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MEMS Sensor based Online Physiotherapy System

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***Abstract*— Physical Therapy is a branch of rehabilitative health that uses specially designed exercises and equipment to help patients regain or improve their physical abilities. We propose a MEMS inertial sensor based Physical Therapy Application that guides patients to perform exercises and assists therapists to monitor as well as teach the specially designed exercises to patients. The application includes an Automated Exercise Generator for therapists to record exercises, an Automated Posture Recognition and Tracking System to track and guide the patients while they perform the exercises and a Visual Feedback System for patients to correct the position and movement of their Joints through Direct and Inverse Kinematics approach. In this paper, we investigate how to enable continuous tracking of patients for pre-authored physiotherapy exercises. We introduce a state-machine-based approach that tracks a patient's progress and provides continuous feedback indicating whether the patient is doing an exercise correctly or not. Patients seeking physiotherapy treatments are mostly aged and frail people who find it difficult to travel to hospitals and hence seek treatments by themselves. So they rely on others' help which and some would be forced to skip the sessions as the centres may not be near. The people seeking physiotherapy may be suffering from ailments as minor as a normal leg sprain to severe cases like Cardio-respiratory dysfunction. This paper makes use of MEMS sensors like MPU6050 which can be interfaced to our software suite that can recognize and record the exercises to be done by the patient. This suite can mimic the actions of patient subjected to, flexi-bands fastened around his joints to read his body movements and facilitates the system to understand the motion and hence the discrepancies between the optimal values prescribed by the physiotherapist and recorded observations of the patient respectively will be compared, checked for the regularity of the exercise performed, recovery pattern among different individuals for similar kinds of disorders would be studied.**

Index terms - accelerometer, physical rehabilitation, MEMS based inertial sensor, Direct and Inverse Kinematics.

I. INTRODUCTION

In the modern world the needs are growing so is the demand for developing novel techniques to transform the large distance barriers in our lives. This growing concern has to be addressed by making everyone self-sustainable. The modern era has witnessed a sudden ubiquitous growth in the bio medical engineering field which was neglected till a few decades back. The physically ailing members of our society need the assistance of others. An attractive alternative, an embedded device with inertial and accelerometer sensor has been papered to sense the activities of the user, which comes as a great relief to the ailing patients. It requires the determination of the parameters by the data tracking hardware capable of capturing the motion trajectory. To this day only the time of therapy has been investigated but in this paper it's been extended to the efficiency and the various possibilities of executing the same exercise has been studied. This technology would revolutionize the medical field with positive reactions from the consumers. Conventional researches in this field of motion sensing could be broadly classified as: data glove based and computer vision based. The proposed methodology of introducing high grade sensors would impart more precision to the various calculations. In this approach the frail patients can be easily be attended from home as the interfacing suite can accommodate auto scaling for multiple uploading with great ease. Over the past few decades many approaches for posture identification have been proposed, one such technique involves the determination of the recognition factor which often is dependent on the distance between the two points lying the frame which further requires the prediction of path taken. These techniques have been implemented only to an extent of still and static documents and not completely accurate. As a dynamic picture conveys more information and is fairly challenging for the existing methodologies. In general conventional approaches takes an image and further breaks down it into several parts in a phase known as fragmentation. Hence the Direct and Inverse Kinematics approach was followed in this system, so as to provide the rea-time analysis of each and every body parts. The study here is focused on the Human arm (1 limb) which would be extended later to all body parts by considering and providing individual reference frames as elaborated in section IV.

Based on technical reports collated on this mems based accelerometer technique segmentation forms an integral part of most techniques which involves determination of start and stop time which clocks a frequency of 80 MHz The modern gaming consoles also have similar technology like Nintendo Wii and PS torch. Telephysiotherapy has focused again the attention of many researchers during the last few years. Yet another improvement in this field has been in cloud hosting of data by WBAN technology used to analyze data, diagnose patient health state. The difficulties being in dynamically updating the information. In which the auto regressive moving average is determined to find the changes in the patient's current state.

II. RELATED WORK

Over the past few decades many approaches for posture identification have been proposed, one such technique involves the determination of the recognition factor which often is dependent on the distance between the two points lying the frame which further requires the prediction of path taken [6]. These techniques have been implemented only to an extent of still and static documents and not completely accurate. As a dynamic picture conveys more information and is fairly challenging, a recent advancement was made which involves measurement of active time by continuous time analysis [4]. In general conventional approaches takes an image and further breaks down it into several parts in a phase known as fragmentation. As an effort to bridge the differences in these methods an acceleration quantization method was proposed by which the DTW algorithm was implemented with the reference stored in a template Library which would give the minimum distance [5].

