

ТЕХНИЧЕСКИЕ НАУКИ

EMPLOYEE HEALTH MONITORING SYSTEM USING SMART INSOLES

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ABSTRACT

The article describes an application of an employee health monitoring system that consists of insoles with built-in sensors and a smartphone app. The system controls employees' static and dynamic load in a vertical position using built-in gyroscopes and accelerometers. It calculates the pressure force and time spent in static and dynamic positions and provides recommendations for changing the posture to reduce the risk of spine, and joint deceases. It is shown that the presented complex increases the safety and productivity of labor and reduces the risks of industrial injuries. Moreover, the employer gets the opportunity to evaluate the working day general pattern, analyze the time spent in a static and dynamic position, track and check worker's location in complex environments.

Keywords: Posture detection; gait detection; employee health; SVM; sensors

1. Introduction

Industrial enterprises managers demonstrate an increased interest in the objective data regarding employees' whereabouts during the working day. Working efficiency depends directly on employees' health, making intelligent devices for disease prevention and accelerated rehabilitation the most popular trend in the digital industry. The application of such devices results in the reduction of sick days and improvement of working efficiency.

The human foot is a perfect anatomic construction for support and locomotion; due to its arch structure, the foot is a "biological leaf spring" that provides even weight distribution, shock absorption, smooth walking, and cushioned standing. Static deformations affect the anatomy of the foot and its functions. Longitudinal arch flattening weakens shock-absorbing functions of the foot, which increases shock effects on the knee and hip joints. This results in rapid fatigue and leads to pains in different body regions distal from the foot [1-5].

The real-time control of foot condition is possible under the application of SMART insoles. The pressure sensors embedded in insoles are applied in different spheres. For instance, in [6, 7], the application of pressure sensors to monitor older people with a high risk of falling and other mobility problems is described. In [8], insoles with pressure sensors were applied to study Tai-Chi Chuan. Moreover, there are studies regarding the application of insoles for the rehabilitation of patients after the stroke [9], for people with neurological disorders [10] and for orthopaedics purposes [11].

Obtaining the information on people's whereabouts for the systems of presence control can be

indicated as another sphere of SMART insoles application [12]. The main restriction of these systems is that they are based on GPS/GLONASS signals, which cannot be registered on the strategically important objects developed by industrial enterprises and underground, underwater, and inside capital buildings/facilities. Therefore, mobile applications using satellite signals cannot detect precisely employees' whereabouts. The systems, which can receive information on people's whereabouts in such conditions, require a specially structured environment [13], which is not always possible.

To overcome such restrictions, we propose using the local detection system based on a sensor unit in SMART insoles, which does not depend on satellite signals. Such a system allows monitoring employees' activity during the working day and estimates employees' efficiency and workload.

2. Methods

Wearable devices consist of a pair of smart insoles used for employees who work on rough surfaces. We embedded eight piezo sensors [15-17] into a FizioStep [14] silicone insole, evenly distributing them over the insole surface to test our prototype. Piezo sensors were connected with an analogue comparator and microcontroller module. The location and number of sensors can be adjusted to tasks and reach up to 32 units [18]. A power supply is performed through a 12V 2000mA Li-ion accumulator. Foot location in space is done with one of the Arduino modules – a 10-axis gyroscope-accelerometer-magnetometer. We covered sensors with eco-leather to protect sensors from a short circuit and wire breakage and preserve the insole's aesthetic and hygienic qualities (Figure 1).

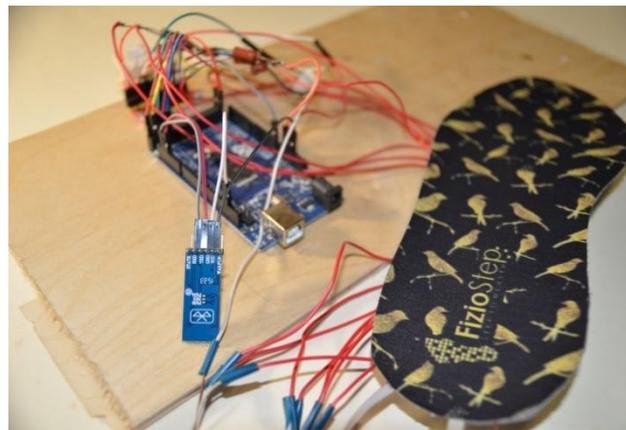


Figure 1. Prototype with Arduino 2560 and piezo sensors covered with eco-leather

The sensor unit is located both in the right and left insoles (fig. 1 demonstrates the left insole) and is used for obtaining the following data: mass distribution between legs (detection of the symmetry between the left and right legs); distribution of the mass and pressure force of the body between feet in a static mode (staying); distribution of pressure force between feet in a dynamic mode (walking/running/jumping); detection of pressure force and vector movement on a supporting and jumping arches; angle location of feet in space (adduction/abduction); walking and running speed.

Programming and firmware upgrade of the microcontroller are performed in Arduino development framework, which also allows obtaining the data from the platform using a UART serial protocol (through wire connection, USB connection or Bluetooth wireless connection) without any additional software shell,

which accelerates and facilitates device adjustment at initial stages.

