Techniques of measurement for Parkinson's tremor highlighting advantages of embedded IMU over EMG

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***Abstract*—For Parkinson's disease (PD) detection at its best, early diagnosis of the disorder is the key criteria to be focused [5]. Tremors are one of the primary characteristics of PD [11][13]. The paper presents some of the effective biomechanical techniques that can aid in measuring PD tremors with a high grade of accuracy and sensitivity. The paper describes the application of salient tracking tools like magnetic trackers and optical markers, electrical diagnostic practices like Electromyogram (EMG) and the use of Microelectromechanical systems (MEMS) based inertial sensor modules(a combination of 3 axes accelerometer + 3 axes gyroscope) to record movement. The IMU and electrodes were suitably mounted on the hands of subjects who were made to perform certain pre-defined actions to record the wrist movement and electrical activity simultaneously. The ability of a subject to precisely follow a pre-defined task's motion trajectory is a crucial indicator of tremor. In this paper we study two techniques of trajectory measurement, in terms of the accuracy of measurement of the slightest deviations from a prescribed trajectory. It is shown that an IMU based motion tracking is more accurate than that tracked by EMG sensors.**

Keywords—Parkinson's disease; Tremors; Accelerometer; Gyroscope; Electromyography

I. INTRODUCTION

Parkinson's disease is a chronic brain disorder of the basal ganglia. The progressive syndrome is caused due to the dysfunctioning of dopaminergic neurons (source of biochemical dopamine) adversely affecting the overall movement and co-ordination of the body [2]. The prime symptoms of PD include body tremors (rhythmic to and fro oscillations of body parts), bradykinesia (slowness of movement), abnormal gait and posture (unusual position while walking), speech impediments and imbalances [1][3][4][11]. Estimates suggest that about 6.3 million people are affected by this neurological condition on a global scale. The disorder progresses drastically with age. Studies state that roughly 2000 in every 100,000 people over 80 years of age are diagnosed with this disease [5]. This demands a critical need to detect the clinical disorder at earlier stages. Amongst the high variability and diversified symptoms, tremors seem to be one of the earliest effective signs of PD.

II. DEFINITION OF TREMORS

Tremors are uncontrolled, periodic, oscillatory movements present in different parts of the human body [17]. It is not seen during sleep and its effects are commonly seen on fingers, hands, legs, head and voice [13]. They are seen as a result of uncontrolled contraction and expansion of muscles. Tremors are also seen in healthy individuals under stressful conditions but do not impair normal motor functions required in day-to-day activities [14]. As a mechanical vibration, it is observed to have low amplitude and well established set of frequency ranges [12]. Attributes used for classification of tremors are:

A. Location of the tremor

Tremors are possible at any part of the body which is free to move. The most common locations are arms, hands and legs. It is also observed if they exist on both left and right side of the body. Specific topography of tremors are classic markers of neurological disorders; the "pill-roll" for Parkinson's disease and tremors in the neck for Essential tremors [13]. Location of the tremor alone has been vital in identifying its root cause.

B. Conditions for activation:

Tremors are described on the basis of actions, which have been observed to be the root cause for impairment of normal movements. Under this category, tremors are further classified as rest tremors, postural tremors and action orientated tremors. Rest tremors are visible when the body is relaxed and well supported. Postural tremors are specific to postural holdings against gravity without support. Postural tremors appear with small time gap after achieving a specific posture, this period is referred to as latency period and is unique based on the cause of the tremors. Action tremors are vibrations present only during specific voluntary movement of body parts.

C. Frequency range:

In general, human tremors are in the range of 3 to 40 Hz. Further each disease is seen to have a smaller range within

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these values. Parkinsonian rest tremors have been known to have a frequency range of 4 to 7 Hz and postural/kinetic tremors in the range of 6 to 13Hz [19]. Essential tremors occur at 4 to 11 Hz [19].

These three categories together have been used in clinical practices for diagnostic purposes [17].

III. MEASUREMENT TECHNIQUES

A few systems capable of recording tremors are described in this section.

