A wireless goniometry system

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Abstract. Gait laboratories comprise a diversity of devices of medium and high complexity with which it is possible to obtain records that quantify spatio-temporal patterns of human movement. Scientific knowledge achieved on the basis of such records in the normal and pathological gait is being applied to the diagnosis, treatment and monitoring of various diseases, as well as to the design of better methods for rehabilitation of motor disorders. In this paper we present a goniometry system designed as part of the gait laboratory of the Institute of Biomedical Engineering, Faculty of Engineering of the University of Buenos Aires. This system allows the measurement of angles in three dimensions between different body segments. Angles are sensed by means of electronic goniometers and presented real-time on a computer screen through a wireless communication channel.

1. Introduction

Human walking is a complex process involving many body segments moving harmoniously under the control of the central nervous system. Their study, multidisciplinary, is approached from the point of view of biomechanics based on records of the kinematics and dynamics of the different body segments set in motion. For some years we have had technology that allows such records in upper and lower limbs.

It is of central interest for the kinematic study to know the angular variations of the body joints together with the tilt twist and swing of each segment. Additionally, the study involves dynamic ground reaction forces as well as the moments and muscle forces actuating on the joints [1], [2]. This paper describes the design and implementation of a wireless system for recording real-time angle measurements obtained on the basis of electronic goniometers.

The immediate context of application of this design is the research project on human walking carried out by the Institute of Biomedical Engineering at Buenos Aires Faculty of Engineering.

2. Materials and Methods

The system provides simultaneous recording of two channels providing the ability to measure bending and twisting movements on a single joint or simultaneous recording of angles in a single plane into two different joints.

Its main components are: (a) sensors (b) portable electronic module (c) acquisition and display software in computer

2.1 Sensors

Traditional goniometers are useful for the static measurement of joint angles, for example they can be used to measure the maximum knee angle flexion achieved by a patient under treatment. Its structure is similar to rulers that must be aligned to the respective body segments trying to keep its center of rotation located on the joint that is evaluated.

In recent years electronic goniometers allow joint angles dynamic measurements in function of time while the subject performs an activity. The technologies mainly used in these devices are: potentiometric goniometers, flexible goniometers and others flexible developed with fiber-optic.

Electro-potentiometric goniometers are based on the resistive changes of a potentiometer that moves integrally with respective rod-like structures attached to the studied body segments. The most serious problem is its rigidity as it complicates fixation to the body which promotes measurement errors.

Flexible electrogoniometers are relatively small and easy to install. They offer simultaneous measurement of angles in two planes of motion, which allows measuring flexion/extension in the sagittal plane and abduction/adduction in the frontal plane.

Fiber optic goniometers are based on a curvature dependant magnitude of light transmission losses. In one of the extremes of a short optic fiber there is a light source and in the other sensors that detects a measurable change in the light intensity [3]. There is a commercial device, the Joint Shape Angle Sensor, which is manufactured by the Canadian company Measurand [4].

The goniometers that we used for this work belong to the flexible type and they are manufactured by the company Biometrics Ltd [5]. This goniometers, for signal conditioning purposes, may be analyzed as a Wheatstone-bridge type structure as suggested in the technical manual provided by the manufacturer. Using a power source of 5 volts, a 10 μV/degree sensitivity is obtained on each measuring plane.

2.2 Portable Module

Its operation is described by the functional block structure shown in FIG 1. Signals from the sensors are firstly processed in an analog stage for conditioning and amplification. Then it is digitized to be transferred to a PC. Sampling and transmission are controlled by a microprocessor.

