

## Research Article

### Outdoor Portable System for Quantified Analysis of Human Walking

<sup>1</sup>Samir Hesses, <sup>2</sup>Idir Belaidi and <sup>3</sup>Mohamed Rachedi

<sup>1</sup>Hôpital Central de l'Armée-Kouba, Algérie

<sup>2</sup>University M'hamed Bougara, 35000-Boumerdès, Algérie

<sup>3</sup>Hôpital Militaire Universitaire Spécialisé-Staouali-Alger, Algérie

**Abstract:** The aim of study, is to collect gait by the wearable sensors attached to the person's body, then we propose a homemade system called Digit Eye Jockey. This system gathers a mechanical structure and an electronic device based on potentiometers for measuring spatiotemporal parameters and joints angles in the sagittal plane for hip and knee and in both sagittal and transverse planes for the ankle. The responses are very linear and the relative error is less than 5%. This instrument is a robust and light tool to assess the instantaneous spatiotemporal and articular parameters during gait, over a great number of steps, on any type of ground and even outdoors.

**Keywords:** Kinegram, kinematic, potentiometer, spatiotemporal, walking

#### INTRODUCTION

Quantified Analysis of human Walking (QAW) in all its forms, i.e., kinematic, kinetic, energetic and dynamic, requires increasingly more accuracy and specific tools, also less expensive and easy to implement. In the medical field, for the assessment of the needs of a patient, clinicians use the QAW approach routinely, in order to continuously monitor the evolution of the effect of the applied therapy (botulin toxin, physio therapy, surgery, etc.).

Many tools are available to perform both spatiotemporal, kinematic, kinetic, neuromuscular, electromyography and energetic analysis in gait. Among these tools, one could cite simple time keeping procedures, optoelectronic systems (as detailed for example in Sutherland (2002)), electromyography (Sutherland, 2001) and goniometry (Oberg *et al.*, 1994). Most of these systems are adapted only for indoor protocols (or at least in a reduced space) protocols, imposing on patients specific conditions such as walking tracks, distance limited walking, treadmill, bonding time markers on the body, etc. These conditions often do not reflect reality and may induce various bias by putting the patient into uncomfortable situations (Kirtley and Heller, 2002).

In addition to these unrealistic laboratory conditions imposed on human walking, two other major limitations of QAW, i.e., a highly qualified staff is necessary for the system monitoring and gauging and the recorded data shows high variability which lead to a difficult analysis.

The development of a new system therefore proves necessary; to make the QAW more accessible, faster

and even possibly used outdoors. Our system is limited up to now to cinematic measurements.

In the future and to consolidate the (QAW) with Digit eye jokey, further work is planned on designing a belt with Force Sensing Resistors for the detection of pressure twitching and identifying braced muscles during cycle walking.

The system presented in this study answers increasing needs of clinicians to obtain a robust and easy to use analysis tool able to quickly detect a pathological gait. It should contribute to the advancement of medical research, by offering extended analysis possibilities thanks to its wireless technology.

#### MATERIALS AND METHODS DESCRIPTION

Having regard to the functional complexity of lower limbs, we design a light structure (800 g), as neutral as possible on walking and perfectly matching the shape of the body. Our tool is mainly based on goniometer, i.e., a potentiometer specifically assigned to measure joint angles. It comprises two arms: one attached to one of the joint segments and the other to the second segment.

Aiming at designing a robust system, HWL60 potentiometers (Metallux AG, year) were chosen. Their technical features include a Resistance range (Rn) 10 kΩ, electrical angle of rotation up to 320°, mechanical positioning range 360°, continuous rotation and service life 10 million cycles.

The potentiometer (Fig. 1) sends an electrical signal linearly proportional to the value of the angle between the two arms.