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Yet another improvement in this field has been in cloud hosting of data by WBAN technology fused with VM services used to analyze data, diagnose patient health state [1]. The difficulties being in dynamically updating the information. In which the auto regressive moving average is determined to find the changes in the patients' current state [2].

In the scientific literature the most relevant work deals with the design and implementation of the input perceived. Efforts to make physiotherapy online has been made many times by the international scientific fraternity [2,3]. One such efforts made involves the determination of the recognition factor which often is dependent on the distance between the two points lying the frame which further requires the prediction of path taken [9]. These techniques have been implemented only to an extent of still and static documents and not completely accurate. Numerous approaches are proposed for literature based on the fuzzy logic, Gabor wavelet transform and dynamic time wrapping which estimates the shortest path by numerical value. Most researches and reports from technical articles indicate that the modern game consoles also have similar technology like Nintendo Wii and PS torch [3]. Telephysiotherapy has focused again the attention of many researchers during the past few years which adopts the NFC technology which trumps over the conventional RFID technologies but comes with a downside of poor range and dependency of a mobile phone [7]. Yet another development in this field has been in cloud hosting of data by WBAN technology used to analyse data, diagnose patient health state. The difficulties being in dynamically updating the information [1,2]. In which the auto regressive moving average is determined to find the changes in the patients current state [6].

III. KINEMATICS OF HUMAN ARM

Kinematics is known as the study of motion without considering the forces that create the motion. Direct Kinematics is the representation of the robot's end-effector position and orientation through the geometries of robots i.e., joint and link parameters. Using Kinematics, the mathematical model is developed to compute the position and orientation of each fingertip (end-effector's) based on the given human joint position. Each human joint is considered as a revolute joint. The homogenous transformation of the fingertip related to the base frame (arm) is formulated using Denavit-Hartenberg (D-H) method.

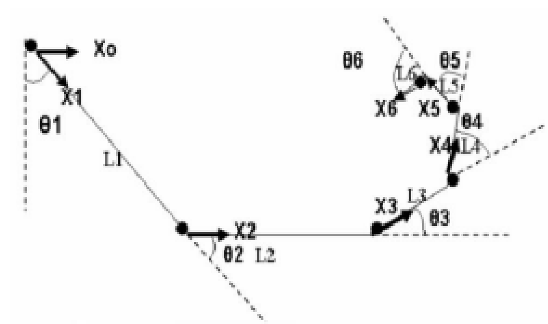

Fig 1: Frames of individual joints linked together.

The human arm was modeled using the Direct Kinematics method. The problem was solved geometrically by attaching individual inertial frames to human arm joints with the reference frame being considered with its origin in the point situated at the middle of the scapular belt. Then all the individual frames of joints are attached to links as shown in the figure 1.

B. Overview of the proposed Mechanism

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3
4	0	L_3	0	θ_4
5	0	L_4	0	θ_5
6	0	L_5	0	θ_6
7	0	L_6	0	0

Table 1: Denavit-Hartenberg table

Using the Denavit-Hartenberg table and the general formula for determining the homogeneous transformation between each frame as shown in the below matrix,

$$T = \begin{bmatrix} cos\theta i & -sin\theta i & 0 & \alpha i-1 \\ sin\theta i.cos\alpha i-1 & cos\theta i.Cos\alpha i-1 & -Sin\alpha i-1 & -Sin\alpha i-1.di \\ sin\theta i.sin\alpha i-1 & cos\theta i.Sin\alpha i-1 & -Cos\alpha i-1 & Cos\alpha i-1.di \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

a final overall transform is obtained by applying the set of transforms sequentially as shown in the below matrix.

$$T = \begin{bmatrix} C\theta 123 & -S\theta 123 & 0 & L1c1+L2c12+L3c123 \\ S\theta 123 & c\theta 123 & 0 & L1s1+L2s12+L3s123 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

We use the following segment lengths for study purpose based on average statistical data.

Subject	L1(Upper)	L2(Fore)	L3(Hand)
Adult Male	0.315m	0.287m	0.105m
Adult Female	0.272m	0.252m	0.091m

Table 2: Segment Lengths.

