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SHOE INSERT EMBEDDED FOOT PRESSURE MONITORING SYSTEM

Key words: foot plantar pressure, in-shoe system, foot disorders, health monitoring, ground reaction forces.

Abstract: The article presents the technical solution of the shoe insert, which can measure the foot pressure on the ground, and the proposal of an algorithm, which based on the received data of a shoe insert, decides whether the investigated person walks or runs. The algorithm is characterized by low computational complexity, which allows it to be used in mobile devices.

Wbudowany system do pomiaru nacisku stopy na podłoże

Słowa kluczowe: ciśnienie podeszwy stóp, pomiarowe wkładki do obuwia, monitoring zdrowia, siła reakcji na podłoże.

Streszczenie: W artykule przedstawiono propozycję rozwiązania technicznego wkładki do obuwia służącej do pomiaru nacisku stopy na podłoże oraz propozycję algorytmu, który na podstawie otrzymanych danych z czujników tensometrycznych wkładki podejmuje decyzję, czy badana osoba idzie czy biegnie. Algorytm charakteryzuje się małą złożonością obliczeniową, co pozwala na jego zastosowanie w urządzeniach mobilnych.

Introduction

Recently, in the field of health monitoring, a whole range of products used in physical medicine and rehabilitation have appeared. Currently, not only physicians or physiotherapists can diagnose problems of the locomotor system. A new field of diagnostics has emerged - pedobarography - allowing for the examination of foot disorders. Diagnosing the problem of abnormal foot placement at an early stage of the disease is important, because it prevents injuries or degeneration. The forces acting on the foot by the ground are known as ground reaction forces (GRF). An example of a GRF monitoring device corresponding to human steps can be a force measurement platform that measures foot pressure, and registers foot alignment and acting pressure forces, both in static and dynamic testing [3, 5]. Different types of examinations allow for precise detection of reaction forces acting on the human locomotor system and the determination of the position of the centre of gravity, while standing and walking. The disadvantage of the measurement platforms is the ability to perform tests only in the laboratory.

An alternative to measurement platforms are shoe inserts. With the advancement of technology and the miniaturization of electronic systems, many systems have been developed and placed on the market for the construction of miniature systems for the measurement of foot loads. Incorrect loading of individual foot areas can result in problems related to the entire locomotor system or can just signal such problems. A different aspect that many researchers focus on is the problem of foot ulcers due to diabetes [9]. Another problem that can be diagnosed by measuring plantar pressure distribution is a problem related to gait instability in elder people and other people with imbalances. The information obtained can be used to improve balance in elderly people [8]. These measurement systems can also be used in a variety of sports (e.g., football, running, walking) to improve training results [5].

Measurement systems allow one to trace the physiology of the gait. Thanks to the use of shoe inserts, the test can be carried out under real conditions. Often, data from such measurement systems, in addition to diagnostic applications, are used for footwear design, sport biomechanics, or injury prevention [4].

Plantar pressure measurement systems available on the market differ in sensor configuration due to different requirements. Capacitive, resistive, piezoelectric, and even optical sensors are commonly used. Typically, a complete system consists of a foot force measurement system, a data transfer system, and data visualization software. In literature [2], it has been shown that the extra weight of the measuring device placed in the shoe up to 300 g does not affect the characteristics of the natural gait.

This article presents results obtained in a designed and constructed system for ground reaction force measurements. The presented system was designed in its original version for the monitoring of hip-joint or knee-joint overloads during rehabilitation after prostheses insertion. Due to market demand, ideas are emerging to test people in motion and distinguish whether a person is running or walking.

The purpose of the study was to develop algorithms which, based on the signals received from the sensors in the shoe inserts, would distinguish the run from the gait.

1. Measuring system

Shoe inserts were constructed to be used for the tests. Each insert consists of two measuring platforms located in foam. The placement of the measuring platforms was chosen on the basis of the anatomical foot areas [1]. The strain gauges were mounted on the shoe inserts and placed in the heel and metatarsal area. Figure 1 shows the construction of the measuring element.