A. Magnetic tracking systems

Magnetic tracking systems (MotionMonitor^{TM}) are sensor modules that measure 3D displacements and orientations of various body parts during motor activity. The movement is calculated relative to a fixed transmitter. The variation in the electromagnetic field gives a measure of the transducer position. These transducers or sensor modules are held bilaterally at different positions like arms, legs and head. Displacements are computed by analysing the change in Cartesian co-ordinate position (x, y, z) with respect to a fixed reference. The root mean square value of all the 3 components is calculated to get the peak amplitude of tremors. Averaging of the RMS components exhibit overall body movement. The motor fluctuations are evaluated using rotational sensors that quantify angular displacements and irregularities in signal amplitude. Clinical examination of different types of tremor amplitudes can be done by filtering out the unwanted frequency components. The MotionMonitor^{TM} system has shown a positional resolution of 0.04 cm and angular resolution of 0.3° [7] [8]. Previously performed experiments have sampled at 100Hz, thus frequency ranges less than 14Hz can be accurately measured [7]. Similar diagnostic tools are available in the name of Polhemus, Colchester etc [6].

B. Optical marker system

This system makes use of multiple cameras and retro reflectors to calculate the position of an object in 3D space. For tremor detection in this system, retro reflectors are positioned strategically on the human body. A test rig consisting of multiple cameras and IR lights are used [16]. The person undergoing the test is placed in the test rig and performs few basic actions. Movement from these actions are recorded by the cameras in high resolutions and further fed to a computational device to calculate the position of the reflectors, this data over a period of time displays any form of tremors. Optical trackers have shown the ability to track objects with good accuracy.

C. Electromyography

This technique measures electric potential developed in the muscle cells on activation. It requires multiple electrodes to measure the voltage fluctuations as the muscle contracts and expands. There are two types of EMG electrodes, intramuscular and surface EMG. Surface EMG records the voltage difference between two surface electrodes and is limited to measure activity only in the superficial muscles. Intramuscular EMG uses needles to approach deep muscles and measure their activity. Voltages measured by the electrodes can be less than a milli volt and thus requires active and robust signal processing. Electromyograms have been used in the previous researches and have proved to be a valid method to record tremors [18].

D. Accelerometers

They are sensors which measure either static or dynamic acceleration of a body [15]. Most accelerometers work on the principles of inertial movement, they contain a frame of reference which moves and a proof mass inside the frame of reference which opposes the movement. Acceleration of the frame is obtained by measuring the amount of deviation achieved by the proof mass. Deviations are measured using techniques of capacitance. Advancements in MEMS technology allows construction of these sensors on a silicon chip and thus allows the possibility of very small sensors which are self-sufficient. Modern sensors use capacitive principles to measure the smallest movements. They are presently being used in all portable devices to obtain orientation and movement data. Measuring acceleration instead of displacement or velocity is a better choice as it tends faster towards zero when the body is stagnant, thus reduces noise in measurement. Sensors like BMI160 from BOSCH, MMA8452Q from Freescale Semiconductors and MPU6050 from InvenSense have sensitivity ranges of up to as small as 61 micro g. Their physical size is less than 5 square mm which makes it appropriate to be placed at any required position on the body.

IV. DESIGN

An experimental set-up comprising of MEMS based accelerometer/gyroscope MPU6050 (IMU) and Teensy 3.1 microcontroller was designed as shown in figure 1 to measure tremors discussed in the study. The embedded sensor was connected to the microcontroller via the I2C as shown in the figure. The controller was programmed to read data from MPU6050 and transfer it to a computer using the serial port. The sensor was programmed to a full-scale range of ±2g and 250°/s and data was sampled at 1 KHz via a 16-Bit ADC[20][21].

The Electromyogram module built involved three stages; firstly an instrumentation amplifier with a gain of 50, followed by a Low-pass filter with a gain of 15 and lastly by a High-pass filter of gain, 4.7. The overall gain of this setup was found to be 3525. The resulting output was sampled using a 10-Bit ADC and filtered using a notch filter at 50Hz to eliminate transmission line interference. Figure 2 describes the basic setup employed in the EMG device.