At the second stage, after adjusting the mechanical part, data from sensors will be transmitted to a smartphone through a particular mobile application (Figure 2) for the analysis and processing of the data. The primary function of this application is to provide the user with information regarding load distribution between feet and recommendations on feet positions in static and dynamic conditions to reduce the risk of locomotor diseases and accelerate post-trauma rehabilitation. This function is performed through the analysis of walking biomechanics. The additional function is analyzing movement activity and detecting employees' whereabouts based on the combination of the data obtained from pressure sensors, accelerometer and gyroscope.

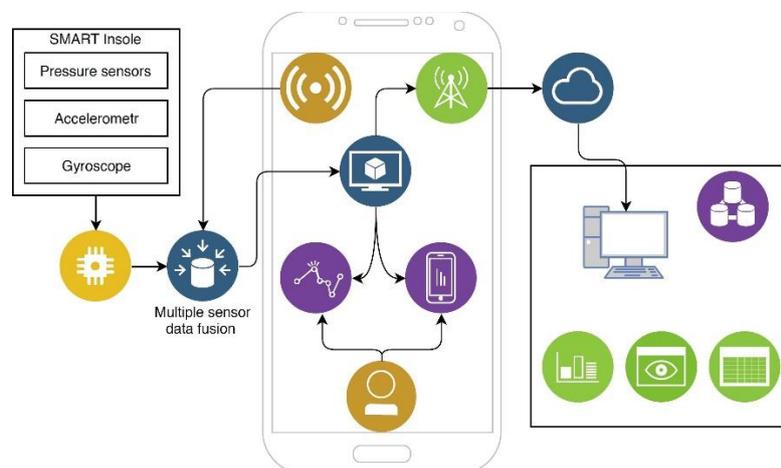


Figure 2. General scheme of data processing and representation

The system of whereabouts detection is based on the algorithm of registering steps, their length and direction. In [19], it was established that accuracy could be improved by 7% by applying more than one accelerometer and gyroscope located on different body areas. In this case, the information obtained from different sources can improve accuracy by compensating the disadvantages of one sensor with the advantages of another one. The application of machine learning for errors correction allows improving accuracy up to 20% [20]. For this purpose, apart from the sensors embedded into insoles, we propose using a

smartphone accelerometer/gyroscope and apply the SVM (Support Vector Machine) algorithm to adjust a mathematical model of movement activity classification and whereabouts detection.

Some enterprises prohibit using smartphones, which decreases data accuracy and makes analytics unavailable during the working day. In this case, data will be stored in a flash memory connected with Arduino 2560 USB output. The additional gyroscope located on the body (for example, on a name tag) will also improve the accuracy of whereabouts detection similarly to the smartphone.

3. Data analysis and processing

The data obtained from insoles are subjected to several stages of analysis:

- Multiple sensor data fusion [21];
- Signal filtration and enhancement;
- Application of a pre-trained SVM model for a movement activity classification;
- Application of pre-trained SVM model for analyzing pressure and classification of the pattern obtained according to possible health-related problems (arthritis, arthrosis, problems in various spine regions);
- Visualization of feet position with the characteristic of pressure and voice commands to change load distribution;
- Whereabouts estimation algorithm.

In comparison to fitness trackers, which count steps based on the data obtained from the accelerometer, we combine different sources of data collection: step detection is performed when the user puts his foot on the ground under a certain pressure. Combining these data and the data obtained from the accelerometer and gyroscope improves the accuracy of step length detection. Therefore, we exclude false signals from the accelerometer and pressure redistribution (stationary walking), which prevent classifying steps correctly.

In a model of movement activity, steps can be classified into five categories: sitting, plain walking, stair ascending, stair descending, running, stationary walking. The accelerometer embedded into the insole provides the data regarding Y-axis (for example, stair ascending as acceleration during ascending is more significant than during plain walking or descending). The gyroscope in the insole provides the data for Z-axis (for example, rotation of the leg), which allow distinguishing descending and downward rotation peak. The information obtained from the second accelerometer located on the body (in a smartphone) updates the data with the information on the X-axis,

improving the accuracy of movement activity detection.

In a model of foot pressure analysis, we established the force of pressure on sensors, distribution of load between pressure sensors (heel to toe roll, roll from the outside to the inside of the foot), fixation of foot position in a support phase during walking/running (landing on heels/outer edge of the foot/toe/entire foot).

Having combined the data obtained from sensors, we performed the filtration of signals using Chebyshev Type II filter.

4. Results

Test data were collected during the experiment, the participant was proposed to perform a specific type of movement activity for 20 seconds (stair ascending, walking forward and backward), the total number of experiments is 6, during each experiment the participant made 8-12 steps. With the help of accelerated video recording, we performed time registration to establish the phases of leg movement, step trajectory and direction, distribution of load during the contact between the foot and surface. Signals were registered every 0.1 seconds to collect 2400 signals from 12 sensors. The following features were obtained from the sensors: min, max, mean, slope. To classify step length, we collected 200 recordings for short, middle and long steps. To classify step directions, we also collected 200 recordings for side steps and steps forwards/backwards.

