Bogdan DZIADAK[1], Valentyna DUDNYK[2], Marcin JURCZAK[2], Przemysław WISZNIEWSKI[2], Kamil WOJTAS[2]

Institute of Theory of Electrical Engineering, Measurement and Information Systems, Warsaw University of Technology (1)
Warsaw University of Technology (2)

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Platform posturographic system using polymer sensors

Abstract. The aim of presented research is a system that can monitor human posture. The project is based on scaled platform and polymer Force-Sensitive Resistor (FSR) to detect pressure on predetermined points of examined person's feet and to measure change of Center of Pressure COP. The data is collected by an Arduino UNO and sent to PC via UART for further analysis and results display (stabilogram and histogram of COP) using Python. The system can be used to support the diagnosis of locomotor and balance system.

Streszczenie. *Celem prezentowanych badań jest system posturograficzny bazujący na sensorach polimerowych. System bazuje na wyskalowanej platformie z rozlokowanymi sensorami rezystancyjnymi FSR. Sensory wykrywają zmianę nacisku w określonych punktach stóp badanej osoby co umożliwia pomiar* Center of Pressure *COP. Akwizycja danych odbywa się za pomocą Arduino. Wizualizacja wyników którym są stabilogram i histogram trajektorii COP, przedstawiana jest w autorskiej aplikacji napisanej przy użyciu języka Python. System może być wykorzystany do wspomagania diagnostyki układu ruchowego i równowagi.* ***(System posturograficzny bazujący na sensorach polimerowych)***

Keywords: Posturograph, Center of Pressure, Stabilogram, FSR.
Słowa kluczowe: Posturograf, Stabilogram, Sensory polimerowe.

Introduction

Posturography is an objective method of determining human posture. During the examination, the patient's shift of the center of gravity is observed and analyzed. Evaluation of the results can help in detecting certain injuries of the patient (balance disorders). In medicine computerized systems of dynamic posturography are used, where pressure plates are used to determine parameters such as COP (center of pressure), COG (center of gravity) and ROM (range of motion) [1, 2]. These parameters are used to estimate human posture in a non-invasive way and detect injuries involving the central nervous system. Sensors used in these types of posturographs most often are strain gauges. Strain gauges are resistive sensors that change their resistance depending on the tension of the surface they are installed on. But it is possible to replace metal sensors with polymer sensors. Such an approach allows to reduce the size, mass and cost of the device. The accuracy of measurements is also reduced, but it is sufficient for the detection of basic postural and walking disorders.

On this article is presented low cost posturgraph based on polymer sensor are installed on a stable, non-moving platform on which patient tests are conducted. In chapter two short review of different posturagorap are shown, after them the main parameters of used sensors are presented. On chapter four the structure of hardware and software part of described instrument are presented, After them the test results and capabilities of analysis during based test of human posture are shown.

Weight and posture measurement applications overview

There are two main types of human weight and posture measurement applications: platform systems and "shoe-in type" systems [3-9]. First type uses special platforms equipped with sensors (where a patient has to stand) or mats on which patient has to walk through. This kind of solutions are stationary - in contrast to the second type ("shoe-in") - there are no problems with sensors displacement. "Shoe-in" systems are created by placing sensors on shoe sole or insole. To create such systems adequate sensors have to be used – common types of sensors are capacitive, resistance and piezoelectric.

Differences on systems mainly concerns changes in the way of data transmission and computer-system communication. Originally, wired connections were used – it was not a problem in case of platform stems, however, "shoe-in" systems need to be movable. To obtain this feature, frequently used a communication via Bluetooth [10]. The transmitter was situated on users hand or leg and the receiver was a laptop or private computer with a proper receiving module. The main aim of this solution was the appointment of center of pressure (COP). This parameter is used for postural control. In this case FSR sensors were placed in shoe's insole, however, this solution uses both shoes. There were 13 sensors placed per foot. The center of pressure was appointed individual for each foot and plotted in graphical user interface (GUI) with sensors pressure plots. The sampling frequency was 50 Hertz and communication was provided by Bluetooth module. This solution worked with support of STM32 microcontroller.

