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A telemetry system designed for use with a conductive walkway: description and validation

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Abstract We present a telemetry system developed for use with a conductive walkway. A transmitter, a receiver, a conductive walkway and a PC with the appropriate software form the entire system, which is used for the assessment of the temporal parameters of gait and the gait speed. The technique is easy to use in routine clinical practice, easily reproducible and commercially available for research laboratories with restricted financial support. The telemetry system was found to be sufficiently accurate and repeatable, and was validated with a group of 20 healthy male adults (mean age, 34 years). The present results are similar to those reported in the literature for an alike group of subjects.

Key words Telemetry system • Conductive walkway • Gait analysis • Temporal parameters

Introduction

The need for accurate recording of human movement leads to the development of convenient gait analysis techniques. Some of these offer much information regarding the kinematics and kinetics of human gait, but need significant preparation time, are expensive to buy and maintain, and require trained personnel for their use [1, 2]. Some other techniques are of low cost for function and maintenance, and can be used in routine clinical practice. Most of the techniques developed for the recording of footfall timing belong to this category [3–6].

The temporal parameters of gait, such as the single support duration, have been proved to be useful in distinguishing between normal and pathological gait, as much as for the assessment of pre-and post-operative gait [7].

Various systems have been developed in the past for the assessment of footfall timing. Some investigators have taped conductive strips under shoes and have used conductive walkways to assess orthopedic patients', as much as normal subjects' gait parameters [3, 4, 8]. Others have developed sensors that were connected to electronic layouts, which they placed inside subjects' shoes to assess the contact signals of certain parts of the foot and/or the single and double support duration values [9,10]. Addressed walkways have also been developed for the assessment of gait temporal and spatial data [11–13].

The use of gait analysis techniques – such as the ones we referred to – may induce limitations in the assessment of footfall timing, due to an often-encountered obligation of the examined subjects to carry heavy attachments or accessories and wires at their trials [14]. Moreover, many of these systems cannot be easily reproduced due to the complexity of their construction [11] or their cost [15]. The purpose of this paper is to present an easily reproducible, low-cost, on-line system for the assessment of the temporal parameters of gait and the gait speed.

Materials and methods

Description of the system

The technique consists of a conductive walkway, a transmitter, a receiver and a personal computer (PC) with the appropriate software (Fig. 1).

The conductive walkway is made of a roll-up carpet with aluminum foil taped on it. Its overall dimensions are 1 m x 20 m x 0.01 m (W x L x H). The aluminum foil is a Logo product, sold in rolls of 0.6 m x 0.5 m (W x L). Two aluminum strips, 0.05-m wide each, are taped under the examined subject's shoes. The strips are connected to the transmitter via two fine wires.

The transmitter is placed at the waist of the subject. The electronic elements that form the transmitter circuit are placed in a small plastic box, 0.2-kg in mass and 0.08 m x 0.05 m x 0.03 m (W x L x H) in dimensions. The block diagram of the transmitter circuit is illustrated in Fig. 2. This circuit is formed by:

1. An Aurel Totem Line TX-433-SAW radiofrequency transmitter module, which operates at 433.3 MHz,
2. A 9 V battery used for supply and as input to the module, when the aluminum strips that are used as sensors do not close a circuit (Fig. 2),
3. A resistance of 10 KΩ,
4. A telescopic antenna for signal transmission.

The receiver is placed halfway across the walkway and is connected to the serial port of the PC. The block diagram of the receiver circuit is illustrated in Fig. 3. This circuit is formed by:

1. A telescopic antenna for signal detection,
2. An Aurel Totem Line STD-433/R DIL radiofrequency receiver module, which functions at 433.3 MHz,
3. An Aurel Totem Line STD-RS 232 module, compatible with STD 433/R DIL,
4. A 4N28 photocoupler for the isolation of the receiver ground from the PC ground,
5. A 9 V battery used to supply the receiver module, adapter and photocoupler.

Appropriate software has been designed in our laboratory to read the receiver's data, and to analyze and print out results. This software is written in Visual Basic and runs through Windows. The accumulated data can be temporarily stored in the PC's memory for later processing, or be processed immediately after a run, to produce results in electronic form or as printouts.