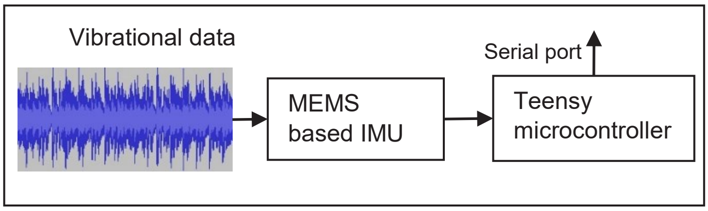

Fig. 1 Basic Block diagram of IMU system

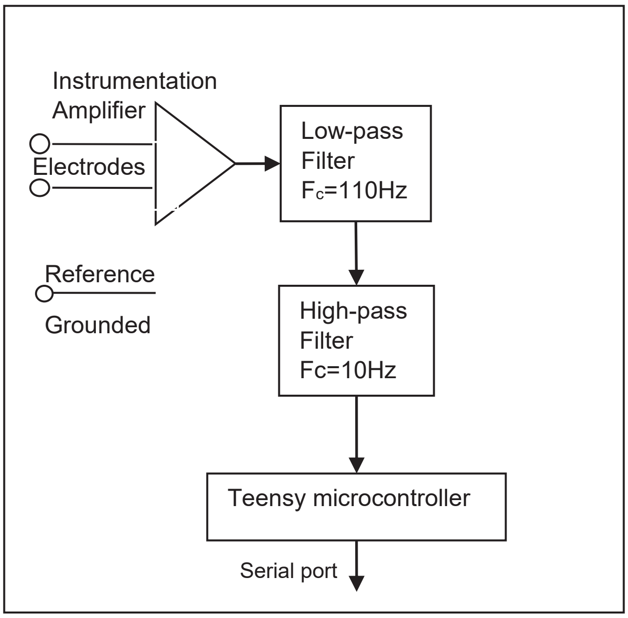

Fig. 2 Basic Block diagram of EMG system

V. EXPERIMENTATION

Common techniques for assessment of PD involves the subject to trace a path and deviations from the specified path is observed. One such test is the Spirogram, in this patients are made to trace the path of a spiral to measure key attributes of movement like small amplitudes of deviation from the trajectory [9][10]. A similar study with extension action of the wrist was conducted on five subjects. In this study, healthy patients were asked to move their palm by only moving the wrist joint holding its base fixed (extension movement) as shown in the figure 3. The aim was to measure which of the two sensors (EMG and IMU) were best suited to measure the smallest amplitude as the tremors themselves are of very small amplitude.

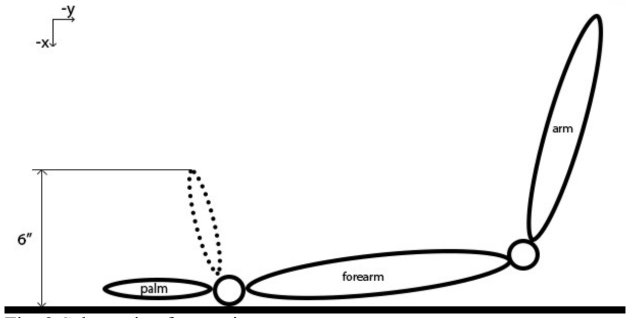

Fig. 3 Schematic of extension

Guidelines were provided for 6”, 3” and 1.5”, subjects were asked to move their palm upwards till the tip of their finger reaches the mark and trace the path back as shown in figure 4. They were made to repeat the movement thrice for each guideline. Two such complete tests were made for each subject. It was known that this action would result in movement of the extensor digitorum muscle. Thus, the differential EMG electrodes were placed on the forearm and ground plate was attached to the bone in front of the elbow. Accelerometer was recording acceleration data with earth’s gravity as its reference, gyroscope recording the rotation of the to-fro movements and EMG, the muscle potential. Data was recorded via a serial port and later processed using MATLAB. They have been presented in figures 5, 6 and 7. Figures 5, 6 and 7 have nine significant peaks, each corresponding to one extension movement. This pattern was observed in responses of every subject from all the three sensors, however the EMG response had a similar pattern but of different amplitude for each subject. This could be attributed to the difference in muscle activity of each individual.

Fig. 4 Picture showing test setup used for extension movement

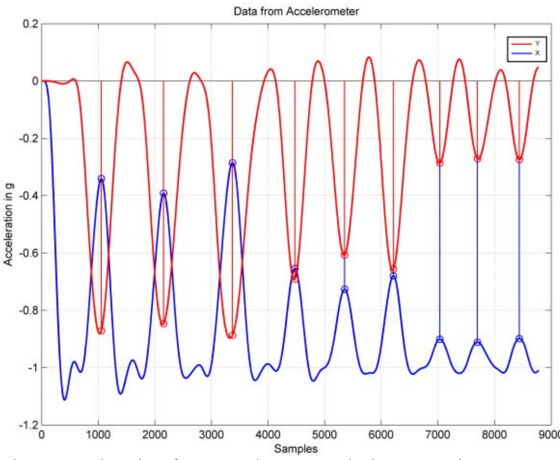

Fig. 5 Acceleration from accelerometer during extension movements

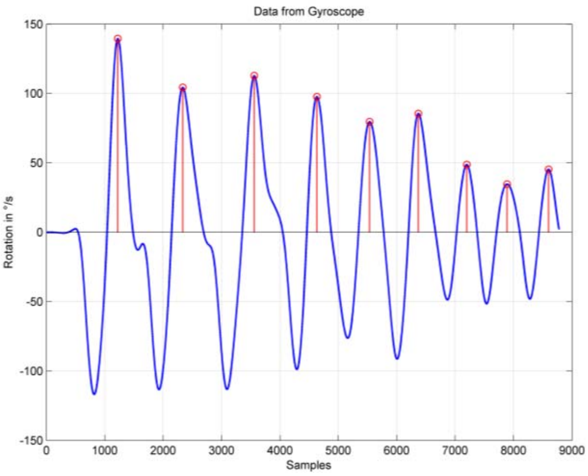

Fig. 6 Rotational velocity from gyroscope during extension movements

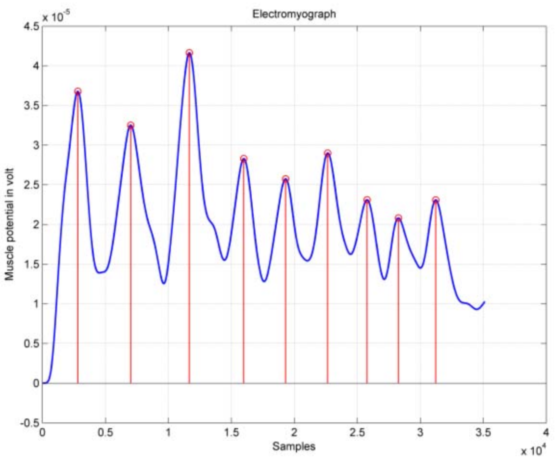

Fig. 7 Muscle potential from EMG during extension movements

Observing the performance of IMU in the first study, a second experiment was conducted to record self-induced tremors using IMU alone. The accelerometer was fixed on the tip of the little finger of a healthy subject and data was recorded while his hand was maintained in a stretched out posture. Subject was asked to voluntarily self-induce tremor limited to a peak-to-peak length less than 0.5”. The data was recorded for 4 seconds to get an optimal amount of readings. It was then filtered with a 5th order low pass Butterworth filter having a cut-off of 20 Hz. The results obtained are shown in the figures 8 and 9.