The newest solutions are equipped with accelerometers for tracking patient's position. This approach was proposed in article [11]. Sensors which were used in this application were FSR (force sensing resistors) sensors 3 pieces. The sensors were placed in shoe insole. Sensors were placed on heel, ball and lateral border. In this solution, 3-axis acceleration sensors were placed which allowed measurements of foot position. The data collected during measurements by PIC18F87J10 microcontroller was sampling with 10 Hz and was sent to base station (PC) by Zig-Bee. Data visualization was also implemented. This solution allowed to detect differences between dynamic postures (walking) and static (sitting). In addition, there was a possibility to measure a pressure exerted on sensors by foot and detect gait phases – this data might be used to check patient's gait. Assessment of human gait anomalies was carried out using the deep learning algorithm and data from FSR sensors placed in the insoles [12].

Next example of posture measurement application is the one described in article [1]. This solution was a platform type system which consists of a rectangular platform. On each corner of the platform a load cell was placed. It allowed to measure center of pressure (COP). Authors used this application to analyze influence of open or closed eyes for COP changes in time of analysis. This system was powered by Arduino MEGA microcontroller and data was sampling with 10 Hertz frequency.

With the help of posturographic examinations and especially after the analysis of COP changes, it is possible to diagnose the diseases of the balance system, such as vestibular neuritis, post-traumatic defect of the balance system, Meniere's disease. COP oscillations have also been found to be a precursor to fall, especially in the elderly [13]. COP measurement is also used to assist in the diagnosis of Parkinson's disease [14].

Project assumptions

In this paper the posture measurement method uses a stationary sensory surface on which the examined person stands. In this case, rectangular electronic bathroom scale was used as a platform. Shoe inserts, that were installed on it, were used to designate the patient's standing place. Consequently, the measurement was conducted in a static position when the patient stands still on both legs in an upright position. To determine detection and posture control FSR sensors were used. Because a single sensor does not contain enough information and can only be used to determine the presence of pressure on the sensor at a given moment, to measure human posture the distribution of stress on three sensors which were located under each patient's foot respectively was analyzed. Using measurements obtained with these sensors, we determined the COP parameter which allows to detect the center of pressure for both feet and individually for each foot as well.

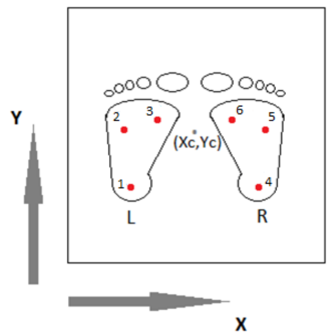

Fig. 1. The center of pressure detection.

Fig. 2 Force-Sensing Resistor.

Then number and sensor localization on the platform is illustrated on the Figure 1. The center of pressure was appointed – according to formulas (1-2).

$$(1)\quad X_L = \frac{\sum_{j=1}^{3} P_j x_j}{\sum_{j=1}^{3} P_j}, X_R = \frac{\sum_{j=4}^{6} P_j x_j}{\sum_{j=4}^{6} P_j}, X_C = \frac{\sum_{j=1}^{6} P_j x_j}{\sum_{j=1}^{1} P_j}$$

$$(2)\quad Y_L = \frac{\sum_{j=1}^{3} P_j y_j}{\sum_{j=1}^{3} P_j}, Y_R = \frac{\sum_{j=4}^{6} P_j y_j}{\sum_{j=4}^{6} P_j}, Y_C = \frac{\sum_{j=1}^{6} P_j y_j}{\sum_{j=1}^{1} P_j}$$

wehere: *X,Y* cooridinates of COP (*L*-for left leg, *R*-for right leg, *C*-for body), *P* – pressure, x,y – distance from center.

In this project, the sensors used for calculating the COP are FSR (Force-Sensing Resistors) IMS-C20B [15]. They are small, easy to install and uninstall. Polymer sensors are broadly used to monitor pressure in industry and medicine [16,17].

FSR sensors are more often used in posturographic system that are meant to be mobile (such as ones that can be put inside a shoe), however, they can also be used in stationary ones like the one proposed in this article. While no pressure is present on the sensor, their resistance is in the range of Mega ohms.