We use the following angle limits (degree same for both male and female):

Angle	Min	Max
θ_1	-140	90
θ_2	0	145
θ_3	-70	90

Table 3: Angle limits

We simulated Forward Pose Kinematics for the entire range of motion from the minimum to maximum angle on each joint simultaneously.

Given θ_1= -135°, θ_2= 90°, θ_3=45°, the unique FPK solutions are:

$X_{male} = [x_H \quad y_H \quad \theta] = [0.085 \quad -0.426 \quad 0]$
$X_{female} = [x_H \quad y_H \quad \theta] = [0.077 \quad -0.371 \quad 0]$

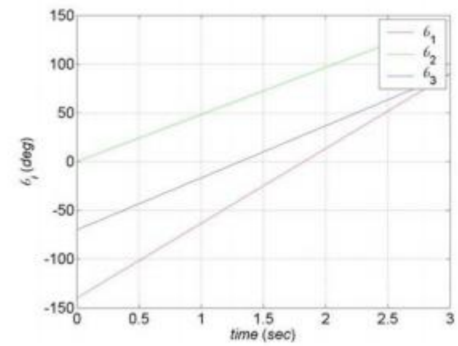

Fig 2: Input Angles

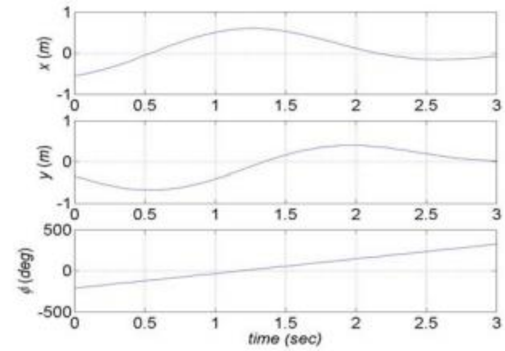

Fig 3: FPK Results (x, y, φ vs. t)

In time series analysis, dynamic time warping (DTW) is an algorithm for measuring similarity between two temporal sequences which may vary in time or speed. Dynamic time warping (DTW) is a time series alignment algorithm developed originally for speech recognition.

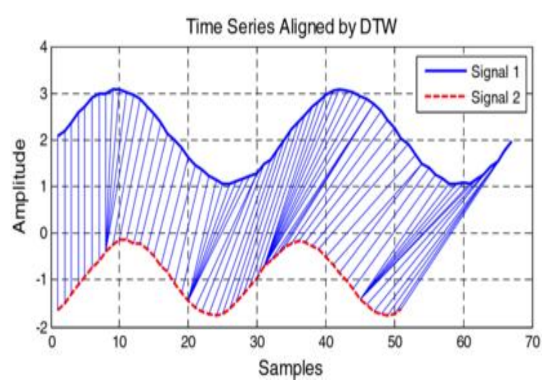

Fig 4: Graphical representation of comparison of two signals using Distance Time Warping Algorithm.

Any data that can be passed on as a linear data can be analyzed by DTW such as audio, video and graphics data. It aims at aligning two sequences of feature vectors by warping the time axis iteratively until an optimal match (according to a suitable metrics) between the two sequences is found. Here, Signal 2 is the reference signal and Signal 1 is the real-time signal. DTW is very fast as it requires O(N2).

DTW is a method that calculates an optimal match between two given sequences (e.g. time series) with certain restrictions.

The sequences are "warped" non-linearly in the time dimension to determine a measure of their similarity independent of certain non-linear variations in the time dimension. This sequence alignment method is often used in time series classification.

The exercise recorded by the physiotherapist is kept as a reference signal showcased as signal 2 in Fig 5, and a dynamic signal of patient's values as he performs the exercise is delivered as an input signal showcased as signal 1 in Fig 5. The Dynamic Time Warping Algorithm measures the similarity between the two temporal sequences and the algorithm's output is recorded and mapped to a percentage scale from 1-100 and recorded on a daily basis as exercise is been performed by the patient.

IV. DESIGN METHODOLOGY

A. Hardware Circuiting

Online Physiotherapy can be achieved by using MEMS Inertial devices. These MEMS Inertial devices are very small and hence can be attached to flex-bands. These flex-bands will be worn on the joint portions of the limbs or arms. The MEMS Inertial devices are interfaced with an ATMega 328 microcontroller through Inter-Integrated Circuit interfacing protocol. The values of MEMS Inertial based sensors are passed to the ATMega328 microcontroller through Serial Data (SDA) and Serial Clock (SCL) links. The microcontroller passes the information to the software on the computer via Bluetooth transmission protocol as shown in Fig 5. A HC-05 Bluetooth module is interfaced with ATMega 328 which facilitates transmission of data to the Bluetooth module attached with the computer.