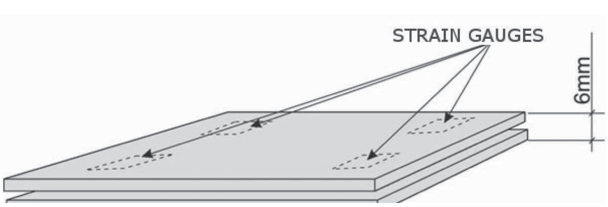

Fig. 1. Construction of the measuring element
Source: Authors.

Each platform (miniature scales) consists of 4 strain gauges. The output signal from each insert is the sum of the signals from both platforms. To increase the comfort of the measurement, platforms were placed in anatomically shaped foam. As shown in Figs. 2 and 3, the insert is designed for placement in the shoe and does not require additional data transfer components. The power source and Bluetooth transmitter were mounted in the platform placed under the metatarsal area.

Fig. 2. View of the inside of the insert
Source: Authors.

Fig. 3. View of prepared insert
Source: Authors.

The insert (Fig. 3) was kept in the shoe for the time of the tests. The study consisted of collecting data during the user's walking and running. The study involved 10 persons, differing in weight and height. Obtained results were normalized to the weight of each person. Prior to data collection, a calibration was performed. This operation was necessary because each test person used his own shoes, so it was necessary to eliminate the influence of individual factors on measurements such as the strength of the shoe binding measured by the inserts. Calibration consisted of determining the average value and the standard deviation of the signal collected from the sensors placed in the shoe inserted on the tester foot. During calibration, the tester held the leg horizontally over the ground. Figure 4 shows a block diagram of the GRF registration system.

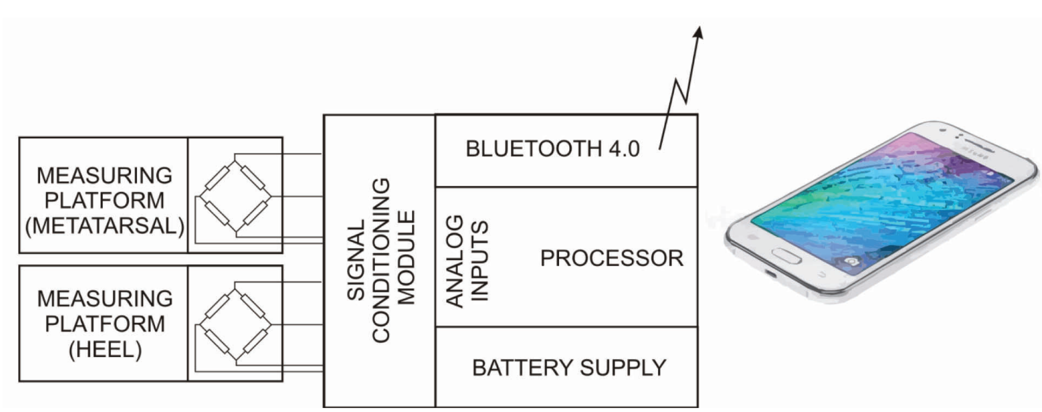

Fig. 4. Block diagram of GRF registration systems
Source: Authors.

Measurement data is transmitted in real time. After receiving signals from both inserts, an output signal y_{out} (Fig. 5) is formed. In this system, the digital signals from both inserts are summed up and are observed as the output signal. Depending on the pace of movement of the test person, the results shown in Figs. 7 and 9, respectively, were obtained.

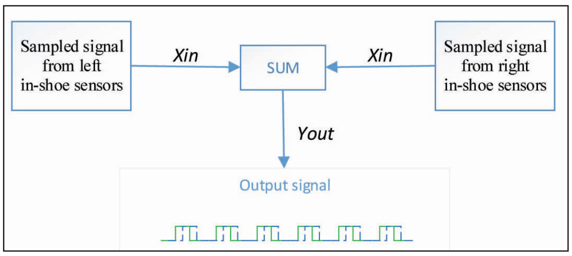

Fig. 5. Scheme showing data taken from the inserts
Source: Authors.

During the gait, the output signal from the shoe insert is composed of the sum of the signals of the platforms located in the heel and metatarsal area. In the block tagged SUM (Fig. 5), the x_{in} signals are summed to give an analogue output signal (Fig. 6). In this case, the heel area is loaded for a longer time and with more pressure.

