2015 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE)
19-20 December 2015, BUET, Dhaka, Bangladesh

# The Development of Low Cost Exercise Monitoring Device for Paralytic

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***Abstract*— Paralysis may not be cured completely but can be recovered by going through proper rehabilitation process. But many of these disabled patients lack the enthusiasm and motivation for time consuming and costly rehabilitation process. Moreover it is difficult for the people of low income group of Bangladesh to afford regular and expensive physiotherapy sessions. The primary focus of the work was to fabricate an exercise monitoring device from locally available materials at low cost. The device will provide audio-visual instructions of exercises like shoulder abduction, adduction, flexion and extension. It will also provide necessary feedback for executing them through an android device. The monitoring device can locate the position and comprehend the motion of affected limb using an accelerometer. Data exchange happens through Bluetooth using serial port profile. The device will gather vital dataset like pitch angle and number of repeated motion to determine correctness of exercise and save for sharing, hence making it possible to trace consistency and improvement of the patient without the need of constant presence of a physiotherapist. This paper presents the fabrication process, performance evaluation of the device. The scopes for future improvements are also discussed.**

***Keywords—paralysis; physiotherapy; exercise monitor***

## I. INTRODUCTION

Paralysis is the loss or impairment of voluntary muscular power which is commonly caused by stroke, head injury and spinal cord injury. It may not be cured completely but can be recovered to some extent through medication and proper physical exercise. Rehabilitation process can take long time; it requires repeating regular specific exercises, commitment, dedication and high motivation. But the rehabilitation process can be tedious, often hard to continue, daunting and expensive as well. In addition, rehabilitation process requires extensive support and supervision of physiotherapists directly. This problem can be handled by the use of appropriate technology. Recently a number of automated and semi-automated systems have been developed to support physiotherapy and rehabilitation [1]. A carefully designed machine controlled rehabilitation system can render the rehabilitation process more fruitful by reducing human effort, providing appropriate feedback and precise results within the fraction of a second. It can be cost-effective as well if properly implemented. Use of technology in rehabilitation process is a promising sector and is being researched thoroughly in first world countries [2]. But they are very expensive to be afforded by the mass people. People of low income group from Bangladesh cannot afford such costly rehabilitation devices. On top of that, Bangladesh lacks the state of art technology and high end components required to manufacture such devices. The main focus of the project was to fabricate a device that will perform the role of a virtual physiotherapist by monitoring specified exercises performed by the patient and ensuring proper exercise by providing apt feedback. The prime concerns while fabricating the device were to reduce cost, utilize available component from local market for easy reproduction and easy, user friendly operation.

In this paper the fabrication process of a low cost exercise monitoring device using locally available materials is presented. The device will provide audio and visual instructions of exercise suggested or prescribed in Bangla through android based smartphone, Observe movement of the limb containing the device during those exercises, collect the vital data and communicate with android smartphone which will save the data for sharing and analysis.

## II. DESIGN CONSIDERATIONS

Following pivotal points were considered in designing of the device:

- Cost effectiveness: The device was fabricated using cheap, easily available and replaceable components available at local retailers.
- Easy operation: The device was designed to be easily operable so that minimum technical knowledge is required to utilize the device.
- Compact size: The device had to be small and compact so that it does not cause any obstruction on the user's movement.
- Safety: The device could not contain any potentially dangerous component which can harm patient in any way.
- Necessary feedback: The device had to have means to interact with the user through visual or audible signal for effective performance.

The device uses an android based smartphone for user interaction, processing and information storage. An android application was developed as a GUI (Graphical User Interface) facilitating to interact with the device and obtain crucial feedback. The android GUI had to be user friendly. The app had to have written and audible instructions and guidelines in Bengali so that less educated and native speaking people can use the device with ease.

### *A. Hardware Design*

Small size, precision and sensitivity of micro electro mechanical (MEMS) accelerometer sensor make it a powerful tool for sophisticated purpose like joint angle calculation of human body to analyze motion pattern and other physical activities [3]. Thus the device contains an accelerometer ADXL 335 for sensing motion, a microcontroller ATmega 8 for processing purpose, and for wireless communication with the host it contains a HC-05 Bluetooth module. Few other components like buzzer and led are present for visual and audible feedback. It runs on lithium ion battery of 3.7 volt which can be charged using a conventional cell phone charger. So the user does not have to buy charger separately. The output of the accelerometer is ratio metric, i.e. output voltage changes depending on the change in supply voltage. When the device is static, the output voltage on any axis parallel to ground, that is, sensing no gravitational pull, the output voltage will be half of the supply voltage on that axis. Data from the device are transmitted to android smartphone through SPP (serial port profile). The device also contains an adjustable elastic cuff to attach it with patient's arm or leg. The cuff maintains the orientation of the device.