Fig. 1: A precision potentiometer HWL60



Fig. 2: System sagittal angular measurement of the hip and knee



Fig. 3: Measurement system in sagittal and transverse angular foot



Fig. 4: Xbee wireless module

The tool supports two levels of observations: joints rotations in the sagittal plane for the hip, knee and ankle, with (02) potentiometers (Fig. 2) and joint rotations in the transverse plane for the ankle only, with (02) potentiometers (Fig. 3). The system supporting

both the sagittal and transverse rotation for the ankle, it was made easily interchangeable from left to right foot (Fig. 3). The transverse plane sensor is made out of two potentiometers. The first one is so positioned on the lateral malleolus and guided by two rods, respectively attached by leather straps on the foot (adjustable in length and height). The second one is fixed to the fibula with the second potentiometer, which measures ankle rotation in the transverse plane. For a better guidance, the potentiometer is housed in small aluminum box. In order to minimize weight, we proceed to a recess in materials by drilling (08) holes.

As guiding rods need to be as stiff and light as possible, either fiberglass or carbon fibers could be used. Resistance to tensile is generally between 2000 and 5000 Mpa (Vieille *et al.*, 2009). Young's modulus of these fibers is also very different, varying in a proportion of 1 to 7 between fiberglass and high modulus carbon fiber. Fiberglass was chose for its price.

Each potentiometer is connected to a wireless radio-frequency transmitter coupled to a signal receiver card, using the Xbee technology (Fig. 4). The sampling frequency of each potentiometer is 75 Hz. The transmitter card is carried by the volunteer on its back while data is sent real-time and stored in a distant computer. Recordings include: joint angle values in sagittal plane for the hip, knee and ankle; ankle angle in the transversal plane. From these records additional data are computed: the percentage of each phase of the gait cycle; the speed and frequency of walking and the kinegram.

To summarize, our system includes a mechanical structure, a frame grabber and potentiometers. It combines lightness, ease of use by clinicians, adaptability to various volunteer morphologies, interchangeability from right to left and ease of maintenance.

**Technical validation:** This mobile electronic goniometer is a system that has been developed for assessing human gait based on joint parameters in transversal sagittal planes. In a first step, linearity of

Table 1: Comparison error result by the decalage of rods

Lower limbs	Decalage (cm)	Relative error (Max.)
Hip	0.5	Less than 4%
Knee	1.0	Less than 5%
Ankle	0.5	Less than 3%

Max.: Maximum

Table 2: Comparison of spatiotemporal results

Parameters	Digit eye jokey	H/P cosmos
Cycle time	1.5 sec	1.5 sec
Rate	79 steps/min	79 steps/min
Phase support	0.95 sec	0.94 sec
Swing phase	0.56 sec	0.55 sec
Single phase support	0.61 sec	0.63 sec
Double stance phase	0.18 sec	0.17 sec

