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A Wireless System for the Objective Assessment of Dyskinesia

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Abstract—**In this paper, we describe a novel wireless system to facilitate the objective assessments of neurological movement disorders like dyskinesia. The ability of the prototype system to provide precise, objective biomechanical data about human motor performance has been demonstrated via controlled tests using a robotic arm. The system is designed to be used in clinical settings and will not require an extensive setup or training. The system may be used to supplement the clinical routine examinations by providing objective performance data to aid diagnosis or to monitor therapeutic success. In addition, it can be a useful tool for research on neurological movement disorders.**

I. INTRODUCTION

Parkinson's disease affects both men and women in almost equal numbers. In the United States, it is estimated that 60,000 new cases are diagnosed each year, joining the 1.5 million Americans who currently have Parkinson's disease. While the condition usually develops after the age of 65, 15% of those diagnosed are under 50. Doctors often prescribe Levodopa to reduce Parkinsonian symptoms. Unfortunately, chronic Levodopa therapy has the side effect of dyskinesia [1-11], impairment in the ability to control movement characterized by tics, spasmodic and repetitive movement. Recently, there has been interest in quantifying dyskinesia for the evaluation of pharmacological and surgical interventions and as input to the Levodopa dosing schedule. To date there has been a number of promising studies that have shown by making acceleration or gyroscopic measurement on various body segments that is it possible to develop algorithms that show good correlation to dyskinesias graded with either a modified abnormal involuntary movement (AIM) or the Goetz scale.

Current motion capture systems require the patient be tethered to the measuring instrument. In other words, sensors, which are place on the subject, are connected to the measuring instrument via wires. The instrumentation described in this paper eliminates these wires by using a low power, expandable, wireless network. The instrumentation consists of two types of devices. The first device is a battery-powered, wireless, three axis gyroscope and accelerometer module whose volume is approximately one cubic inch. The second device is a wearable wireless data recorder (shirt pocket size) that collects the data from the modules. This will allow an ease of use not found in any other ambulatory system for motion capture. The expandable wireless network will enable simultaneous operation of several modules on different body segments.

In this study a prototype sensor system was constructed and evaluated by comparing its ability to measure the movements of a robotic arm to measurements obtained with an optical system and to angular measurements obtained with a goniometer.

II. EXPERIMENTAL METHODS

A. Body-Worn Sensor Design

The wireless sensor prototype hardware architecture is shown in Fig. 1. Movement sensing is performed by a tri-axial gyroscope manufactured by Memsense and 3 axis accelerometer, a Freescale MMA7260Q. Both the accelerometer and gyroscope signals were conditioned with low-pass filtering and gain stages before being fed to the 10-bit A/D converter on board the Microchip 18LF4620 8-bit microcontroller. A crystal based timing module is used to ensure accurate sampling timing. Sensors are sampled at 256Hz with the data being decimated to a 64Hz rate before being transmitted to the base station. We chose to use IEEE 802.15.4 wireless communication, and selected the Microchip MRF24J40 compliant radio running the MiWi stack. At the time of development the selected wireless protocol offered an easily implementable, low power, small memory footprint option. A rechargeable lithium ion battery powers the system and we estimate a battery life of 8 hours of data streaming.

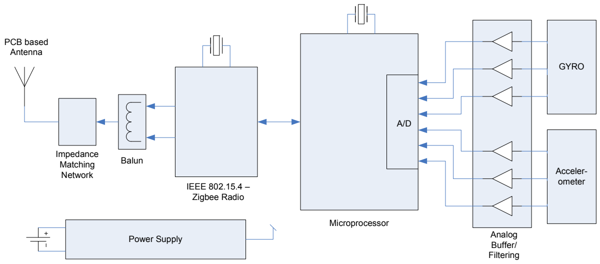

Fig. 1. Prototype wireless inertial sensor hardware block diagram.