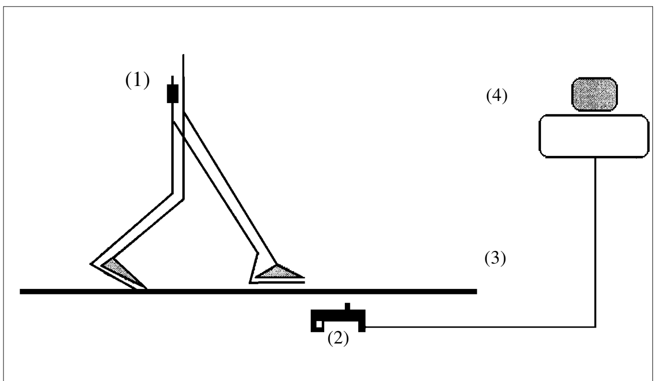

Fig. 1 Telemetry system for analysis of temporal parameters of gait and of gait speed (1) Transmitter, (2) Receiver, (3) Conductive walkway, (4) PC

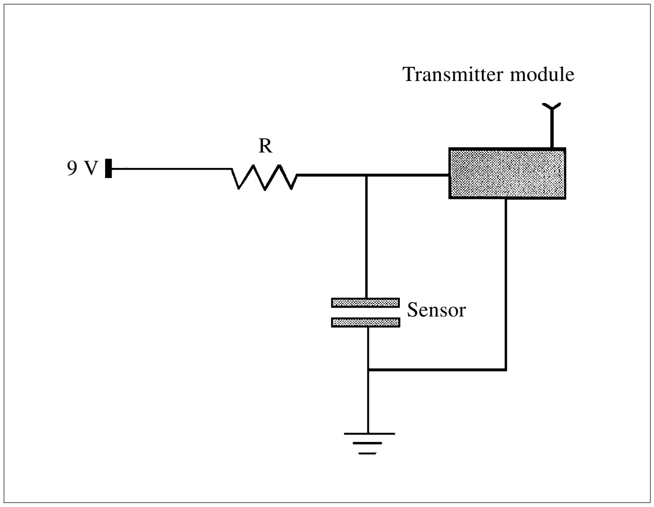

Fig. 2 Transmitter circuit. *R*, 10 k Ω resistor

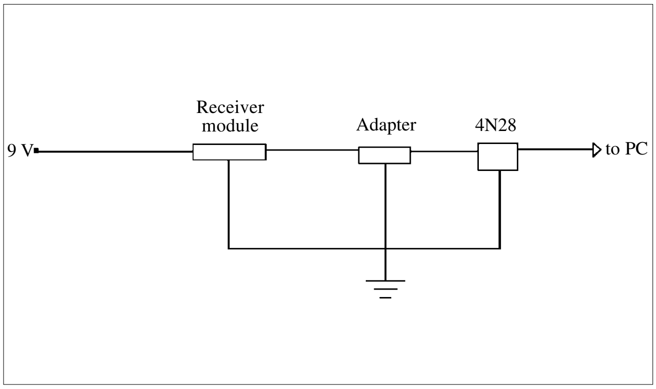

Fig. 3 Receiver circuit

The transmitter-sensor circuit allows the transmission of one signal. When both feet of the subject are in contact with the walkway, the module's input is 0 V. This input corresponds to the double support duration. In any other case, the module's input is ~9 V. This signal corresponds to the single support duration of either foot. An initial transition from 0 to 9 V is used as ignition for data sampling. The examined subject is asked to start his run using his left foot. The first transmitted signal corresponds to the single support duration of the right foot (9 V input at the transmitter module). Then will come:

- A double support duration with the left foot in front (0 V input). In this paper this phase will be called left double support duration.
- A single support duration of the left foot (9 V input).
- A double support duration with the right foot in front (0 V input). In this paper this phase will be called right double support duration.

- A single support duration of the right foot (9 V input) etc. This cycle of events will go on during the whole run.

The single step duration, as well as the gait cycle duration are assessed as sums of the appropriate single and double support duration values, to which we have just referred. The gait speed is assessed with the PC software's help, by the time taken by the examined subject to traverse the walkway.

Method of validation

The telemetry system was tested for its reliability and validity with a digital waveform generator. The waveform's duty cycle was adjusted to 50%. The generator's output was connected to the transmitter module's input. Twenty measurements were taken at frequencies of 0.5, 1 and 1.5 Hz, which correspond to 'slow', 'normal' and 'fast' gait speeds, accordingly.

The system has also been validated with a group of 20 healthy male adults (mean age, 34 years; standard deviation, 5.5 years), who volunteered in this study. The subjects were tested according to the principles established in Helsinki, 1964, and gave written consent for their participation. After an initial run, they were asked to perform 3 runs with slow gait speed, 3 runs with normal speed and 3 runs with fast speed. The first and last four steps were excluded from the data analysis. Ten consecutive full steps for each run were analyzed. The parameters recorded were:

- Gait cycle(s),
- Single support duration for both feet (% cycle),
- Double support duration for both feet (% cycle),
- Single step duration for both feet (% cycle),
- Gait speed (m/s), and
- Mean step length (% height).