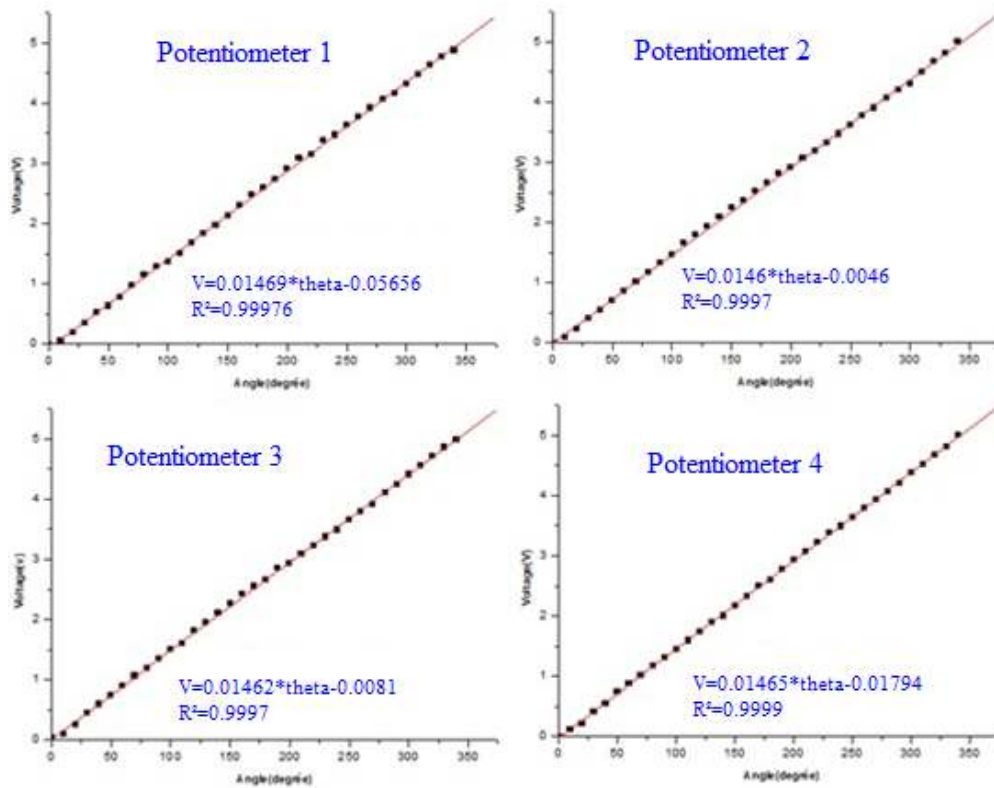


Fig. 5: Calibration curve of each potentiometer used

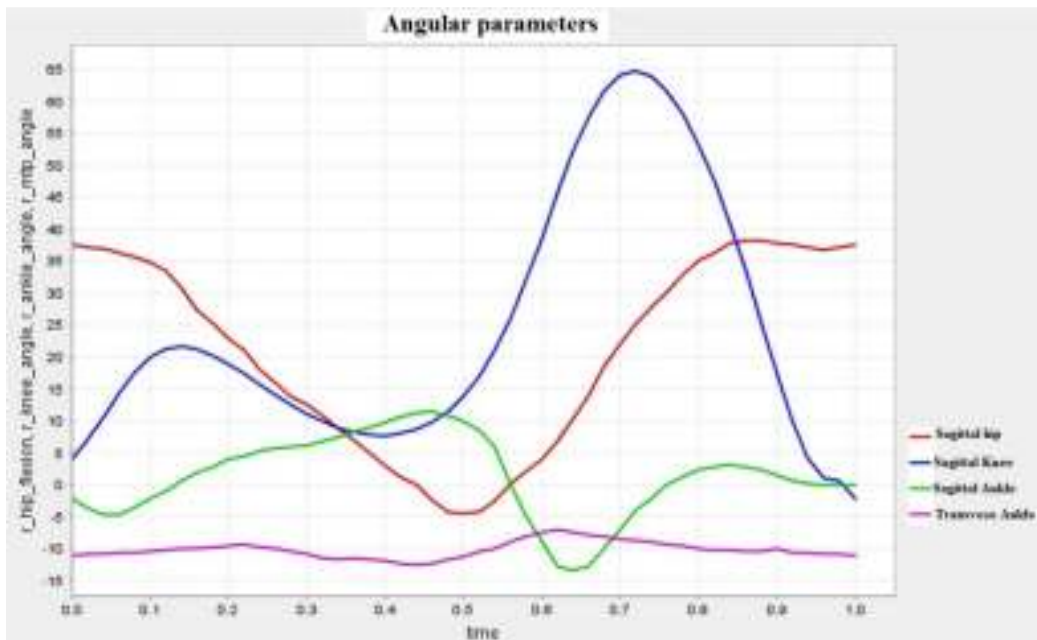


Fig. 6: Typical curves obtained during one cycle of gait

potentiometers was evaluated. Figure 5 illustrates the resulting calibration curves of the four potentiometers.