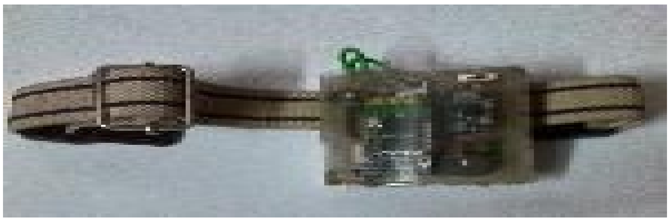

Figure 1: Prototype of the device

### *B. Working principle*

Accelerometer converts acceleration into electrical signal. Both dynamic and static acceleration can be measured using an accelerometer. The sensors measure the difference between linear acceleration along any axis and the earth's gravitational field vector. In absence of the linear acceleration, the accelerometer output is a measurement of the rotated gravitational field vector and can be used to determine the accelerometer tilt angles which in turn can be used to obtain accelerometer pitch and roll angle [3, 4]. The device utilizes tilt sensing capacity to calculate elevation and rotation of affected arm or leg of the patient. When the accelerometer is static, the axes aligned parallel to the earth's gravitational field vector, which is acting downward, will give output equal to 1g. A dual axis accelerometer can only sense tilt using only one axis; the other axis will give a constant output for full range of rotation. Since there is a reduction in resolution and accuracy beyond 45 degrees of tilt, a 2 axis accelerometer can be used to overcome this drawback.

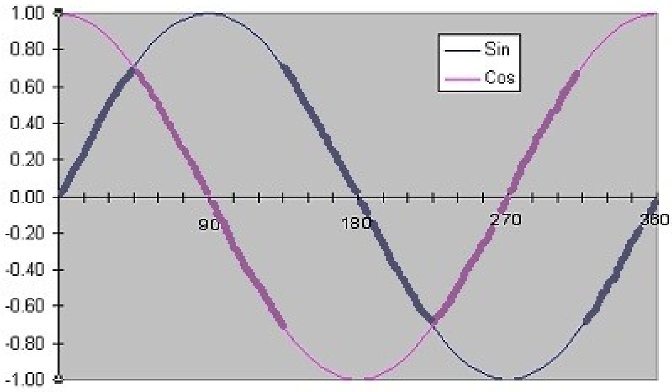


Figure 2: Sensitivity of accelerometer using two axes [3]

The graph above shows that in case of a two axis accelerometer, the value of gravity vector along X-axis follows the sine function while the value of gravity vector acting along the Y-axis follows the cosine function. The tilt sensitivity of X-axis is lowest where the tilt sensitivity of Y-axis is highest and vice versa. Therefore, maximum tilt sensitivity can be obtained by combining both the X and Y outputs. So 3- axis accelerometer is used. In case of a 3–axis accelerometer, pitch (θ) is defined as the angle of X-axis relative to ground. Roll (ψ) is defined as the angle of the Y-axis relative to ground, and (Φ) is the angle of the Z-axis relative to direction of gravity. By analyzing pitch and roll angle, orientation of the accelerometer can be successfully determined. [3, 4, 5, 6, 7, 8, 9, 10]

There are a number of exercises for rehabilitation of paralyzed patients to recover and improve their deteriorated fine motor skills. These exercises are often carefully selected and prescribed by the physiotherapist according to the patient's requirement and ability. For this work shoulder abduction-adduction exercise was chosen to be demonstrated which is a fairly common and effective exercise affecting shoulder muscles. To successfully complete this exercise, the patient has to lift affected arm sideways up to shoulder level. Keeping arm straight, the arm has to be lifted out to side to shoulder height, elbow straight and palm downward. Then the arm has to be returned to its normal position, that is parallel to the imaginary midline of the body, the fingers pointing downwards to the ground. The correctness of exercise is determined by knowing the number of up and down movement performed by the affected limb, and determining the maximum pitch angle reached during the exercise. The device is attached to the patient's arm or leg with the help of the adjustable cuff which fixes the orientation of the device. When the hand of the patient is lifted then the value of the gravity vector along the axis normal to gravity will change and a corresponding voltage output will be obtained. A graph of output voltage drop associated with the change of gravity vector against time is plotted below. In this case, x-axis of accelerometer was pointing down and shown in green color in the figure.

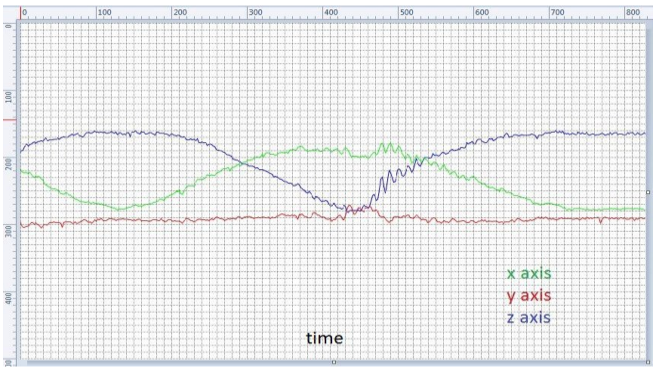


Figure 3: Graph of voltage drop due to orientation change of the device with respect to time

By plotting voltage output against time, a repeating wave form is obtained. For a complete cycle the signal consists of a positive slope representing upward motion of the hand and a negative slope indicating downward motion, i.e. returning of hand to its normal position. When the signal reaches its local maxima, the hand with the device attached was assumed to be at its maximum height. The opposite was assumed in case of the negative slope. The average of local maxima and local minima is the local average. Whenever the voltage output exceeds the last calculated local average, the hand was assumed to have completed a full up-down movement cycle. But since the local maxima and minima were not fixed, and a global crisp value for local average could not be obtained, so the local average was updated after a certain number of cycles. Continuous updating of the local average made the algorithm less susceptible to error when the hand achieved variable height and provided more accuracy. We can measure the corresponding pitch or roll angle from the voltage value using simple trigonometric equations.