By increasing the force applied the resistance drops to the range of few kilo ohms. This can be observed on fig. 3. The resistance changes in a non-linear way. This means that conductance changes in a linear way, which is useful for calibration [4]. Despite this, the FSR sensors can be unreliable at times. For example, small changes to the way a person stands on the sensor can alter the results by an observable margin [18,19]. The project involved the use of sensors with maximum pressure of 20kg and 50kg. The authors conducted a series of measurements for two types of sensors. The following formula for the characteristics was assumed (3):

$$(3)\qquad R_{FSR} = \frac{a}{F}$$

R_{FSR} - resistance measured in kOhms, F – force measured in Newtons, a – assumed constant.

The least squares method was used to approximation the "a". The “a” coefficient for 20kg and 50kg approximation curves was estimated to be 3508 and 8686, respectively. On Figure 3 and 4 the obtained characteristic for 20kg sensor are presented.

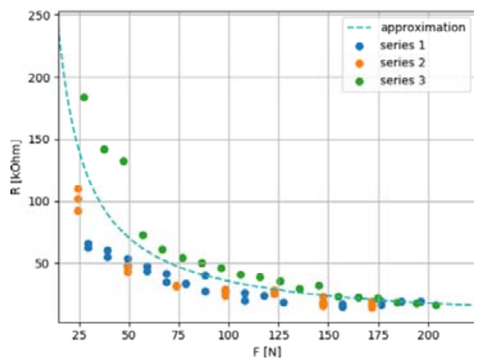

Fig. 3. Fitting curve of resistance vs force for 20kg FSR sensor.

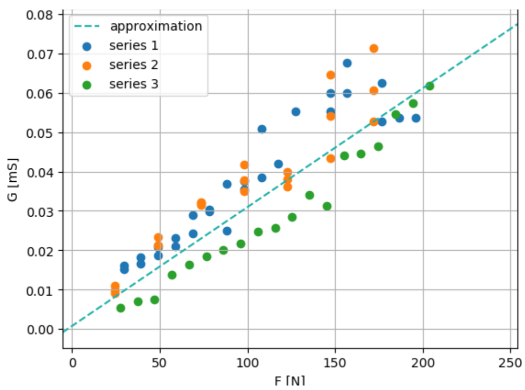

Fig. 4. Fitting curve of Conductance vs force for 20kg FSR sensor.

The block diagram of solution presented in this article is shown on the Figure 7. An Arduino UNO microcontroller is connected by USB to PC to transfer measurement data. There are a total of 6 force sensitive resistors (FSR) used along with 6 analog inputs, each corresponding to a sensor. To measure voltage properly, voltage dividers were implemented, powered by 5V (Arduino pin) – resistors are connected to FSRs. Resistance of these resistors was appointed depending on the FSR resistance (measured during load tests).

Two of the sensors used have working range up to 20kg and one up to 50kg for each foot. These sensors were properly installed on the shoe inserts placed on the platform. Next, the six force sensitive resistors were covered with other insoles to improve the quality of the measurement due to the distribution of stress. The sensors are placed between the insoles as shown on figure 8. The insoles have been symmetrically mounted on a square platform (scale) to ensure patient's comfort while standing during posture analysis. The placement of the FSR has been chosen specifically to include foot pressure points which depend on anatomical foot areas. Sensors with bigger range of measurement were placed in the points where the largest pressure is supposed to be – under the heels – while the patient is standing in upright position. The distances between the sensors mounting places were 5.4cm, 13.5cm, 15.5cm for each foot, where the minimum distance is the distance between two sensors with a smaller working range.

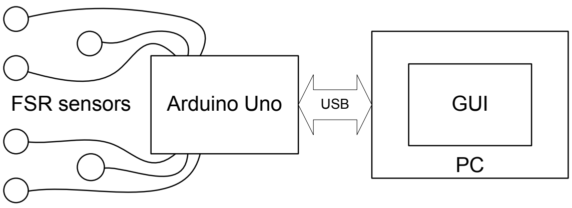

Fig. 7. Block diagram of presented posture measurement solution.

To detect the center of pressure during the analysis of human posture, it is necessary to determine the stress distribution on the FSR and select the origin of the coordinates with the following calculation of the sensor's location with reference to the origin [20]. In our case, the coordinates are calculated in the Cartesian system, and the COP is determined for each foot separately, as well as for two feet together. For both cases, the origin of the coordinates was determined individually (see Figure 8). The platform dimensions are 28x28 cm.

