Development of Computer-Based Gait Monitoring System

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ABSTRACT

We have developed a compact, wireless, wearable sensor-impregnated shoe that is used to monitor the ground reaction force data exerted on the foot during walking. This paper discusses the entire system that consists of two basic units: mobile transmitting unit and stationary receiving unit. Detail information about the pressure distribution and relative position of the foot is provided with real-time and wireless transmission of the data from instrumented shoe attachment to a receiver connected to a nearby personal computer. This is designed and tested that it can overcome the physiological constraint problems of most kinetic method of gait analysis.
Keywords: *Gait, Kinematics, Gait Monitoring System, Transceiver, Repeatability, Wireless*

INTRODUCTION

Gait analysis (also called motion analysis) is the quantitative measurement and assessment of human locomotion including both walking and running. A number of different disciplines use gait analysis primarily to seek a better understanding of the mechanism that normal ambulatory use to translate contractions about articulating joints into functional accomplishment [Davis et al., 2000], as well as for clinical use e.g., diagnosing and allowing selection from amongst treatment options [Baker, 2006]. The diagnostic effectiveness of gait has been criticised based on inaccurate interpretation of data—this varies from clinician to clinician and from institution to institution [Simon, 2004]; lack of efficacy data showing that functional outcomes are improved due to gait analysis; and the act of processing and transforming valuable raw data from one platform to another for analysis gait analyst may include some artifacts leading to analytical errors. As a consequence of these issues, the cost-effectiveness of gait analysis as a clinical tool was called into question [GCMAS, 2008]. The importance of gait analysis, e.g., the systematic evaluation of the dynamics of gait, is gradually being recognized enabling Medicare coverage. The technologies involved in clinical gait analysis include:

i Utilising specialised computer-interfaced video cameras that measure patient motion.

ii Placing passive reflective markers on the surface of a patient's skin, aligning with specific bony landmarks and joints, and enabling the kinematics to be data-captured by the video cameras, which may be interfaced with a centrally-controlled computer.

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iii Using multicomponent force platforms imbedded in the walkway to provide kinematics measurement; i.e., the reaction between foot and ground as the patient walks.

iv Placing electrodes on the surface of the skin or inserted as fine wires into specific muscles allowing the patient's dynamic electromyography (EMG) to be monitored as the patient walks.

Kinematic gait analysis is limited by simplified marker sets and related models. The majority of sets in clinical use were developed with low resolution imaging systems so required various assumptions about body behaviour [Collins et al., 2009]. Thus, there is a need to develop a gait measuring device that is high sensitive, accurate, non-intrusive and that allows wide measuring range permitting data be transferred and stored wirelessly.

This paper presents a gait device developed that measures a wide measuring range permitting data be recorded, transferred and stored electronically and wirelessly in microseconds. The gait system allows repeatability of measurements.

System Design: Figure 1 shows the Gait Monitoring System (GMS). The GMS is designed as a telemetry system comprising two major units based on the physical separation produced by radio links between the two end units, namely: (a) the lightweight, battery powered mobile transmitting end unit, and (b) the stationary data processing and receiving unit.

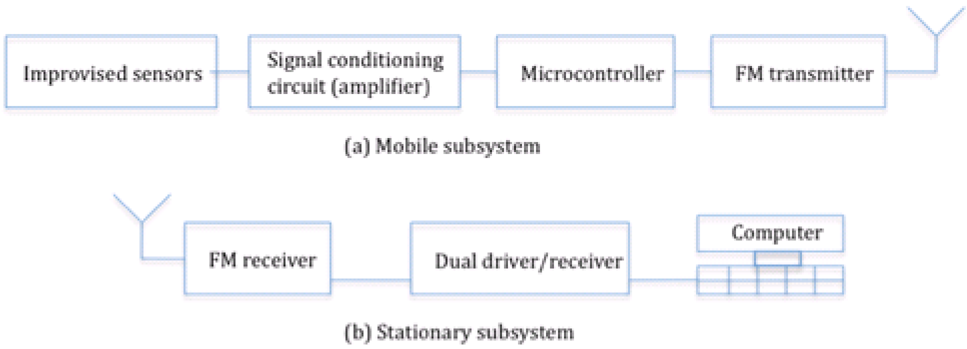

Figure 1: Block diagram of Gait Monitoring System

The mobile subsystem is the portable part of the system, which is carried on the body of the subject during gait monitoring. This subsystem consists of a pair of instrumented shoes, signal pre-processing circuit and a FM transmitter. The measurand of the system is the ground-foot force that is exerted on the floor during walking. The transduction is done using improvised sensors impregnated to the sole of flat-soled sport shoes—also developed—as shown in Fig. 2. The sensors are constructed of two layers of flat plates, which are separated by polystyrene that was impregnated with paste of electrolyte. The signals from the multiple force sensors