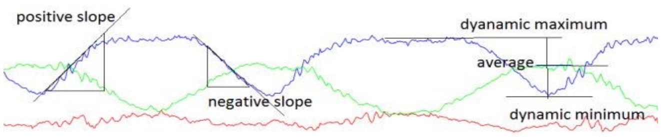


Figure 4: Visual representation of dynamic maximum, minimum and average

*C. Interface and Game Design*

The android app interface and the game were designed to be easily navigable by the user. The game was focused on engaging the patient more with the rehabilitation process, encouraging interaction with the content, involving the patient in physical activity both in the game and in reality [11]. It was developed with a viable difficulty level so that the player does not lose motivation. The interface was made colorful for visual comfort and aesthetics. The game contains all essential guidelines for comfortably following. The device first requires calibrating itself according to the user's muscle strength. For instance, the user has to lift the arm to the maximum height he or she can reach. Once the device is calibrated, the user then can continue with the game which responds to the motion of the affected limb containing the device providing feedback to correct motion pattern in form of numerical score. The app has an option to save and send the score of current game to the preset number of the designated physiotherapist via text. This way the physiotherapist can keep track of activity and improvement of the patient. Some screenshots of the game are given below.

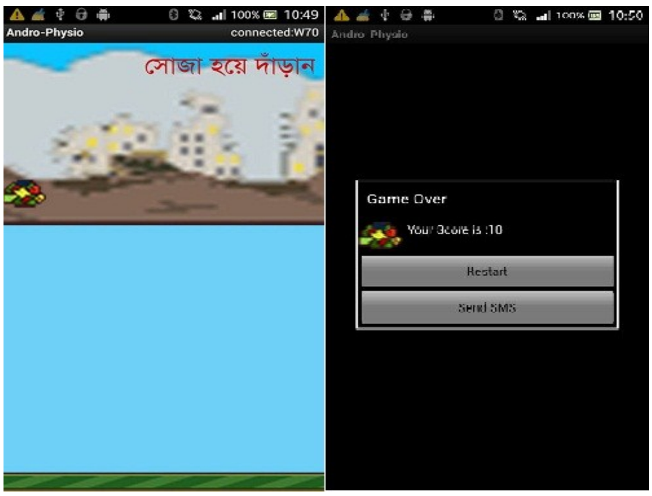


Figure 5: Screenshot of the android app

## III. PERFORMANCE

The data set necessary for the game were the number of up and down movement and the maximum angle reached by the affected limb. For successful performance, the device had to provide accurate data of these two actions, without any unwanted random movement or rapid tremor of the limb should get recorded and the angle measured should be as accurate as possible. A test was arranged involving 5 test subjects of age ranging from 25 to 50 having varying upper body strength. The device was attached to the subject's left or right arm and the procedure was briefly explained. A table of output data of the device is presented below.

TABLE I

| Subject No | Age | Number of up-down movement actually performed | Number of up-down movement recorded by the device | Accuracy percentage % |
|---|---|---|---|---|
| 1 | 40 | 8 | 7 | 87.5 |
| 2 | 27 | 10 | 10 | 100 |
| 3 | 52 | 6 | 6 | 100 |
| 4 | 40 | 5 | 5 | 100 |
| 5 | 43 | 7 | 6 | 85.7 |

## IV. LIMITATION AND FUTURE WORK

Exercises which require to know yaw angle, that is motion of the limb taking place in horizontal plane are not possible to monitor by this device. Integrating a tilt compensated digital magnetometer can be a practical solution [12]. Besides, in spite of the implemented filtering system, some noise was incorporated during capturing signal from accelerometers. These noises are attributed to voltage spikes caused by improper discharge of the battery, sudden involuntary tremors of the affected limb of the patient and other unavoidable reasons. A more advanced filtering system is needed to avoid unwanted voltage spike and reduce noise.

At present the app developed for the device is available to android platform only because it is open source. But this work can be extended to other platforms like iOS and windows.

Currently the android app can send SMS to a designated person preset by the user. For easy accessing of the data, an online database can be developed which will contain the data of all registered patients using the device individually, which can be uploaded from the app via web. Also an enhanced and updated list of exercises is needed engaging all possible body parts exposed to the threat of paralysis.

## V. CONCLUSION

The reach of technological innovation is growing very fast. It is playing an increasingly significant role in healthcare in a global scale. A low cost exercise monitoring device for paralysis patient rehabilitation was developed as an attempt to take part in this technological advancement. With more in-depth research and further development this device can play a substantial role in paralysis patient rehabilitation.

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