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Equipment for the Detection of People Falling

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***Abstract* - There are people whose state of health requires permanent supervision. There are a number of medical or aging-related conditions that can have quite an impact on the daily life of these people, therefore, in order to provide them with proper assistance and care, various health monitoring devices have been developed. This article proposes the use of advanced technologies with the help of which we can observe and record the changes in the position of a person with such problems. The equipment has a sensor that can determine the position of the body by measuring the height from the ground. The device can be integrated into a belt or bracelet to record data in real time. This data is analyzed and interpreted by means of a program. The program can detect changes in posture, providing notifications and alerts when the person has suffered a fall. Greatly simplifying surveillance, the device also provides an objective assessment of a person's balance ability. Since each person has a specific posture and movement, the developed device must be tested and adapted to adjust the coefficients in the program, to avoid the triggering of false events.**

Cuvinte cheie: *stare de sanatate, gradient de presiune, echilibru posturii.*

Keywords: *state of health, pressure gradient, posture balance.*

I. Introduction

Many older adults experience balance problems and dizziness. Problems can be caused by certain medications, balance disorders, or other medical conditions. Balance problems are one of the reasons older people fall. Maintaining good balance as you get older and learning to prevent falls can help with walking, ensuring independence and carrying out daily activities. Several of the body's organs, including muscles, bones, joints, eyes, balance organ in the inner ear, nerves, heart, and blood vessels, must function normally for normal balance to exist. When they don't work well, they can cause balance problems for people. Many medical conditions can cause balance problems. Also, aging is a degenerative process that affects most organs and therefore balance problems are more present in the elderly people. This device helps those responsible for the care and assistance of patients, and sends alerts in case of important changes in position (such as after a fall), so that it can be observed by anyone who has access to the created web interface. The device have an advanced technology (in terms of design and algorithm) capable to detect the variation of pressure in direct correlation with height, combining a very good precision sensor, whose essential role is to measure parameters such as body position, [1], [2]. Data is broadcast in real time, in specified time interval, signaling when there is a problem. Equipment can distinguish between fall of person and the small pressure variations that the sensor can detect when the person in question moves, climbs stairs, etc. The device is created in such a way that it reaches a minimalistic size so that it can be integrated as easily as possible into a bracelet or a belt. With the help of software that provides not only alarms or the detection of abnormal changes in movement posture, but also an objective assessment of the balance of the person concerned. An unusual change in posture is identifying by permanently measuring distance toward ground. If essential changes happen, the warning signal is triggered.

II. Sensitive Device Used

A. Sensors

Almost every aspect of life, including safety, surveillance, monitoring and general awareness, requires the development and use of sensors. The use of equipment and devices for diagnosis, monitoring, patient care and public health ensures greater safety and objectivity in decision-making. Smart sensors are those that process data and obtain relevant information, such as time evolution of parameters outside intervals or connectivity to a repository for data storage. Proximity sensors, for example, come in a variety of varieties, including capacitive, photoelectric, magnetic, and inductive. For the considered device, height measurement is used, for which, in a first phase, sensors can be used to measure the distance. Distance sensors are often confused with proximity sensors for their similar functions, the functions of each sensor can be misunderstood most of the time.

In the present work, a pressure sensor is used, which uses the phenomenon of pressure drop with height increase. Thus, the pressure gradient is monitored and if a certain limit is exceeded, this is signaled. Pressure gradient sensors are devices used to measure the pressure difference between two points in a fluid or gas. Medical, aviation and other industrial applications are areas where these sensors can be used. Gradient sensors work by detecting pressure differences between two points in a fluid or gas. Pressure gradient sensors are divided into two types: piezoelectric sensors and differential pressure sensors. The pressure difference is measured by piezoelectric sensors, which convert the pressure into an electrical signal. The sensors are extremely sensitive and can detect very small pressure variations. Differential pressure sensors, on the other hand, use a measuring element that is sensitive to the pressure difference between a reference and the measuring point. Because they have lower sensitivity, these sensors are cheaper and easier to manufacture than piezoelectric sensors, [3]. Air pressure is determined by the weight of the air column at that point, or it can be said that it is determined by the density of the atmospheric air column at that point. It is considered that the atmospheric pressure varies depending on the temperature. If we consider that the air column at a point decreases as the altitude increases, the result is a decrease in atmospheric pressure with height, Fig. 1, [4].

