HemiPhysio App:

A smartwatch-based application for measuring upper limbs movement in children with Hemiparesis

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***Abstract*—A smartwatch's constant contact with the wrist provides opportunity to measure the differences in the movements of hands (upper limbs) in children with Hemiparetic Cerebral Palsy (CP) while performing daily physical activity (e.g., walking, eating). Children with Hemiparesis have significant weakness (spastic, contractures) on one side of the body that leads to impaired functions on that side. This paper gives the concept and design of a "HemiPhysio" app to collect the activity-related data of both upper limbs using sensors in a smartwatch. The machine learning models trained on collected data are then used to detect the impaired functions by the smartwatch. The child is then instructed for appropriate movement or correcting posture using alert or haptics. The HemiPhysio app should work for dynamic motion activities (e.g., walking) and for the static posture activities (e.g., eating), as well as the related upper limbs movements in these activities. The goal of our application is to encourage Hemiparetic children to use both hands during daily activities.**

Keywords-Smartwatch; Hemiparesis; machine learning; alerts and haptic feedback; activity and gesture detection.

I. INTRODUCTION

Today's smartwatches are like strapping a networked computer with sensors to one's wrist [1]. Recently, the hardware and software capabilities of smartwatch technology has advanced to an extent where these smartwatches can be used to diagnose certain medical conditions. The latest smartwatches have many sensors with sufficient computing to recognize variety of human physical activities [2]. These sensors provide accurate data to apps to track user's movements and other health related activities. However, it is still too early to know that smartwatches will work as truly independent computing devices.

Motor skills are heavily affected in the children with the Hemiparesis or weakness on one side of the body (arm-dominant or leg-dominant) [3]. Hemiparesis is often associated with Cerebral Palsy (CP) or pediatric stroke, and characterized by functional motor impairment [4]. Children with impaired function on one hand (arm dominant) typically experience problems with day-to-day activities that can range from using the bathroom, and eating to difficulty participating in sports or playing video games. This functional impairment is due to muscle weakness and/or mild paralysis on the affected side of the body.

These children tend to use only the normal side to do all their routine tasks and they need a constant reminder of using weak arm and hand as well. These physical impairments can impact social and emotional health and cause significant stress on the family. Physical and occupational therapies are natural approaches to rehabilitation that encourages the use of two hands during daily activities, and hence improving the gross and fine motor skills. However, it is costly in terms of therapy sessions, transportation, and time for parents and caregivers.

Hemiparesis leads to muscle weakness, decreased coordination, decreased control of muscles and muscles spasticity. Spasticity prevents the stretching of muscles and tendons and if not treated it causes contraction where the muscles and tendons are stuck in the shortened position, and forming difficulty with fine- or gross-motor movement. For example, if ankle is spastic it can lead to toe walking.

A smartwatch's constant contact with wrist and high user acceptance makes it ideal to collect, understand, measure, and compare hand, wrist, forearm, elbow, upper arm and shoulder movements of both upper limbs of hemiparetic children using accelerometer and gyroscope sensors.

Section II describes the existing work using smart devices and wearables in health informatics. Section III gives high level functional requirements and the conceptual design of HemiPhysio app. The acknowledgement and future work close the paper.

II. SENSOR BASED ACTIVITY AND GESTURES RECOGNITION STUDIES

Smartphones and smartwatches today come with many advanced sensors and programming interfaces to interact with them. These sensors collect real time data about the world around these devices. Most smartwatches have at least accelerometer, gyroscope, and pedometer sensors. These smartwatches give a unique opportunity to understand user's hand and arm movements. In the remaining section, some related work to evaluate the progressive use of sensors technology, mainly in health, is discussed.

A study conducted with young, healthy participants showed that smartphone applications and wearables using pedometer and accelerometers are accurate for tracking steps count [5]. The smartphone applications included iOS and Android apps, whereas waistband and wrist devices were used as wearables.

The accelerometer and gyroscope sensors in smartwatch can identify user's arm, hand and finger gestures [6]. Motion energy measured using the smartwatch is sufficient to uniquely identify hand and finger gestures. Accelerometer and gyroscope data reflects the movement of tendons (passing through the wrist) hand and fingers gestures. These features uniquely identify 37 (13 finger, 14 hand and 10 arm) gestures with an accuracy of 98%. The finger gestures are especially challenging to detect using smartwatch since the movement in the wrist when doing a finger gesture is very small and it is not clear whether it can be recognized uniquely. The possible application of gesture recognition is to remotely control the devices such as televisions, computers, and smartphones.