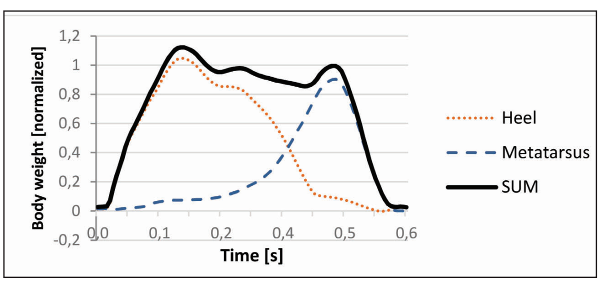

Fig. 6. Forming the output signal from the insert while walking
Source: Authors.

After summing up the signals received from both platforms, the SUM signal shown in Fig. 7 was obtained.

It can be seen that the signals from the left and right inserts do not deviate from each other in terms of shape, duration, and registered force. During the run, the ratio and time of the metatarsal and heel are changed. The formed signal from the insert during running is shown in Fig. 8. It is not hard to notice that the shape and duration of the received pulse differs from the pulse received for walking (Fig. 6).

Figure 9 shows the output signal received during running. The duration Δt between successive peaks of the signal will depend on the speed of the run. With the speed increase, the Δt will also increase.

Figure 10 shows that during running, there are moments in which the output signal is close to zero, while in the walking gait, a variable value signal appears at a level other than zero. In this case, the detection of the run consists in detecting a value of 0 in the output signal.

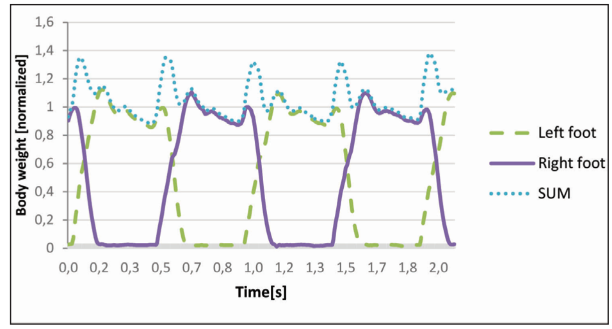

Fig. 7. Output signal when walking
Source: Authors.

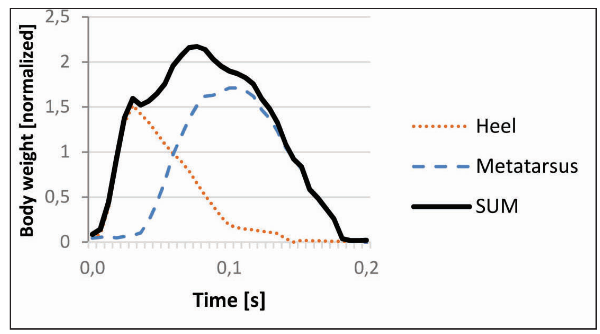

Fig. 8. Forming the output signal while running
Source: Authors.

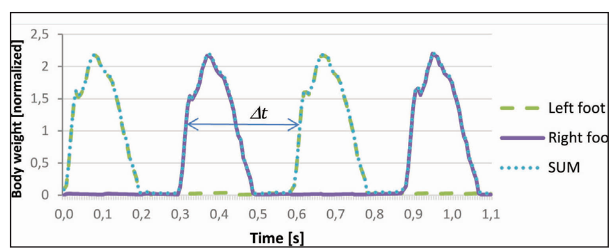

Fig. 9. Output signal received during the run
Source: Authors.

When assessing the type of movement (running, gait) of the person using the inserts, the signal that is generated in both cases should be considered. These signals are shown in Fig. 10.

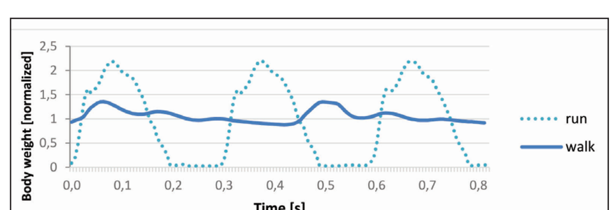

Fig. 10. Output signals for running and walking
Source: Authors.