Mean values and standard deviations were computed for the previously listed parameters.

Results

With the use of the pulse generator, the coefficient of variation (% standard deviation/mean value) was 0.279%, and inaccuracy error (% {theoretical value-computed value}/ theoretical value) of the 'slow' speed values was 0.24%. The corresponding values for 'normal' gait were 0.28% and 0.13%. The corresponding values for 'fast' gait were 0.28% and 0.24%. These values prove the high repeatability and sufficient accuracy of the system in the assessment of low-frequency (0.5-1.5 Hz) signals.

The mean and standard deviation values for the 20 healthy adults who participated in this study are illustrated in Table 1.

Table 1 Mean values (standard deviations) of gait parameters for a group of 20 healthy male adults

Parameter	Gait speed		
	Slow	Normal	Fast
Single support left (% cycle)	34.1 (1.5)	36.7 (1.5)	39.4 (1.6)
Single support right (% cycle)	33.8 (1.4)	36.4 (1.4)	39.4 (1.5)
Double support left (% cycle)	16.1 (1.4)	13.5 (1.4)	10.6 (1.5)
Double support right (% cycle)	16.0 (1.5)	13.4 (1.4)	10.6 (1.6)
Single step left (% cycle)	50.2 (0.4)	50.1 (0.5)	50.0 (0.5)
Single time right (% cycle)	49.8 (0.5)	49.8 (0.5)	50.0 (0.5)
Cycle (s)	1.32 (0.05)	1.14 (0.05)	0.93 (0.05)
Gait speed (m/s)	0.8 (0.2)	1.4 (0.2)	2.0 (0.2)

Discussion

The single and double support duration values detected in this study correspond to the values reported in the literature for an alike group of subjects, with the use of alternative, currently accepted techniques: Murray et al. [5] studied 12 healthy male subjects with ages ranging from 30 to 35 years (mean age, 32.2). Murray et al. used the interrupted light photography method, and reported the following mean values: 1.08 for the gait cycle, 11% cycle for double support duration, and 39% cycle for the single support duration. Aminian et al. [16], on the other hand, used miniature accelerometers to record footfall timing for a group of 30 normal subjects. Aminian et al. reported values (mean ± SD) between 37% and 41% for the single limb support, and values between 9% and 13% for the double limb support.

The single and double limb support duration values detected in this study are similar to the established values for the normal population, which are around 40% for the single limb support and 10% for the double limb support, and remain largely unchanged throughout most adult life [16, 17]. These results prove the adequate accuracy and reliability of our system for the assessment of footfall timing.

There are systems reported in the literature which are inexpensive to build but cannot be easily reproduced [11]. The use of telemetry enables the reproducibility of this system without difficulty. Moreover, commercially available systems for the measurement of stance and swing phases are usually expensive [15]. Other low-cost systems require wiring from the examined subjects to the computer [9, 10]. This system is of extremely low cost (~$170 plus the price of the PC), thus commercially available to research laboratories with restricted financial support. Furthermore, the use of telemetry enables freeing of the examined subjects from long wires and heavy or bulky accessories, which may affect or hinder their gait.

No specifically trained personnel are required for the system's use in routine clinical practice. Each test requires 3–5 minutes. Results on a run can be presented immediately after, in electronic form or as printouts. This on-line function of the system makes it better in this aspect over currently accepted systems like the VA-Rancho Gait Analyzer, where the recorder used for the accumulation of gait data is connected to a calculator after each run for further data processing.

Unlike aluminum plates that cannot be easily transferred and set up, the walkway carpet can be quite easily moved. Its weight is ~4 kg. Unlike aluminum plates that become dirty and tend to oxidize, a new aluminum foil can be glued on the roll up carpet when the old one starts getting destroyed. This ensures the long-term reliability of the system and its usefulness for clinical practice.

It is reported in the literature that sampling rates for gait studies typically range between 20 and 200 Hz [10]. In this study, the sampling rate was 200 Hz. In this way, events with an accuracy of 5 ms could be distinguished.

In conclusion, the new system has been found to be sufficiently accurate and repeatable in the assessment of known signals, as well as in the assessment of the gait of a group of healthy adults, in comparison with similar results reported in the literature. This fact, combined with the low price and the ability for reproducibility are the technique's strongest aspects. Like other currently accepted conductive walkway systems [13], this one can be widely used for the assessment of the gait of orthopedic patients with a variety of diseases (e.g. osteoarthritis, cerebral palsy), athletes, mountaineers or children.

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