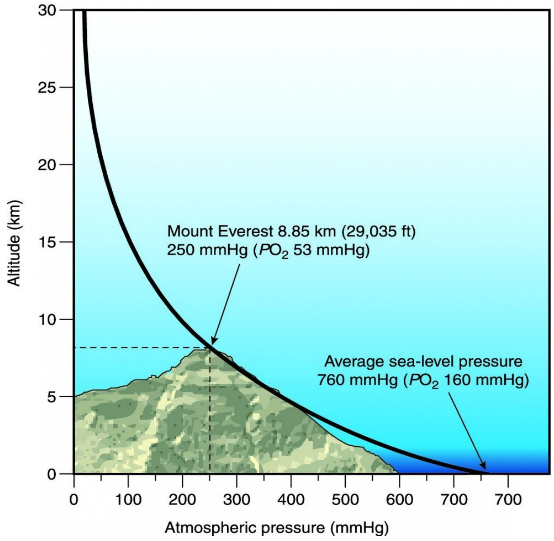

Fig. 1. Pressure gradient vs. altitude, [4].

At sea level, the average atmospheric pressure is about 1013 hPa, which is equal to 1 atmosphere (atm) or 14.7 psi. (pounds per square inch). Make sure that depending on the weather conditions, the atmospheric pressure can vary a lot in time and altitude. In general, if the weather conditions are stable, the atmospheric pressure decreases by approximately 1 hPa for every 8 meters of altitude, [5], [6]. Information about the pressure sensor used and how it works is present in the next section.

B. *SPL06-001 Sensor*

The sensitive pressure sensor SPL06-001 with high accuracy is to measure the pressure in the atmosphere and make the difference between any abnormality such as normal walking, wind, climbing stairs, etc. and a fall. The SPL06-001 sensor is a miniaturized digital barometric pressure sensor as well as a temperature sensor. The sensor is characterized by high precision, and is great for mobile and portable devices. This pressure sensor is based on a capacitive sensing principle that ensures high accuracy during temperature changes. The internal signal processor of this sensor converts the output of the pressure and temperature sensors into 24-bit results. Pressure sensor accuracy is ± 0.006 hPa (or ±5 cm) (high precision mode), according with specifications, [9], [10], [11].

III. Application

The code is written in Python, chosen for its simplicity and for the fact that this programming language has the possibility of intrinsically managing a website. The application starts with the import of the libraries, each one being important for its function. Communication between the sensor and the Raspberry Pi is done via SMBus, a two-wire interface based on the I2C protocol, is used to communicate with the I2C sensor.

The "time" library provides functions to handle the necessary timings. The "ctypes" library is used to define certain data types in communication with certain hardware devices. The last but the most important is request library can make requests to web servers, with the help of sending and transmitting data through HTTP and HTTPS protocols (It can be used Django or Flask framework).

The pressure values will be continuously read through the infinite while loop, and if there are different values in the list, the pressure value will be added to the event list and a corresponding text will be displayed. The algorithm will check if the message is negative, clear the past values displayed and add the current value, which may indicate a new patient fall. The user interface can be as intuitive as possible, easy to use, in the form of a web interface, Fig. 2.

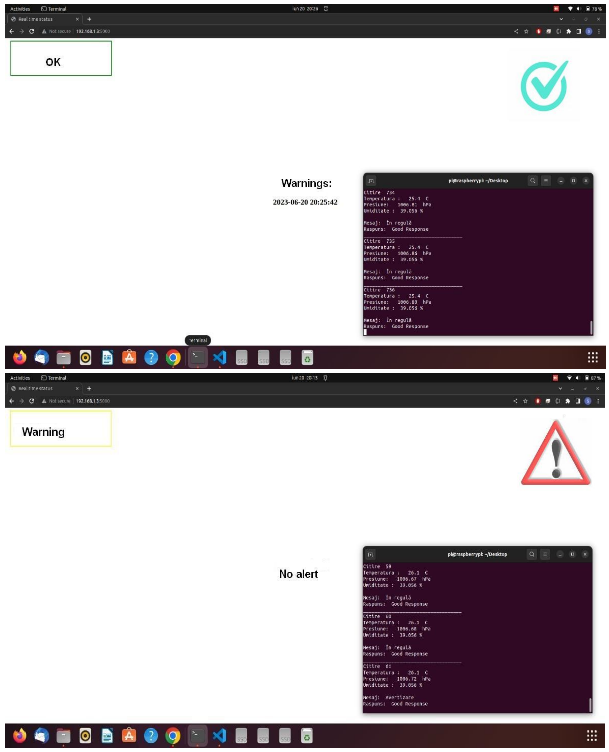

Fig. 2. Aspects of interfaces (OK – top; Warning – bottom).