**Functional validation:** After the validation of potentiometers and after the assembly of the system, a

preliminary test was realized during gait of a healthy male subject, aged 25, 180 cm tall and weighing 75 kg. This dynamic test was made during a 10 min continuous walking on Mercury walking track (HPCosmos, Nussdorf-Traunstein, Germany)

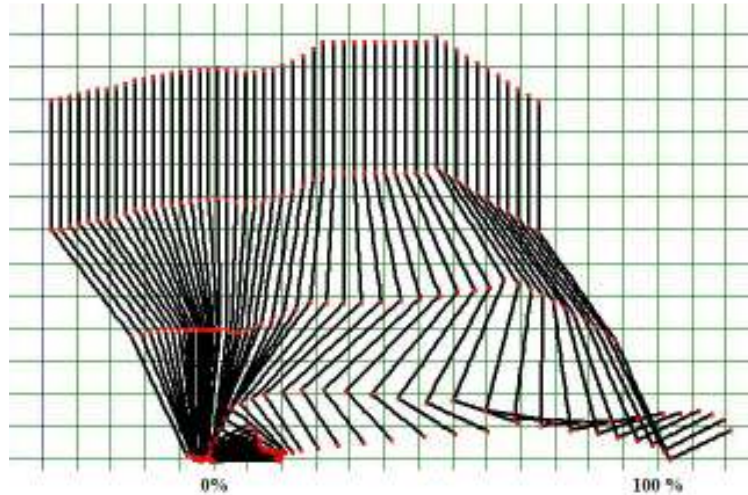


Fig. 7: Kinegram

commonly used in rehabilitation centers, as it records spatiotemporal parameters of the patient walking cycles by means of force sensors. The mercury track speed was set to 1.45 m/sec.

In addition, landmarks were drawn on the volunteer skin in order to measure any possible shift of the rigid rods and therefore the calculation of the absolute error (Table 1) after the trial.

Figure 6 presents the graph of one set of height typical curves obtained during one cycle of gait and the corresponding kinegram presented in (Fig. 7).

In addition to the test, results recorded with our system could be compared to those recorded by the Mercury track. The results of the comparison are shown in Table 2.

**Error measurement:** To measure the relative error of our system, result by the decalage of rods during walking, we proceed to the following protocol: once the equipment placed on a healthy person and walked a fast speed of 2 m/sec, during 15 min, stepping down results are obtained and are shown for each lower limb in Table 1.

**Clinical trials:** The system was used in the clinical record of 30 patients, for various analyzes as well on a treadmill in the laboratory and even some outside. A questionnaire for each, to assess the possible feelings of discom for thas been established, it follows that the volunteers, in the majority said, they were not hindered in their work except for the Older and younger.

## RESULTS AND DISCUSSION

The system need when mounted on the body adjusting potentiometers on the anatomical points is steps that must be done by a clinician or by a manipulator specialist. The system presents no gene or

walking or running, which does not, alters the movement and offers the possibility to study the race outside. The duration of implementation of the tool is from 05-10 min: all depends on the age of the person, which allows a large number of tests per day. The movement analyzed by the system is: flexion-extension of the lower limbs and inversion-eversion of the foot. The system is equipped with a radio frequency transmission by Xbee component that allows a field of freedom around 200 m, leaving the subject walks very freely and without conditioning.

There is a concordance of the results between the two tools especially in terms of cycle time and walking pace. The rods of the system move and shifted during 15 min ' walk, but only of 1 cm, the maximum relative error induced, is therefore less than 5% on knee, that we judge not too important in walking but so important in field of sport.

At the beginning of each test, the actual size of the segments of the subject is measured, in order to draw a kinegram which represents the shape of the human gait.

A kinegram, is the chronological displacement of the different body segments which gives an (X-ray) of the walk, nevertheless, we note that the displacement of the trunk is always vertical and that because our system does not yet have a potentiometer linking the hip and pelvis and we just simulate the trunk's movement.

Concerning the spatio-temporal parameters and compared to the treadmill (H/P Cosmos), this tool is cheaper, portable, wireless (Fig. 4) and permit a natural human walking.

The test realized on the gait of healthy subjects and the data obtained encourage us to continue the validation of this tool including the articular measures.

This digit eye jokey is robust tool to assess the human walking over great number of steps, then; it offers an objective, low cost documentation of healthy and pathological subject gait.

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