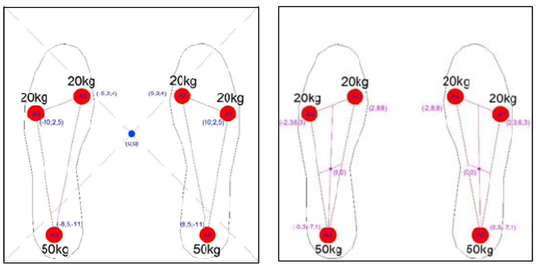

Fig. 8. Positioning the origin for pair for pair (left) and each foot separately (right).

A desktop application to visualize and analyze data was made. The application was written in python using external modules. The program receives data from each sensor in a loop, and then converts it to force and center of pressure (COP). The data is then visualized in the form of charts. The user can write and read data in the CSV file. Flow chart of application is presented on figure 9.

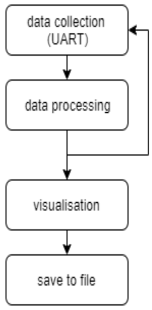

Fig. 9. Application flow chart.

Tests and results

The tests were conducted on a group of people, aged 23-25, with similar body shapes and body weight varying from 61 kg to 87 kg.

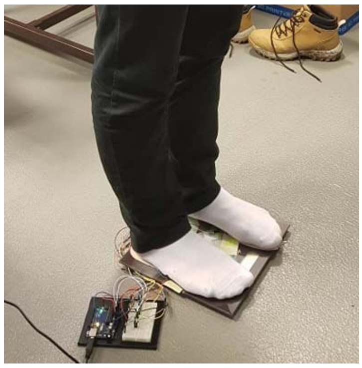

Fig. 10. Person standing on the platform.

The participants underwent two main tests – one with open eyes and one with closed eyes. Graph on Figure 11 shows changes in force converted to weight on every sensor in time. The person has open eyes but was asked to hold a weight of around 8 kg on a straightened left arm. As can be seen, the highest amplitude of mass is observed on heels with rest of the readings of the installed sensors much lower. The additional load led to an uneven and unstable weight distribution, which resulted in a loss of balance for the test person This is visible in Figure 11 showing the change in sensor pressure as a function of time

The stabilogram presented on figure 12, is the type of graph demonstrates trajectory of center of pressure of tested person. The left side of the Figure 12 contains the COP of the person being tested, while the right side shows the COP of each foot individually. The test was conducted for 90 seconds. The measurements were taken with a frequency sampling of 100 Hz – every second 100 points were marked in real time. The points were connected with a black line which results can be seen below. The orange dot is the last measure point.

The application allows for trace the COP variations at a given time, which is useful when the labyrinth falls. In addition, the application allows for visualize the above data in the form of a histogram as illustrated in Figure 13. Looking at the Figure 13 a conclusion can be drawn that a person with closed eyes has more trouble keeping balance than with opened eyes (Fig. 12). The analysis can be carried out for the whole body or for pressure on the left and right foot separately, which is important when detecting lower limb diseases.

Fig. 11. Visualization of the load on the sensors over time (test of a person holding a weight of 8 kg).