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B. *Base Station Design*

The hardware design of the base station shares the same RF platform and microcontroller as the sensor design shown in Fig. 1 and adds a USB interface to allow communication to a host PC. Firmware was written to manage wireless communication and to transmit data to the PC for display and analysis. The PC-based movement monitoring software receives the gyroscope and accelerometer data, applies a user-specified high-, low- or band-pass digital FIR filter then plots waveforms, as shown in Fig. 1.

System hardware evaluations were performed and included power analysis and RF range and communication reliability. Power measurements made while streaming confirmed the sensor lifetime estimate, and reliable communication was observed at a distance of 20 meters with no observed dropped packets over a period of two hours.

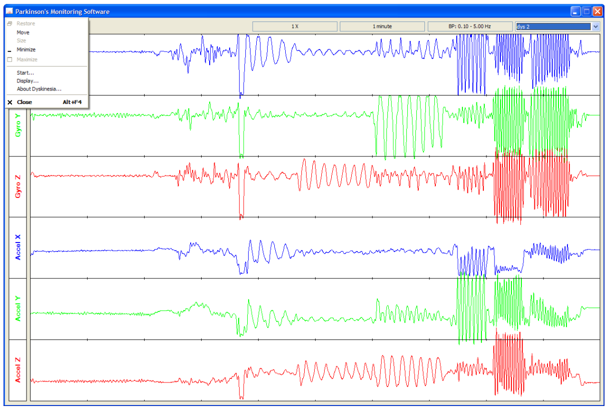

Fig. 2. Screen capture of the movement monitoring software

C. *Experimental Design*

The goal of the experimental effort was to determine feasibility of the proposed method by comparing the data measured by the wireless gyrometer-accelerometer system prototype to measurements obtained both with optoelectronics and a goniometer. Controlled experiments were performed with an instrumented multi-joint robot. In Fig. 3 the locations of the reflective markers, the goniometers and the wireless sensor are shown.

The optoelectronic camera system (Peak Motus Version 8, Vicon Inc., USA) consisted of three infrared light sensitive cameras that tracked the motion of four reflective markers that were attached to the robot near the rotational axis of the robot's joint axes. The sampling frequency of the optoelectronic system was set to 120 Hz. After data acquisition, the 3-D coordinate time-series data were reconstructed offline and the angular data of elbow and shoulder joints were computed using algorithms written in the Matlab Programming Language.

In addition, two twin-axis goniometers (Biometrics Ltd., England) were attached to the robot - one goniometer was placed across the robot shoulder and one across the elbow joint of the robot. The goniometers were attached so that they closely crossed the joint rotational axes. The sampling frequency of the goniometers was set to 100 Hz.

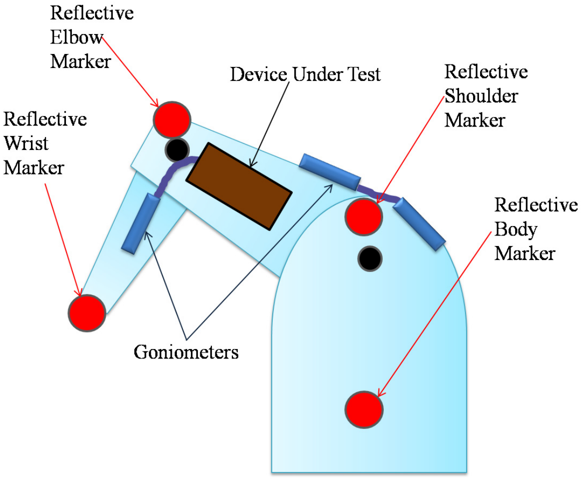

Fig. 3. Illustration of the multi-joint-robot showing the placement of the optical reflective markers, goniometers and the device under test.

The prototype sensor module was attached to the upper arm near the elbow joint. The sensor module had six output channels. Data from channels 1 to 3 represented linear acceleration (both static and dynamic) in each Cartesian plane (x, y, and z), while the gyrometer provided data about angular velocity in the three planes of motion x, y, and z axis.

The robot then initiated a defined sequence of elbow and shoulder joint movements, while the three different motion capture systems recorded kinematic signals at the same time line. Trials were recorded at movement durations ranging from 60-120 seconds.