2. Results

In the scheme presented in Fig. 5, the authors proposed changes that allowed the binarization of the output signal. This solution is dedicated to race-walkers. Monitoring during training will answer the question whether one of the feet of a competitor is always in contact with the ground. Figure 11 shows the modified system for signal x_{in} processing.

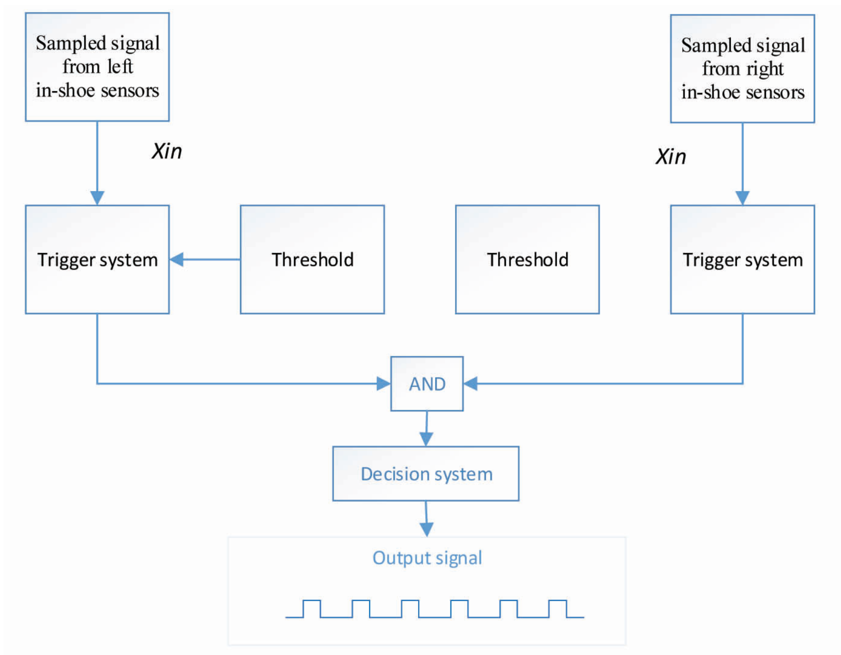

Fig. 11. Data processing method
Source: Authors.

Input signal x_{in} is thresholded by expression (1):

$$y_{out} = \begin{cases} 0, & x_{in} < \beta_e \\ 1, & x_{in} \geq \beta_e \end{cases} \quad (1)$$

where

x_{in} – input signal,
σ – standard deviation,
$\bar{x}$ – average,
$\beta_e = 3\sigma + \bar{x}$

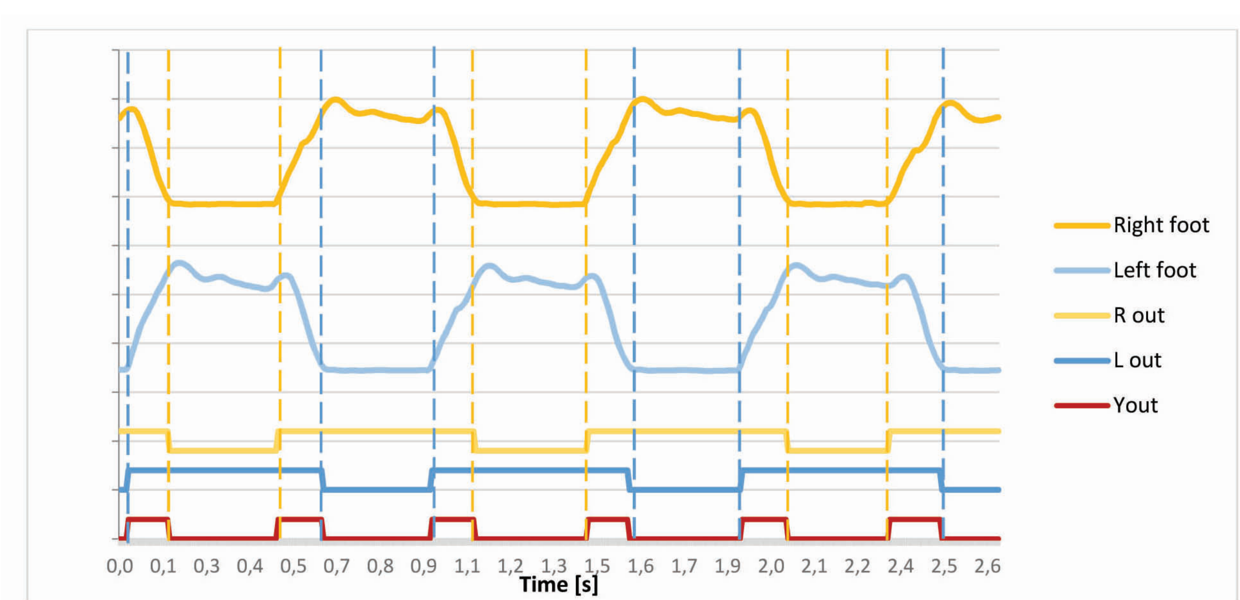

Fig. 12. Threshold operation and input signal formation
Source: Authors.

Signals L_{out} and R_{out} (Figs. 12 and 13) are the signals obtained by the threshold operation.

Figure 12 shows the signals used to obtain the output signal, which is the result of a logical AND operation of the L_{out} and R_{out} signals. In the case of a walk, a rectangular wave is obtained at the output Y_{out}.

Figure 13 shows example data for running. In this case, the output signal is equal to 0, because there is no situation in which L_{out} and R_{out} signals are 1 at the same time.

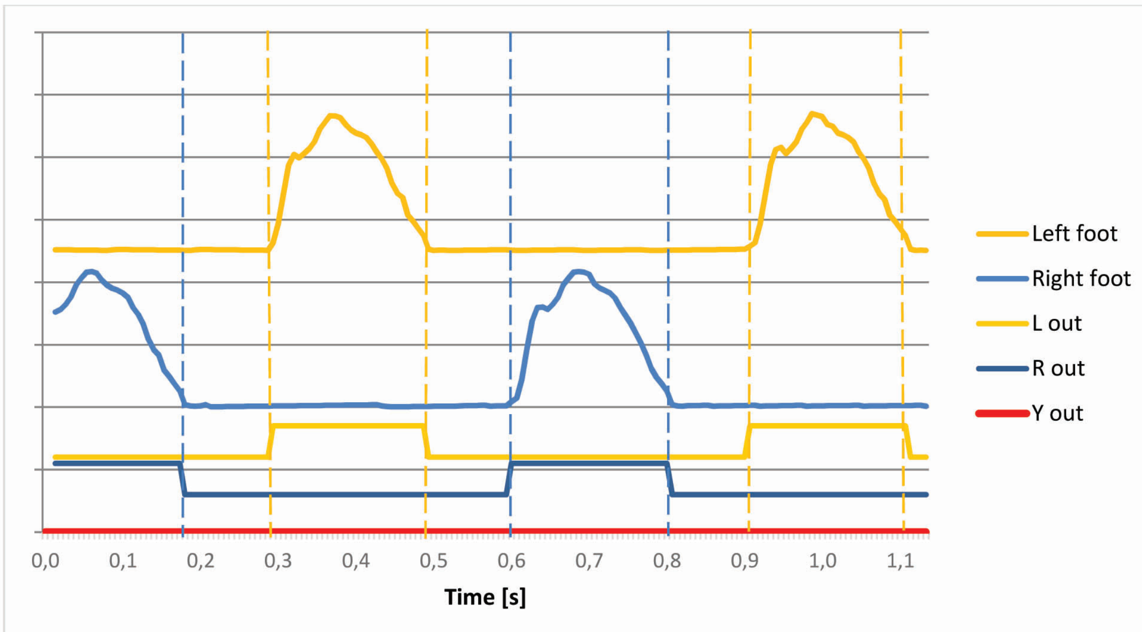

Fig. 13. Threshold operation and input signal formation
Source: Authors.

Conclusions

The presented system can be successfully used to monitor race-walker training. In the target version, the program on the mobile device could sound a warning to the athlete that he went into a run. Because the presented system is relatively simple, one could be tempted to implement this in hardware. The supervisory part could be implemented in the form of a wrist strap. Finishing the whole system – shoe inserts + supervisory system – in the form of a program and / or wrist strap could be a great tool for keeping track of training progress.

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