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were amplified, converted to digital signal format, encoded, frequency-modulated at 433MHz and transmitted. The Stationary Receiving End Unit is composed of FM Receiver—the front-end of the receiving unit, dual driver/receiver—enabling decoding, voltage regulation and transmitting decoded signals at up to 120kbits per second to a Personal Computer (PC) using Digital Interface Module with serial port. The data is stored in the PC for further processing and analysis.

The radio link between the mobile part and the stationary processing part helps to overcome a lot of problems common to most gait-monitoring equipments; e.g., the psychological restraints on the subjects. The radio link unit also provides means of continuous monitoring of the gait data, and more importantly, it provides electrical isolation of the transmitting end from the stationary part of the system, and thereby isolating the subject from the mains supply. A Visual C++ programming language was used for the Programmable Interface Controller Microcontroller because of its powerful features in developing applications for embedded system without compromising performance or control. A database of measurements was developed ensuring usage for immediate and future use; thus serving as research and clinical assets.

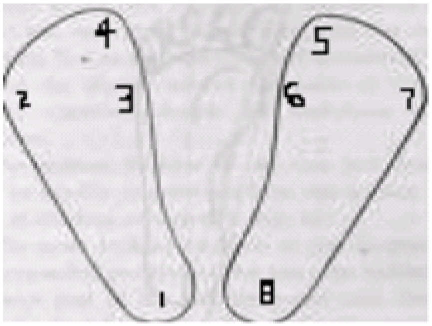

Figure 2: Strategic arrangement of sensors for the instrumented shoes

MEASUREMENT METHOD

A total of 30 males and 45 females, without any known physical disabilities, were selected from among students and staff members of the Federal University of Technology Akure using a simple random sampling method. Each subject, at a time, was made to wear the instrumented shoes and made to walk with it. Before starting acquiring data from a subject, the Sensors offset was activated. This is necessary for soft nulling of the Op-Amp Offset. The subject is then asked to stand erect and to remain in this posture for some time. At this time, the gait capturing command was activated to acquire the data from the force sensors; the data acquired at this point correspond to the subject's body weight. After this initial measurement, the subject was then asked to start walking at his/her normal walking speed (on a flat floor of the laboratory i.e. free walking speed). This subject is allowed to continue to walk with instrument on, so as to make him/her get accustomed to the instrument such that the measurements were taken at the subjects steady state, and at time

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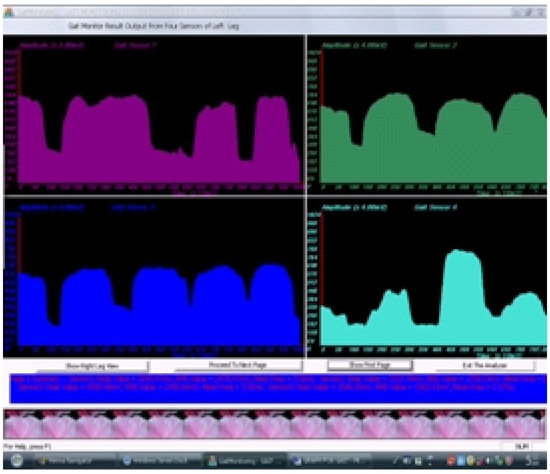
when he/she will not be aware. This greatly helps to overcome the psychological effect of the instrument on the subject [Oyeniran, 2012]. Each run of measurement cycle is stored in the computer memory-along with the subject's identification data, which were taken before the test. These identification data include the subject name, weight, height and sex. Almost immediately after the test run, the outline of the foot forces is displayed for each of the foot sensors for visual observation of the subject's gait. This is followed by further analysis of the acquired data. The kinetic data were examined in the frequency and amplitude domain since this is less affected by slight variation in waveform and sharp discontinuities, and would reflect the symmetry in the gait data better. The kinetic data for each sensor were transformed to the frequency domain through Discrete Fourier Transforms. Invariability of the kinetic variable is considered a sign of symmetry of the gait waveform, and standard deviation has been suggested to be a measure of the step-to-step asymmetry variation in gait [Hannah et al, 1984]. This method is particularly pursued in this research to determine gait asymmetry— typical for hemiparetic gait [Mayer, 2002]. Since the test runs are independent, the resulting samples from the single subjects can be considered as random sample. From the theory of random sampling, a sample can be considered as random of successive trials if the experiments are independent, and the frequency function of the random variable remains the same from trial to trial.