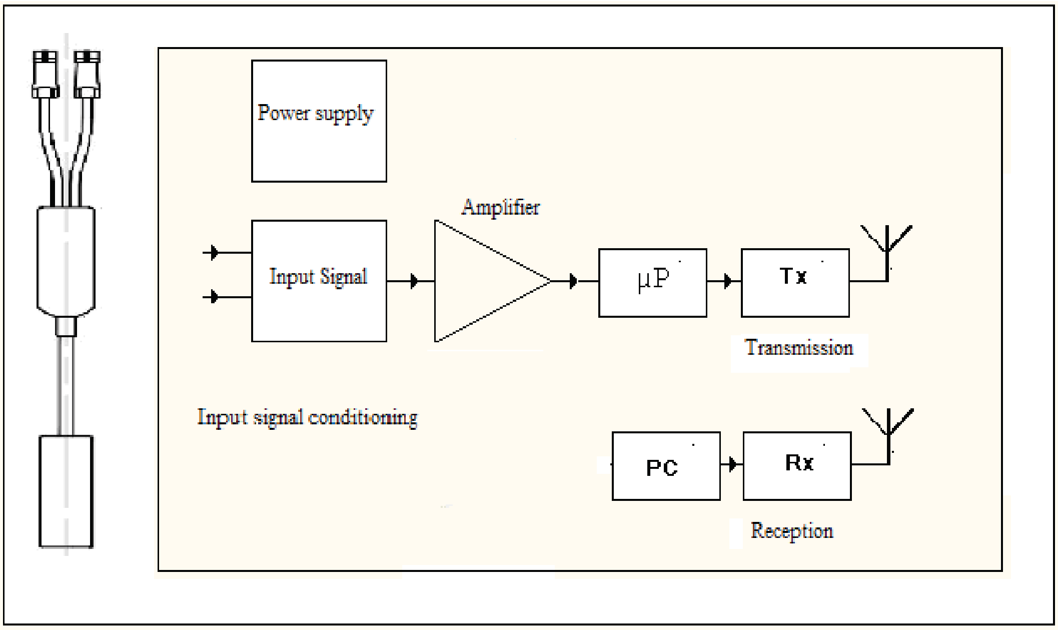

Figure 1. Block Diagram of the system.

The signals produced by the goniometer are electric potentials relatively small and require amplifiers to facilitate quantification .The primary purpose of the amplifier is increasing the level of the signal obtained from the sensors excluding any noise. The main noise source we observed is 50/60 Hz power line interferences in common-mode.

The analog stage is based on an INA instrumentation amplifier which features high common mode rejection and very low offset voltages which fit very well to the requirements of this project.

An Atmel ATmega328 microprocessor performs the functions of sampling digitizing and data formatting according to the transmission protocol designed for this application. This processor incorporates on a RISC architecture of 8 bits, 10-bit analog inputs and an USART (Universal Synchronous / Asynchronous Receiver Transmitter) interface.

MaxStream XBee modules are used for wireless connectivity both for transmission and for reception. They work on radio frequency in the 2.4 GHz band with 802.15.4 communication protocol. Their indoor range is 30 m and it extends up to approximately 100 m outdoors with a 2mW transmission power. We use in our application point to point configuration and AT commands. The portable module is powered by lithium ion batteries.

The radio transmitter is located inside the portable module while the receiver is wired to the computer via an USB port. Our ad-hoc communication protocol includes coding of samples for transmission. A sampling frequency of 200 Hz was chosen according to usual bandwiths in gait analysis.

By combining its wireless communication capabilities with laptop computers this system gives the possibility of obtaining outdoor records. Its ease of transportation also allows sharing it between different laboratories.

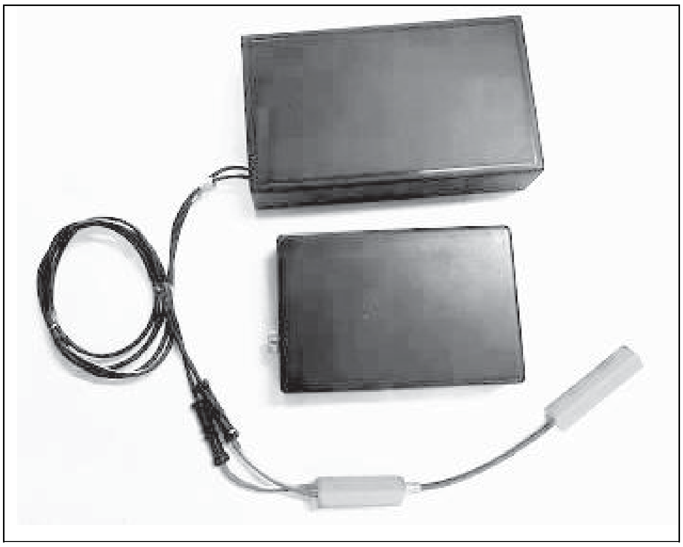

Figure 2. Prototype

Figure 2 shows the developed prototype that consists of the transmission and reception units and the goniometric sensor. The sensor has two output connectors, one measures flexion/extension and the other radial/ulnar deviation. According to manufacturer's specifications, crosstalk between both outputs is less than ± 5% over an angular range of ± 60°, accuracy is ±2° over a range of ±90° and repeatability is ±1° over a range of 90°. Our system comprises two channels that we currently use for measuring flexion/extension of right and left knees.

