the system.

A 93 % acceptance rate with minimal suggestions related to UI changes indicate that *KinoHaptics* is easy to understand, requires little learning, has appropriate mapping of controls to actions, and provides precise user feedback. One hundred percent of the users completely relied on haptic feedback and there was very little to no dependency on the visual feedback.

Users received vibro-haptic cues instantaneously, and they were able to clearly distinguish between haptic cues for start, end, and repetition of an exercise. A higher acceptance rate for vibro-haptic feedback indicates that users found haptic feedback intuitive, immersive, and most importantly, unobtrusive. Also, a vibro-haptic feedback system reduces the demand on users' attention, since in haptic feedback, unlike visual feedback, a user has to pay attention only on haptic cues.

One hundred percent of the users reported that they received haptic cues most accurately, when they lifted shoulder to the angle specified. There was no single case of a false buzz. Also, there was no case of a missing buzz while performing a suggested exercise. It is most important for us to comprehensively test the last goal: "System's ability to pursue a user for an extended period of physiotherapy using the automated system and hence support behavior change and habit building".

Based on the results of our user study that conclusively answers all, but one, of the research questions, we strongly believe that *KinoHaptics* is influential enough to motivate a user to strictly adhere to the physiotherapy program even in the absence of a supervisor.

This persuasive nature of *KinoHaptics* will drive behavioural changes and habit building as some physiotherapy programs run for six to 10 months [24]. In the second phase of extended user studies *KinoHaptics* will be tested thoroughly for its ability to support behavior change and habit building; this requires user studies for about four to six months long.

Conclusion

In this research we present *KinoHaptics*, an automated, wearable, haptic assisted, physio-therapeutic system for post-surgery rehabilitation and self-care. The system is built to address multiple goals related to post surgery physiotherapy: a) Reduce dependency on a physiotherapist by using an automated, wearable, physio-therapeutic system with comprehensive feedback, b) Enable physically challenged users (e.g., blind and deaf) to use automated, wearable, physio-therapeutic system by incorporating vibro-haptic feedback, c) Reduce injuries during physiotherapy, and d) To be persuasive toward behavioral change and habit building by supporting personal goal-setting, progress tracking, and life-style compatibility.

KinoHaptics is built using state of the art technologies like Kinect, wearable haptic sensors, wireless communication, and a rich user interface through animations and game objects. The system enables a physiotherapist to create a physiotherapy program for a patient, who can then practice the exercises on his own with the assistance of *KinoHaptics*. Physiotherapy program developed by a physiotherapist comprises of various details like part of the body that needs to be exercised, angle to which the body part needs to be raised, and the number of repetitions.

This information is saved in a physiotherapy configuration file, which can be read by a *Patient Client* that directs a physiotherapy session. A Kinect sensor connected to *KinoHaptics* tracks movements of the patient's body part undergoing physiotherapy. A vibro-haptic feedback is delivered when the body part being tracked is lifted to a required angle of elevation. A unique feature of this system is its ability to provide feedback non-invasively through haptic vibrations. An armband that is created indigenously is worn by the patient during a physiotherapy session; it communicates with *Patient Client* and delivers haptic feedback appropriately.

Aside from one research question on *KinoHaptics's* ability to pursue a user for an extended period of use, the system conclusively answers rest of the research questions: 1) Convenience of use, 2) Intuitiveness of vibro-haptic feedback, and 3) Accuracy of automated, wearable, haptic assisted, physio-therapeutic system. System evaluation shows that, ninety-three percent of the users found the system convenient to use for self-care. A 100 % of the users consensually agreed that vibro-haptic feedback is comprehensive enough to interpret and understand while exercising. Lastly, a 100 % of the users reported that *KinoHaptics* delivered highly accurate feedback.

To summarize, the successful acceptance of *KinoHaptics*, an automated, wearable, haptic assisted, physio-therapeutic system proves the need and future-scope of automated, wearable, physio-therapeutic systems. It also proves that such systems incorporated with vibro-haptic feedback can have profound impact on the physiotherapy experience and higher acceptance rate.

Future work

KinoHaptics can be further extended to support user customization and multi-pattern vibro-haptic feedback. The existing implementation uses only one output pin (voltage) on the microcontroller to control all the motors. This output port is routed throughout the band, and hence, all the haptic motors are either turned on or off at the same-time. A future work will focus on using all the nine output ports on Teensy microcontroller to control haptic motors, and hence, every haptic sensor can be programmed to behave uniquely. The ability to control individual haptic motor will enable new haptic feedback patterns, and each pattern can convey a unique cue. The current implementation considers a movement as accidental, if the angle of elevation is outside of the angle range specified. However, while within the specified angle range unnatural movements like twists, or jerking movements may occur. The system should be extended to identify such accidental movements. Further, the system can be extended to support exercises that are more complex by adding more than one armband. Multiple armbands in conjunction with multiple haptic feedback patterns enable highly customized physiotherapy systems with rich feedback.

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[10] http://srl.tamu.edu

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