A recent study showed high usability and high technology acceptance when a mobile app (mHealth) was used and evaluated by the patients for frozen shoulder physiotherapy [7]. The mobile app provides instructions for exercise at home and tools to monitor patients training compliance and progress. The training compliance and progress data are then used by physiotherapists and physicians to assess the mobility of the shoulder and pain in shoulder movement and adjusting the therapy accordingly. The app includes a mobile phone sensor–based mobility measurement for monitoring the progress of the effect of the treatment of frozen shoulder.

Another study evaluated the accuracy, precision, and overall performance of seventeen wearable devices (fitness trackers, body sensor devices) with direct observation of step counts and heart rate monitoring [8]. The study focused on accelerometers used in applications of trackers on Android or iOS devices. Data of accelerometer sensors was recorded and the mean step count, standard deviation, accuracy, and precision were estimated for each tracker. The accuracy of the tested wearable devices ranged between 79.8% and 99.1%, while the coefficient of variation (precision) ranged between 4% and 17.5%.

Another smartwatch-based activity recognition study using a machine learning approach has shown a high accuracy in recognizing hand-oriented activities [9]. It showed that smartwatches are more accurate (93.3%) for recognizing specialized hand-based activities than smartphones (77.3%) and can form the basis of new health applications. The study focused on apps capable of tracking eating activities to replace the manual methods for maintaining a food diary. The eating-related activities (total 5) have the lowest prediction accuracy than non-eating (a total of 13 e.g., walking, kicking, typing, etc.). Among machine learning algorithms, the Random Forest (RF) algorithm showed overall highest accuracy in classifying activities.

Real-time and Online Assessment and Mobility Monitoring (ROAMM) is a smartwatch-based framework for mobility monitoring and data visualization of personal health [10]. The smartwatch application component is for collecting and preprocessing data and a server component to store, retrieve, and remote monitoring. The framework is limited to measure average minutes spent on some movement activity without requiring any machine learning approach.

The above applications and framework show the suitability of smartwatches in health systems and are considered a replacement of specialized devices for recognizing physical activities.

III. HEMIPHYSIO APPLICATION DESIGN

This section discusses the requirements and conceptual design of HemiPhysio application.

A. *Motivation and Requirements*

As discussed in section II, the existing applications using smartwatches do not collect and identify differences in the upper or lower limbs movements of children with Hemiparesis. Also, the existing studies either recognize gestures of hands, fingers, forearm, etc., independent of any physical activity or recognize the physical activities without considering gestures in that activity. Our work is recognizing the activity as well as the gestures or movements in that activity.

Following are some high level requirements:

1. Collection of patient's data from accelerometer and gyroscope of physical activity and the activity related gestures and movements. For example, a walking activity consists of hands, wrists, elbows, forearms movements. Samples are collected from weak and healthy limbs simultaneously. The HemiPhysio framework will work for dynamic motion activities (e.g., walking, running) and static posture activities (e.g., eating, standing). It will also work for activities where gestures or movements in both limbs are usually symmetric (e.g., walking) and for activities where one limb moves more than the other.
2. Training machine learning models on collected data. Patients are different in terms of spasticity and contractures therefore models trained on patient's own data are preferable. The machine learning models trained using only the participant's own data of activities performed much better in activity recognition than the impersonal models trained on the samples from all participants applications [9].
3. Identify child's spastic parts of upper limb and the resulting contractures using the machine learning models.
4. Measuring the difference in movements of weak and healthy limbs.
5. App reminds the patient to move or use weak limb in order to participate in activity.

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B. HemiPhysio Design

Our proposed design has two main components: the training component, and the detection and notification component. In the first phase as shown in Figure 1, two smartwatches are used, one on each hand, to collect timestamped sensors data from both limbs for a certain physical activity. This data is used to train and create customized Machine Learning (ML)vmodels to recognize sufficient gestures from the dominant (normal) limb and the corresponding impaired functions data from the weak limb.

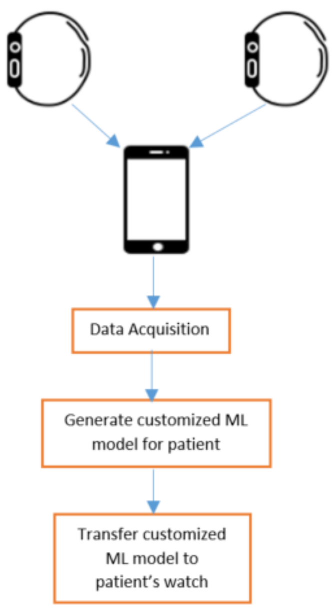

Figure 1. HemiPhysio App training phase.