2.3 Acquisition Software

Computer software, developed by this group, allows real-time monitoring of joint angles and optional storage in customized disk files. It includes data-base features for managing age, sex, pathology, date and time. This data is also embedded in every signal file.

Off-line analysis is accomplished by another piece of software that was also developed by this group. It offers several visualization tools to facilitate the study of signals.

3. Discussion

Figure 3 illustrates one of the measurements obtained by means of this system. It is a screen copy of our signal analysis application and corresponds to knee angles during treadmill walk of a healthy subject.

Flexion/extension angles were measured versus time in left and right leg by two attached flexible sensors. The treadmill was set to 2.5 km/h for comfortable walking speed.

In accordance to what other authors reported about other type of wearable sensors [6], we observed that sensor fixation is a critical factor to consider when using flexible goniometers. In our experiments we detect very high noise levels if a meticulous procedure is not carried out. Noise may be much higher than the signal itself in that case.

We observed that this type of sensors caused minimum motion discomfort.

4. Conclusions

The main motivation for developing the system presented in this paper was our interest in opening a gait laboratory. Our goal was to design a wireless goniometry system under the following premises: long term records, a minimum of two acquisition channels, simple use and easy outdoors transportation. This system was developed and tested on healthy individuals obtaining good behaviour and results that are consistent with the undertaken premises.

Among our future work we foresee a comparative test of accuracy against other recording methods and the development of complementary software featuring more elaborated tools for off-line analysis.

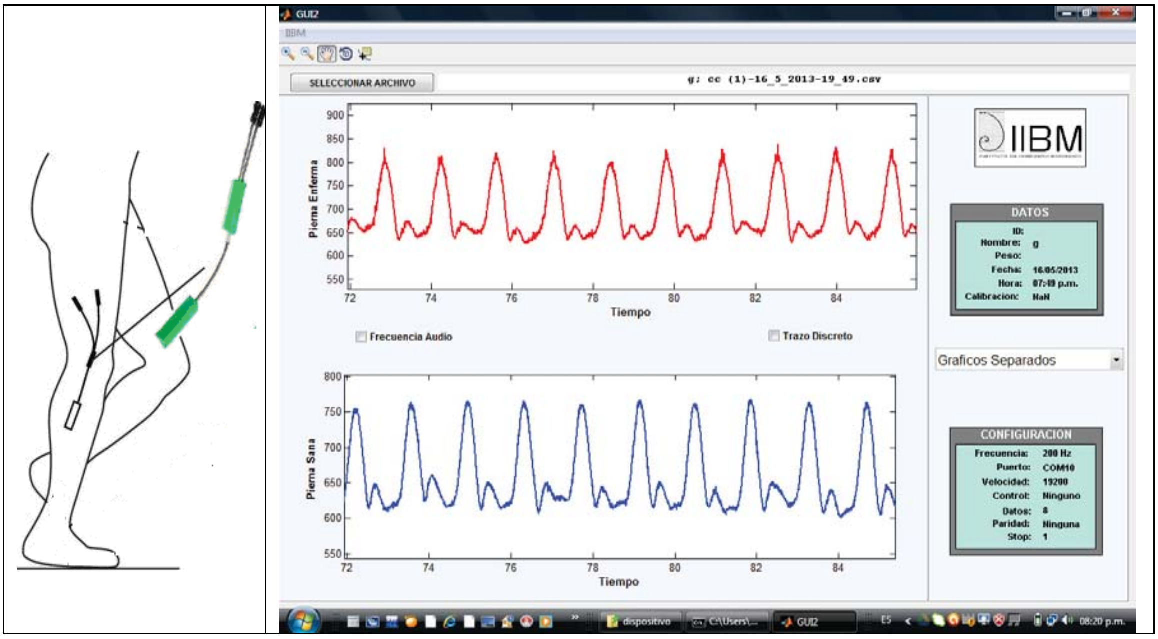

Figure 3. Knee flexoextención

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