Each model receives 42 features as input (40 for pressure sensors, two from Arduino accelerometer and gyro). This input is used to find the best separating hyperplane between classes, maximizing the margin between every two classes. SVM model uses different types of kernels. We were choosing between linear, polynomial and radial basis kernels. Figure 3 demonstrates three SVM models used for steps classification.

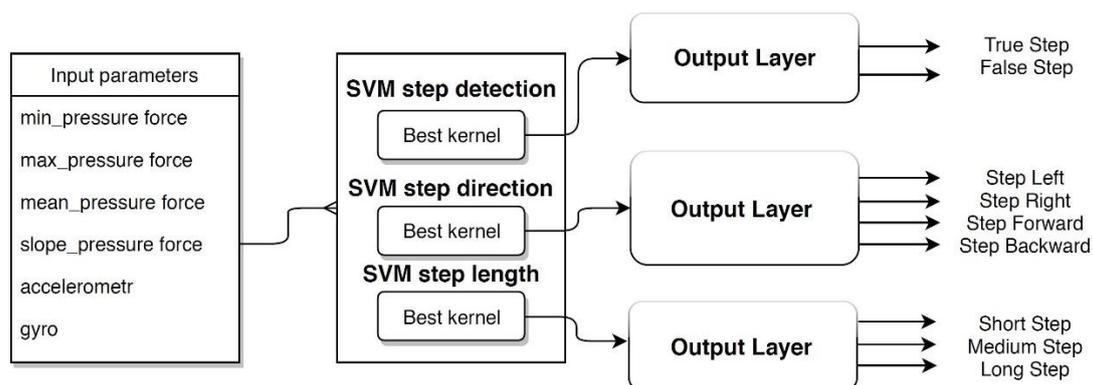


Figure 3. Support Vector Machine for Step Classification

The choice of the kernel was performed based on accuracy results. Inside SVM step detection, one vector indicates that the current step belongs to the positive class and others to the negative. The first vector in SVM indicates that a short step is a positive entry and the

others are negative. The second vector separates medium steps, and the third – classifies long steps. Table 1 contains experiment results for the detection of step length.

Table 1

Quadratic kernel SVM results for step length detection

Step Length	Precision	Recall	F1-score
Short Step	0.97	0.98	0.97
Medium Step	0.99	0.92	0.95
Long Step	0.94	0.94	0.94

The score of the new observations is then estimated using each classifier. This will create a vector with three scores, one per classifier. The index of the element with the highest score is the class index to which the new observation most likely belongs. For example, if the first index has the highest value, then the step is characterized as short. Thus, each new observation is associated with the classifier that gives it the maximum score. Similar models are developed to classify specific static pressure patterns to spine and joint deceases.

5. Conclusion

The application of insoles with sensors contributes to the prevention of locomotor diseases and provides managers with information on employees' whereabouts, workload and collective activity to estimate their working efficiency. Employees also receive valuable data regarding their health and recommendations, which improve post-trauma rehabilitation and prevent the development of osteochondrosis, arthritis, arthrosis—implementing such a system encourages employees to be more careful towards their health and demonstrates personal involvement of managers.

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СОЦИАЛЬНО-ЭКОЛОГИЧЕСКИЕ ЗАДАЧИ И ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ

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АННОТАЦИЯ

В данной статье обсуждается развитие информационных технологий в области охраны окружающей среды в условиях пандемии.

ABSTRACT

This article discusses the development of information technologies in the field of environmental protection in pandemic conditions.

Ключевые слова: информационные технологии, экологическое нормотворчество, индикаторы целеполагания, благоприятная окружающая среда

Keywords: information technology, environmental rule-making, targeting indicators, favourable environment

«Особое внимание хотел бы уделить задачам, которые поставлены в майском Указе, развёрнуты в национальных проектах. Их содержание и ориентиры отражают запросы и ожидания граждан страны. Национальные проекты построены вокруг человека, ради достижения нового качества жизни для всех поколений, которое может быть обеспечено только при динамичном развитии России».

Послание Президента
Российской Федерации В.В.
Путина Федеральному
Собранию 20.02.2019 [1].

В настоящее время в Российской Федерации насчитывается 125 миллионов пользователей интернета [2].

По мнению первого заместителя главы администрации Президента Российской Федерации С.В. Кириенко, влияние интернета в современной жизни растет, и появляются новые риски - роль и влияние интернета и информационных технологий в современной жизни, и в мире и в России, будет только расти, появляются новые возможности использования. Такие вызовы, как пандемия, ускорили переход даже тех процессов в образовании или в медицине, которые всегда были офлайн. Они тоже перемещаются в интернет-пространство. И с одной стороны - это открывает новые, уникальные возможности, с другой стороны, вместе с возможностями в интернет из реальной жизни перебираются и угрозы. И традиционные угрозы с обманом, хищением данных, с угрозой жизни и безопасности людей.

В Докладе Уполномоченного по правам человека в Российской Федерации за 2020 год также большое внимание уделяется развитию и использованию информационных технологий - Рис. 1, Рис. 2 [3]: