Stride length: measuring its instantaneous value

G. C. Campiglio and J. R. Mazzeo
Institute of Biomedical Engineering, School of Engineering, Buenos Aires University
Paseo Colón 850, Buenos Aires C1063ACU, Argentina
E-mail: gcampi@fi.uba.ar

Abstract. Human gait has been studied from different viewpoints: kinematics, dynamics, sensibility and others. Many of its characteristics still remain open to research, both for normal gait and for pathological gait. Objective measures of some of its most significant spatial/temporal parameters are important in this context. Stride length, one of these parameters, is defined as the distance between two consecutive contacts of one foot with ground. On this work we present a device designed to provide automatic measures of stride length. Its features make it particularly appropriate for the evaluation of pathological gait.

1. Introduction
Human gait is a function that, after its learning period, is accomplished almost automatically. Its dynamic control involves posture, equilibrium and locomotion, continuously adapting to a variable environment. The study of gait is of interest for basic research, clinical biomechanics and sports.

From a neurological point of view, the organization of sensory-motor activities is accomplished by the central nervous system. Sensory information (position and displacement of every part of the body that is involved, visual information, vestibular information, and others) is processed at brain level so that neuromuscular effectors are properly controlled [1].

From a kinematic viewpoint, human locomotion is described in terms of movements of the body as a whole and in terms of the relative movements of its parts: angles, velocity, etc. The mechanical viewpoint includes the effects of gravity, muscular contraction and inertia, among others.

Studies of gait, both for clinical or research purpose, require the availability of records that represent its most significant spatial-temporal parameters; the information that these records provide complements the qualitative evaluation realized by the specialist. Some significant objective parameters are: feet separation, knee angle, lateral and longitudinal balance, to name just a few.

This work is focused on one of these significant parameters: the stride length (SL). SL is related to the segment of gait cycle between two consecutive contacts of the same feet (heel) with ground. SL is defined as the distance between those two contact points. It should be noted that SL is different from “step length”, which is defined as the distance between the contact of the toe tip of the balancing feet and the contact of the heel of the other feet [2].

Different parameters that define the kinematics and the dynamics of human gait, including SL, may nowadays be accurately quantified. Devices used for these measurements are based mainly in two technologies: (a) capturing video images and (b) quantifying the distribution of the step pressure by means of a high number of sensors on force platforms and walkways [3][4][5]. The availability of these devices is usually limited by price and also by their requirements on installation and specialized personnel.
An alternative widely used technique for measuring SL in routine clinical studies is based on marks produced on the floor by a marker attached to the shoe [2],[6]. The beginning and the end of the walk are generally not considered because walk steadiness is desirable for the measurement. SL is estimated over a walk usually 10 meters long.

On this work we present a device that provides, on a computer file, a numerical series that comprises the successive instantaneous values of SL measured on normal or pathological gait. Its cost is low and it has minimum installation requirements.

2. Design
The distance between two consecutive contacts of the same foot (heel) with ground is measured by means of a thread attached to the ankle. Contact times are estimated by means of sensors located in the shoes underneath the foot.

The system comprises the following modules: step sensor, distance meter, electronic control module and computer interface. A prototype is shown on figure 1

![Figure 1. Photography of a prototype](image)

2.1. Step sensor
Step pressure is estimated by means of a FSR sensor (Force Sensitive Resistor) under the heel. This sensor is installed within an insole between two layers; one of them is rigid the other one is compressible. Total thickness is only about 3 mm, providing easy placement under the heel in standard shoes. Furthermore, it does not produce discomfort while walking neither it requires height compensation on the other feet.

The resistance of the sensor changes when the subject discharges his weight on the heel. These changes are processed by the electronic control module, which provides contact times estimates related with times when step pressure exceeds a defined threshold. This threshold is dependent on anthropometric characteristics of the subject, so its manual setting is available.

In earlier versions of this device, the estimation of heel contact time was accomplished by means of on/off switches. The necessary structural rigidness of the switch and its relatively big size make a fixation system to the shoe indispensable; this fitting affected gait comfort to some extent. FSR sensors are 0.1 mm thick and its surface, depending on the model, is less than 100 mm².

2.2. Distance meter
As the subject walks away from the electronic control module, which is in a fixed position, he pulls from a thread. The length of the thread that is coming out of the module is electronically measured.

The segment of thread between the electronic control module and the subject is desirable to follow a straight line for an accurate measurement (see section 3.3). For this purpose, the driving system
imposes some resistance on the thread. This resistance is relatively low, so that it does not produce discomfort on walking.

SL may be measured over a maximum walk length of 20 meters, limited by the thread length. After releasing the thread from its fixation to the ankle, it may be automatically rewound by pushing a button on the front panel of the electronic control module.

2.3. Electronic control module
This module comprises an analog section and a digital section. A block diagram is shown on figure 2. The analog section processes the signal generated by the pressure sensor. The main functions of the digital section are: reel rewind control, measuring the thread length coming out of the module, computing SL and sending data to a computer. It is based on a microprocessor from the 8051 family.

On demand rewinding of the thread was implemented by means of a continuous current motor.

Inside the module the thread is guided from the reel where it is rolled towards another reel that rotates as the thread is pulled out from the module. The length of the thread is measured on the basis of the number of turns in this last reel. A magnetic sensor aligned with a magnet fixed on reel provides a reference to detect each turn. Thread length is computed by software on the basis of turn count and reel diameter.

Pulses, which the analog section generates, indicate heel contact times with ground. SL is measured as the thread length dragged in the meantime of two consecutive pulses.

SL values are stored in volatile memory and then transmitted to the computer.

2.4. Computer interface
This interface follows the RS232 standard. A computer file in text format comprises the successive values of SL. This numerical series may later plotted or mathematically processed using standalone software.

2.5. Error sources
One of the issues that may affect accuracy in SL measurements is the precision of thread length measures, which has a resolution of one reel turn. Reel diameter is 1.9 cm, and then the maximum error is 6 cm (one turn).

Accuracy may also be affected when the segment of thread outside the module does not follow a straight line. To minimize this effect, we introduce some resistance in the thread driving system.

Pathologic gait patterns may also lead to measuring error. This may happen when the movement of the leg has a component on the frontal plane (normal to the advance direction). Hemiplegics, resulting from stroke or brain paralysis, lead to this kind of gait pattern [7],[8]. The maximum angle with respect to vertical is usually about 18° in those cases. Considering a mean leg length of 80 cm, displacements on the frontal plane may be as large as 25 cm. The following analysis describes the effect of this lateral movement on the accuracy of SL measurement.

![Figure 2. Block diagram](image-url)
SL is measured as the distance between the module and the subject. SL should ideally be estimated along the advance direction. This segment to be measured forms a square rectangle with the lateral displacement; the hypotenuse is the length of thread coming out from the module and the lateral displacement is the short side. When the subject is 2 m. away from the module the error (difference between the longest side and the hypotenuse) is 1.6 cm and it reduces as the subject keeps walking. The results of our experiments are coincident with this analysis. Considering, with the purpose of minimizing error, distances between subject and module greater that 2 meters is consistent with what it was said on section I about ignoring the first segment of the walk with the purpose of looking for a steady walk.

3. Results
For an experimental evaluation of the accuracy of this method we took the reference provided by the method based on marks left on the floor (see section I). This last method is considered to be the most accurate for spatial measures of gait [10].

Figure 3.a presents a record of SL as a function of step number; it was obtained using our device on a subject with no diagnosed gait disorders. Simultaneously, we quantified SL applying the marker method. Results are shown on figure 3.b. The point-to-point difference between figure 3.a and figure 3.b is plotted on figure 3.c.

Differences between both methods have a mean value of -1.2 cm, or a mean percent error of -0.1%. This negative bias may be attributed to the technique used to estimate the thread length (see section 2.3 and 2.5); its error is lower than a reel turn length but always by defect. By means of a relatively simple technical solution we plan to increase the resolution to a fraction of a reel turn, so as to improve the overall accuracy of the device.

![Figure 3](image)

**Figure 3.** (a) SL record obtained with the device (b) SL record obtained by the mark method (c) Difference between measures on (a) and (b)

4. Conclusions
There is a specific need for objective measures of gait to give greater support to treatment decisions, which many times are based exclusively on subjective evaluations [11]. Objective measures are also important for the evaluation of the effectiveness of a treatment protocol.

The device we present here provides measures of SL, which is among the most significant parameters of the gait function. The information it provides is not just a single representative value of the SL but a series of step-to-step SL values, so reflecting SL variability over a relatively long walk. These records are automatically stored in computer files, which is a significant improvement with respect of the widely used marker method. The device is portable and it has low installation requirements: a computer and a room long enough for the walk.
Systems mentioned on section I have much higher cost and features than the device we present here. These systems allow complete records of several parameters of the gait function. Among these parameters, SL is measured with a 1% accuracy in the case of systems based on pressure sensors (GAITRite) [11]; this is comparable with our results. System accuracy of equipments based on video images (Vicom) is about 0.1 mm [12].

On this work, we present a low cost solution that was conceived to be applied in hospitals. We plan to improve its features by enhancing accuracy as described above and by adding autonomous memory for eliminating the need for a computer while measurement is performed.

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