Figure 2 shows the second component of our design that deals with real time activity detection (e.g., walking or eating). When a certain activity is detected our app running on the smartwatch starts to collect gesture or movements. This data is then fed to the on-device ML model at regular intervals. The ML model will be able to detect if there was insufficient movement on the weaker limb. The app will then instruct the child to move the weaker limb through alerts and haptics. The insufficient movement event is then recorded in the application's database to be synchronized later on with devices of caregivers and parents as this data will be of immense help to them to identify patterns of insufficient use of upper limbs in children.

Currently, we are developing HemiPhysio application on Apple platform as devices (Apple Watch and iPhone) and developers APIs come from same vendor. We found issues with Google's WearOS support for Samsung and other smartwatches. However, later we will test our app on other platforms as well. Apple iOS and WatchOS provide stable framework WatchKit and app services, such as CoreMotion for sensors data, HealthKit for monitoring physical activities, CoreML for creating machine leaning models [11]. CoreMotion API of WatchOS also provides us with software based sensors, such as CMDeviceMotion, which provides us various values of rotation and acceleration of the smartwatch, which can help us better detecting gestures during an activity.

The current health kits that are available on mobile and smartwatch platforms focus more on common activities such as walking, running, climbing steps and storing and retrieving various health related data. Though smartwatches have progressed to detect conditions such as cardiac problems thanks to a heart sensor, however they cannot detect impaired functions on a weak hand in a condition, such as Hemiparetic CP, which our work aims to tackle.

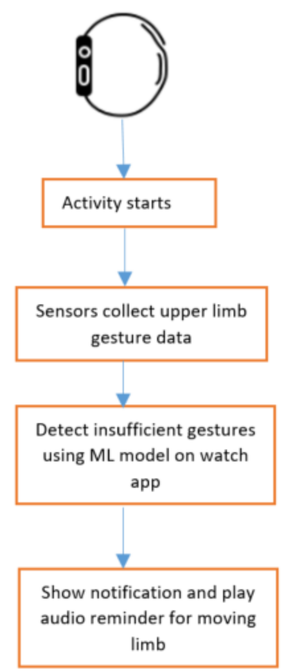

Figure 2. HemiPhysio Detection phase.

C. Data Collection

In our proposed app, the movement data is collected from smartwatch sensors of both (normal and weak) upper limbs. Movements include: arm movement (lateral arm lift, frontal arm lift, lateral external rotation, and back rotation), elbow movement, hand movement, wrist movement, and finger movement. HemiPhysio App prototype will support two sensors initially: accelerometer and gyroscope. An accelerometer measures the linear acceleration of movement. We will use accelerometer to detect the linear orientation of upper limb. A gyroscope adds an additional dimension to the information supplied by the accelerometer by tracking rotation or twist.

D. Machine Learning Models

ML leaning algorithms such as Naïve Bayesian, Neural Networks, Binary decision, Random Forest e.g., will be used as they have been already tested in physical activities classifications [9]. Running ML classifiers on the watch itself ensures the privacy of data and works even without paired device.

IV. CONCLUSION AND FUTURE WORK

We do not argue that these health applications can replace the need for human physiotherapists but augment the work of therapists and caregivers. Health or mobile health (mHealth) apps running on smart devices can be an affordable solution for children and parents and can improve healthcare system. This research will open the doors to extend the benefits of collected data in other health applications for Hemiparetic children. We hope to achieve with HemiPhysio app the CP management goal to increase functionality, improve capabilities, and sustain health in terms of locomotion [4]. The treatment includes physical therapy depending on patient's specific symptoms. Physical training increases muscles strength and possibly improves motor activity in Hemiparesis patients.

Once the application development is complete we will test its working and accuracy on the collected data from the patients. This will be done with the help of healthcare professionals and the feedback from patients and caregivers. The experiment results will be analyzed for the appropriateness of training data collection, the detection of insufficient mobility during the activity, and the alerts to patient from smartwatch to engage the weak side in ongoing activity. This research will help us to develop future apps and games for children with Hemiparetic CP. This includes instructional physical therapy, reminding using voice commands to encourage the use of weaker upper limb, etc. This work will help us in developing an architectural framework that can be used for developing similar health apps, which use machine learning on a smartwatch to detect similar medical conditions.

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