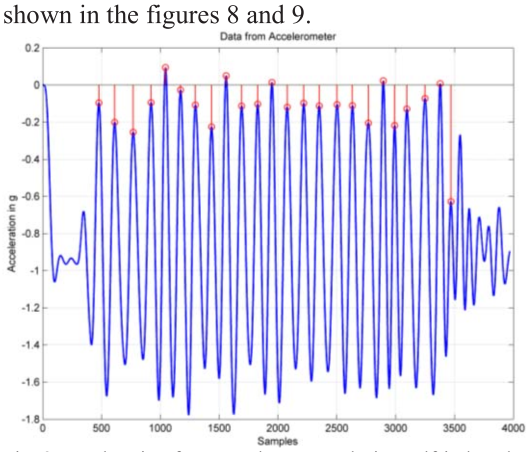

Fig. 8 Acceleration from accelerometer during self-induced tremor

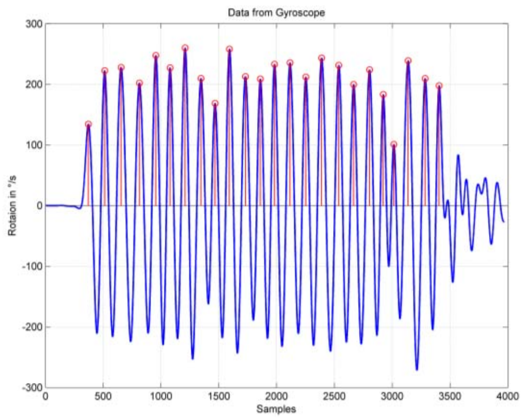

Fig. 9 Rotational velocity from gyroscope during self-induced tremor

VI. DISCUSSION

When subjects performed the extension movement of specific peak to peak lengths, accelerometer and gyroscope combination succeeded in exhibiting uniform amplitude for same prefixed heights. The accelerometer’s record of acceleration due to earth’s gravity (g) acts on X axis of the sensor when the palm faces down and on Y axis when the fingers point upwards. It is observed in the figure 5 that X and Y axes have complementary readings as expected. On the other hand EMG failed to present a deterministic and uniform behaviour. This is due to the fact that EMGs assess the electrical potential produced by muscle cells instead of actual movements [10]. They are also sensitive to electrical noise present in the surrounding power supply lines. Moreover, when the same activity was repeated by the same subject the results were not as correlated as the accelerometer’s data. Though EMG proves to be an accurate tool for tremor analysis, it is limited due to physical constraints like proper placement of electrodes, skin resistance and electromechanical delay. It requires a dedicated effort from the clinician’s side to maintain certain initial conditions before recording the tremor activity.

Figures 8 and 9 which show the data from accelerometer and gyroscope during a self-induced tremor has an average of eight peaks in a period of one sec implying that the recorded tremor was of a frequency of 8Hz. Both the accelerometer and gyroscope have been successful in recording the tremor data accurately for further analysis to be done.

From the data obtained it was seen that the average change recorded for one extension movement following the 6" guide line was 1.03g from the accelerometer, 220°/s from the gyroscope and 23.54μV from the EMG. Similarly following the 1.5" guideline produced 0.33g in the accelerometer, 91.6°/s in the gyroscope and 9.312 μV in the EMG. Such values are presented in Table 1. These values indicate the capability of IMU's and EMG's to measure tremors of very small amplitudes. The average sampling rates of market available IMUs are above 1 Khz and contain FIFO buffers. They use high speed serial communication to transfer data to host computers. Modern portable controllers reach performance scales around a 100 mflops, thus making possible a real-time system capable of tremor analysis using IMUs. Though our study was performed in a non-real-time setting, it supports the idea and feasibility for such a device.

Table 1. Changes recorded by sensors during extension movement

Prefixed height		***6"***	***3"***	***1.5"***
Accelerometer	***X***	1.03g	0.305g	0.122g
	Y	0.869g	0.64g	0.33g
Gyroscope		220°/s	152°/s	91.6°/s
EMG		23.54μV	16.62 μV	8.312μV

VII. CONCLUSION

The study gives a brief overview of various techniques that diagnose PD tremors. In the experiment conducted, both the IMU sensors and EMG display effective results while measuring small amplitudes and low frequency ranges, but comparatively, accelerometer and gyroscope combination succeed in obtaining better sensitivity. The study also emphasizes the advantage of employing 3 axes accelerometer and 3 axes gyroscope combination for a precise recording of the tremor. Though EMG proves to be common medical practice, it relies on physical attributes, initial preparations and environmental noise where embedded IMU sensors seem to be a viable option. We believe that more research towards creating a test bench for diagnosing of tremors using IMUs is of requirement.

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