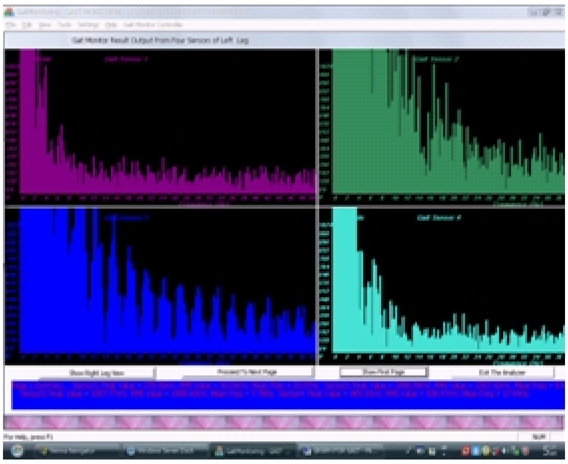
RESULTS AND DISCUSSION

In order to interpret results, it is usually necessary to provide further computations, which estimate the desired parameters of interest or the parameters that describe the physical process being measured. This helps to provide analytical solutions particularly in the evaluation of the test procedure to guide in making useful decision. In computation of the various parameters, scaling of the raw data is necessary since a large volume of data and problems of discontinuities are usually encountered. Since the data processing will have to do more than just plotting, a general and specialised subroutines (or functions) and computer programs must be written to achieve the desired objectives.

Apart from the scaling, other operation that is routinely performed on the data is Fast Fourier Transform (FFT) for frequency (or harmonic) analysis. Frequency analysis is a very important operation in data processing, which provides information about the significant frequencies contained in the data. The Gait system analyser transforms the discrete time gait data into the frequency data and this was used to determine the relative magnitude of the harmonic content of the gait data. The corresponding waveform of each sensor can be viewed clearly in either amplitude frequency plot—as in Fig. 3(a), or amplitude-time plot, as in Fig. 3(b).



(a) Sample waveforms obtained using amplitude-frequency on some subjects
Figure 3: Measurement and Analysis of Gait Data



(b) Sample waveforms obtained using amplitude-time plot on some subjects
Figure 3: Measurement and Analysis of Gait Data

The results obtained from the experiments show the peak value, the root mean square (rms) value, and the mean frequency of each sensor for both right and left legs. Also the software was configured in a way that all the corresponding values show clearly on the screen. The results of the test and measurement carried out on the gait monitoring system show that (a) the peak value, the root mean square (rms) value, and the mean frequency of each sensor for both right and left legs; and (b) a high correlation that the system can be used in monitoring of human gait pattern as well as in analysing the waveform depending on the index of comparison chosen for consideration.

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CONCLUSION

The development of a computer-based gait monitoring system to determine gait asymmetry has been carried out. Also developed is a compact, wireless, wearable sensor-impregnated shoe that is used to monitor the ground reaction force data exerted on the foot during walking. The whole gait monitoring system consists of two parts; the lightweight, battery powered mobile transmitting end unit; and a stationary data processing and receiving end unit. The two subsystems are wirelessly radio linked, thus overcoming the psychological restraints on the patients, as well as providing continuous monitoring of the gait data, and more importantly necessary electrical isolation in the system. The data transfer mode is fast and accurate.The test and measurement taken with the gait monitoring system showed that the system could be used as research and clinical tools. The gait monitoring system is being developed for commercial and clinical use.

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