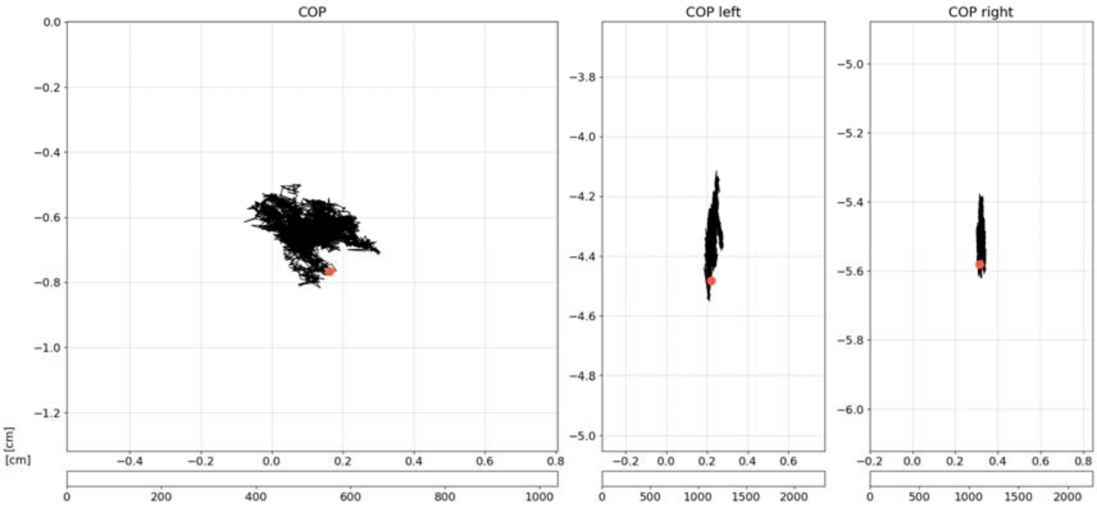

Fig. 12. Stabilogram of the test for a person with open eyes.

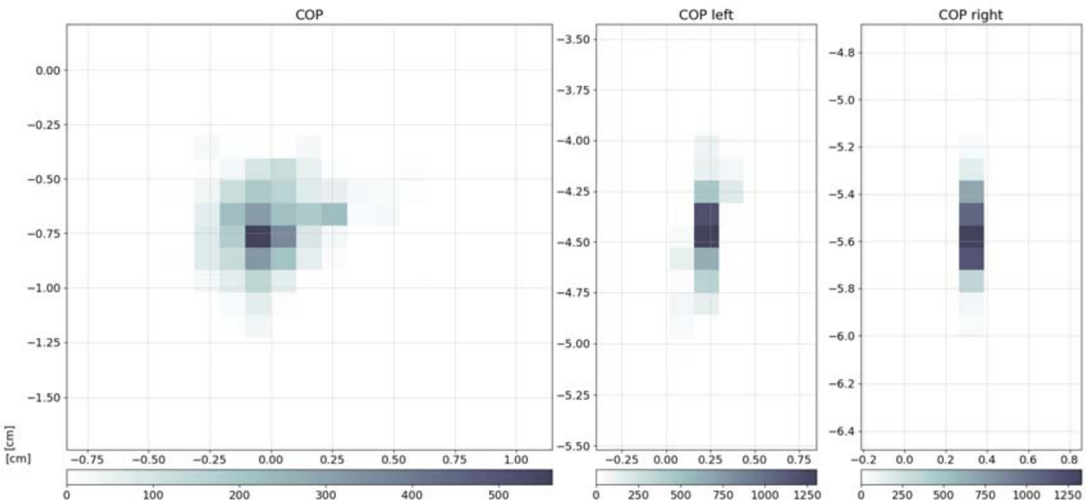

Fig. 13. Histogram COP of the test for a person with closed eyes

Conclusion and future work

This article contains a description of development of a cheap and simple system to measure one's posture. It is difficult to compare the price of a prototype with the price of professional devices with certificates, but the cost of materials not exceeding $100 allows us to think that this is a cheap solution. The implementation of said system works as expected, it can visualize human weight distribution. However, the used force sensitive resistors cannot always be credible. Since the sensors are rather small, the measurements are taken in a small area. This results in the placement of the sensors being a very important factor to take into account. With that said, measured patients must have similar sized feet or else the results of tests can stop being reliable. This issue can easily be fixed by relocating the sensors to accommodate the person being tested. Additionally sensors aren't linear and aren't stable over time. Even after the application of the correction factors, the error in mass measurement was 5%. The main benefit is the ability to install them, for example, in shoes. This leads to a more mobile approach of testing human posture. The low price of the device and relatively low accuracy predispose the use a posturograph more to support exercise in the rehabilitation process than to medical diagnostics where the accuracy must be much higher.

In the future, it is planned to validate the presented posturograph and check its accuracy compared to the devices available on the market. Work is also underway on a mobile version of the posturograph with sensors installed directly in shoes

***Authors**: Bogdan Dziadak, Institute of Theory of Electrical Engineering, Measurement and Information Systems, Warsaw University of Technology ul Koszykowa 75, 00-662 Warszawa, mail: bogdan.dziadak@ee.pw.edu.pl, Valentyna Dudnyk, Marcin Jurczak, Przemysław Wiszniewski, Kamil Wojtas, Warsaw University of Technology. Pl. Politechniki 1, 00-662 Warszawa.*

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