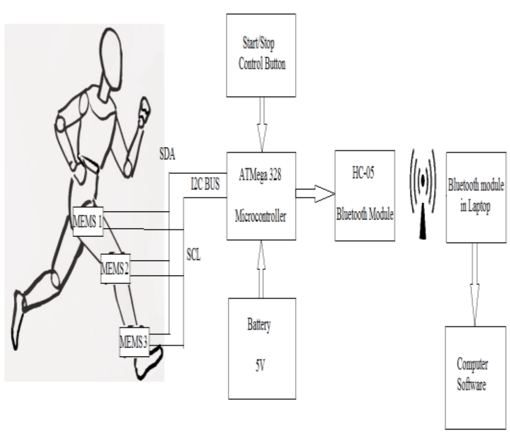

Fig 5: Block Diagram showcasing Data retrieval operation.

B. Software Suite

A fully fledged Python environment Graphical User Interface is used in this paper implemented within the software suite which can detect the continuous changes in the signal and can further be processed. The data acquired through Arduino Uno is read and serially input into the Python based GUI. The three axis data are acquired separately and their vector magnitude is found by calculating the root mean square of the data available at all the three axes. The software analyses the responses and drafts a report on patient's performance. The performance of physiotherapist and patients' limbs are then processed through direct and inverse kinematics approach. The software uses a reference model as prescribed by an expert physiotherapist for evaluation of the patient and compares them through Dynamic Time Warping Algorithm as detailed in above sections. The software then compiles and records daily report of the patient. The above values are then used to perform a statistical analysis of the regularity of the exercise performed, recovery time taken, and the recovery pattern among different patients having similar kind of disorders.

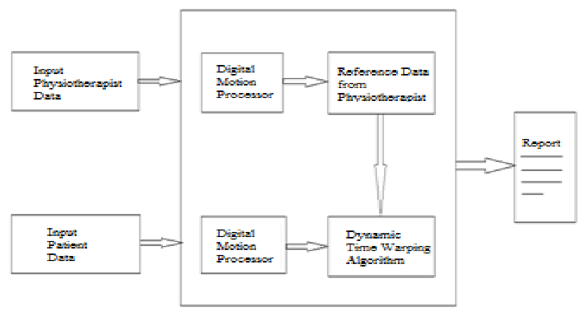

Fig 6: Data Handling inside Software suite.

V. PERFORMANCE EVALUATION

In this paper we could evaluate performance of the patient by tracking the acceleration, angular velocity and angular positions of the movement of the limb as shown in Fig 7, 8 and 9 respectively. We will use both the accelerometer and gyroscope data for the same purpose: obtaining the angular position of the object. The gyroscope can do this by integrating the angular velocity over time. To obtain the angular position with the accelerometer, we are going to determine the position of the gravity vector (g-force) which is always visible on the accelerometer.

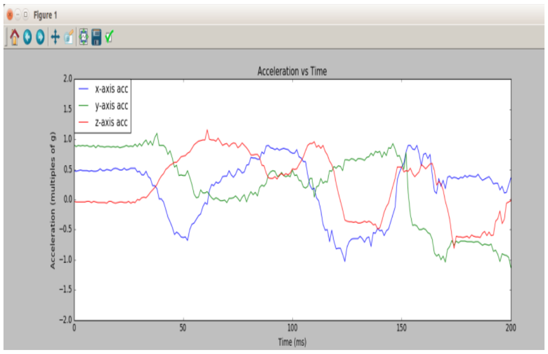

Fig 7: Graphical plot of Acceleration vs Time for x, y, z axis.

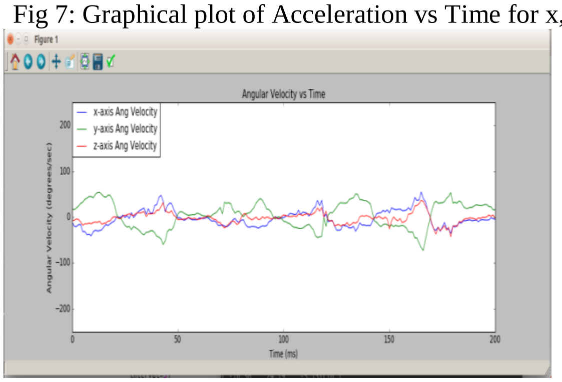

Fig 8: Graphical plot of Angular velocity vs Time for x, y, z axis.

On the short term, we use the data from the gyroscope, because it is very precise and not susceptible to external forces. On the long term, we use the data from the accelerometer, as it does not drift. The complementary filter combines the data from accelerometer and gyroscope to provide a stable result as shown in fig 9.

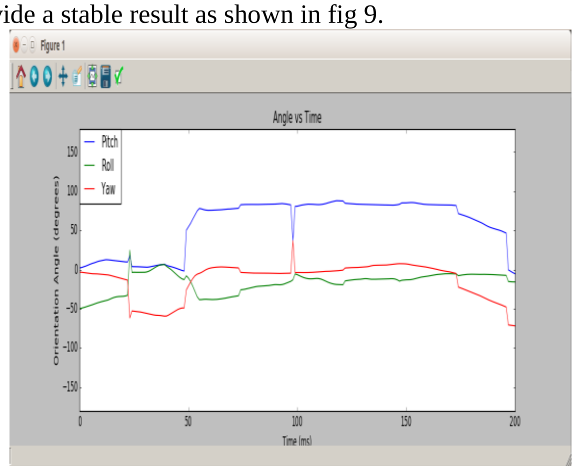

Fig 9: Graphical plot of Angular rotation vs Time for roll, pitch and Yaw using Complimentary filter.

The motion is then compared by Dynamic Time Warping algorithm by comparing the patient's data with the prescribed physiotherapist's exercise obtained. As obtained in Fig 4 an iterative comparison is made with respect to the physiotherapist data for each discrete time sample using dynamic time warping algorithm. The graph shown in Fig 10 contains the deviations in roll axis of one of the MEMS sensors.

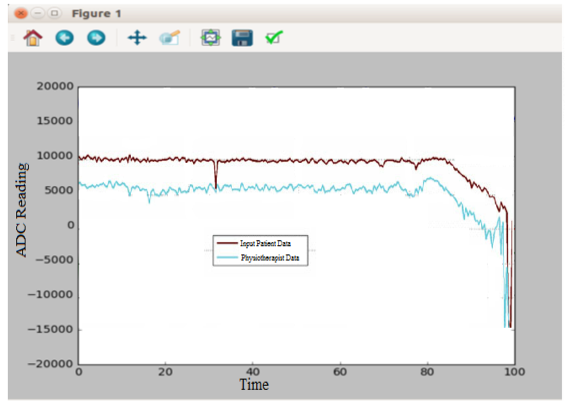

Fig 10: Graphical Representation of roll axis in one of the sensors.

The same concept was applied to pitch and yaw axes in other sensors and the degree of closeness of each MEMS sensor(joint) was obtained individually.

VI. Conclusion

This paper here presented the basic concept and the synergy of methodology for the development of an efficient methodology capable of tracking the movements made by the test subject and results were drawn from comparisons between the optimal and obtained readings. In addition, the methodology has potential for commercial and scientific applications such as patient information retrieval, recovery, etc. This paper produced successful results considering one of the human limb (i.e. the arm) and hence can be extended to other limbs and body parts using the same technology. This paper also attempts to provide a new dimension on the inertial sensor readings' processing. In particular, the methodology presented here deals with helping the patient convalescing and rate of recovery. Statistical and mathematical analysis have shown that the device is capable to track the patient's progress and pattern of recovery among different patients with similar disorders.

The applicability of gesture recognition for physiotherapy is extensive. This project is aimed at the frail and weak building an application suite for dynamically uploading data. It will give quality service to millions of people who are in need of physiotherapy. There are a number of contributions in this paper firstly the power requirement and production cost are seemingly less. It has been proposed to use a long standing battery for optimization in this field. This requires no other additional accessories and only minimal hardware such as bracelet to the arms and legs. Incorporation to the web further enhances the value of this project manifold as cloud seems to conquer the IT industry use of virtual machines can cut down the hardware and makes it rather easy to operate.

Physiotherapy industry is million dollar industry this project was designed eyeing the low income groups. The microcontroller can connect to the PC terminal via the software suite tailored as per user needs. In order to do this we need only bands or bracelet kind of devices for closely monitoring the patient without violating the terms of standard file transfer protocol. It has a robust device operation with greater leeway to incorporate changes.

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