Fig. 4. Mini-robot and optical recording system

III. EXPERIMENTAL RESULTS

As seen in Fig. 5, the absolute angles of shoulder and elbow joints were different, because the angle of geometry of two signal sources (e.g., markers and goniometers) was different. For this reason, we calculated a relative angle for the two joints. In addition, the raw data of prototype wireless sensor system were processed offline to compute joint angles (i.e., integration of the velocity signal). The raw

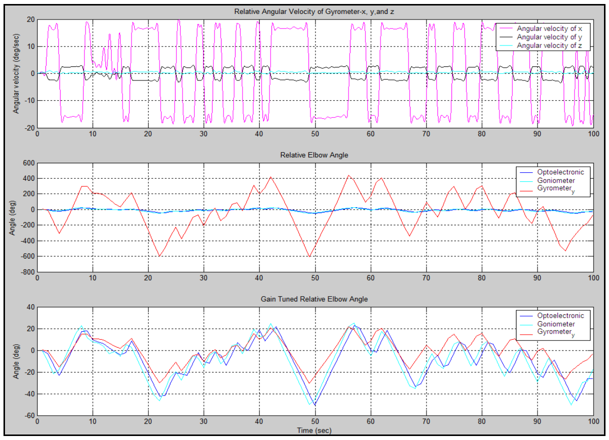

Fig. 5. Elbow angle data obtained by the three motion capture systems. Data reflects robot elbow motion over a 100 second period. Top graph: Raw data of gyrometer in the x, y, z axis. Middle graph: Relative elbow angle obtained through the goniometer and the optoelectronic system in comparison to the integrated gyrometer y-channel data (un-scaled). Bottom graph: Relative elbow angle obtained through the goniometer and the optoelectronic system in comparison to the integrated gyrometer y-channel (scaled).

angular data were then transformed into relative joint angles. The initial value of all three angle-time-series data was set to 0 (zero) degrees, so that change in signal amplitude and phase lag could be computed via cross-correlations. The following procedures were implemented to compare:

1) Check and calculate the shoulder and elbow angle from 3D coordinate data of the optoelectronics system. Compare the angle measurements provided by the optical system with the calculated angle derived from our customized Matlab routines.
2) Compare the absolute and relative shoulder and elbow angles between optoelectronic system and the goniometers.
3) Compute the spatial error between the joint angles derived from the optoelectronic system and the goniometers.
4) Compute the cross-correlation and phase angles between the optoelectronic system and the goniometers.
5) Compute the relative joint angles based on the gyrometer readings of channel Y.
6) Compare joint angular data sets derived from the gyrometer and the accelerometer with the joint angles obtained through the goniometer and the optoelectronic system.

The data shown in Fig. 5 and the cross-correlations presented in Table I document that gyrometer readings were well matched in amplitude and phase lag in comparison to the two other angle signals derived from optoelectronic and goniometer systems. One possible reason for the lack of a perfect correlation was that the gyrometer signal was collected at a lower sampling frequency (64 Hz). The cross-correlation between the goniometer and optoelectronic relative elbow angle was 0.96.

Similar steps were taken to evaluate the relative angle from the linear accelerometer. This data was also well matched in amplitude and phase lag in comparison to the two other angle signals derived from the optoelectronic and goniometer systems. The cross-correlation values are reported in Table I. The cross-correlation between the gyrometer and accelerometer relative elbow angle was calculated to be 0.95.

TABLE I
CROSS CORRELATION RESULTS

Sensor Measurement	Goniometer Angle	Optoelectronic Angle
Gyrometer Angle	0.92	0.89
Linear Accelerometer based Angle	0.92	0.93

IV. CONCLUSION

A wireless sensor system was constructed to facilitate the objective assessment of movement based disorders. A prototype system was created and objective tests performed using a robotic arm. Comparisons between the proposed system and optical and goniometric angular measures were drawn. Correlations between the prototype system and these other measures demonstrated that the wireless sensor system provides a reliable un-tethered movement assessment system.

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