In the lower right part you can see the event log. There are also visual warning elements on the interface (distinctive signs), but the application can be easily expanded for external warnings (sounds and optics).

IV. Equipment Design

The two main components of the equipment are the pressure sensor and the embedded system such as Raspberry Pi or equivalent, Fig. 3. The sensor and Raspberry Pi are connected via digital interface. Raspberry Pi has the role of a small computer on which the application is located. The sensor data can be transmitted to a web interface, or to an alarm, which has the role of signaling any type of patient fall. The web interface will not only receive the sensor data, but also the alerts that will be able to confirm the alert and remain on record to know the date and time of each such event, Fig. 4. In the flowchart, "A" represents the current reading and "B" represents the average of the previous readings. When the device is turned on, the first step it will go through is calibration. Calibration is done through the first readings of the pressure sensor, which establishes the reference value for the current location and current conditions, and ends up having approximately the same pressure after each reading. After calibration, normal sensor readings will follow that will arrive in the ready state, each reading being compared to an average of thirty units less than the current value, [6], [7].

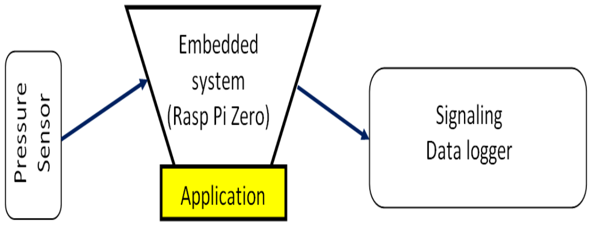

Fig. 3. Block diagram of equipment.

If the reading is less than the threshold of three units (as the difference), the circuit will resume reading, so that the next reading will be taken to the initial state, where it will be compared with a value that is at least ten units higher. If this condition is not met the reading resumes and if the current reading is greater by at least thirty units then the reading will enter the "warning" state.

These values were chosen empirically, for a stable operation of the equipment. These thresholds can be modified and customized depending on the patient.

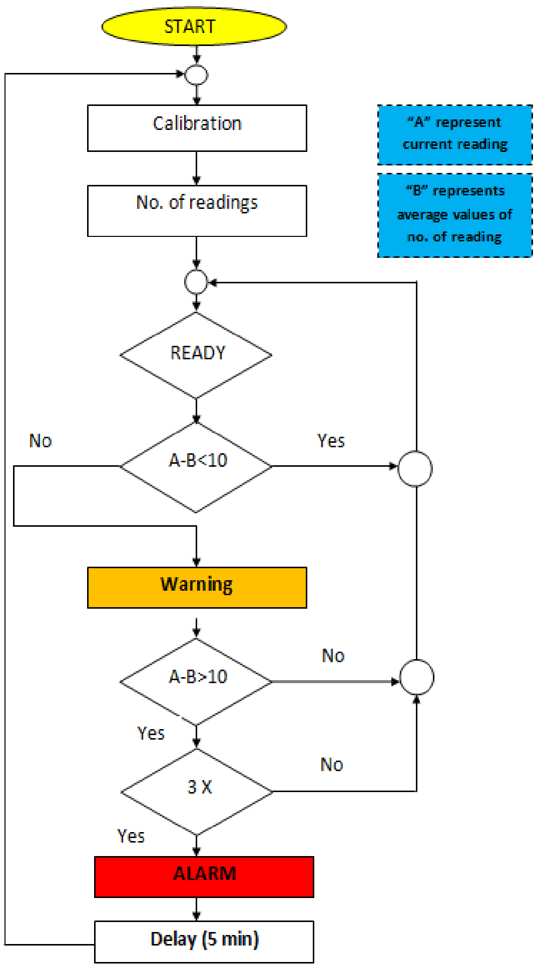

Fig. 4. Flow chart of aplication.

The threshold is set to every ten centimeters so as to result in an average, to have an average error that represents the pressure differences in the atmosphere, whether we are talking about normal walking, climbing the stairs or going down them, [8].

The warning state shows us that the value transmitted by the sensor is quite high and that it can only represent an anomaly so that it would return to the ready state again, or if there are at least three consecutive readings that end up entering the warning state, these will alert in real time an alarm, representing the patient's fall.

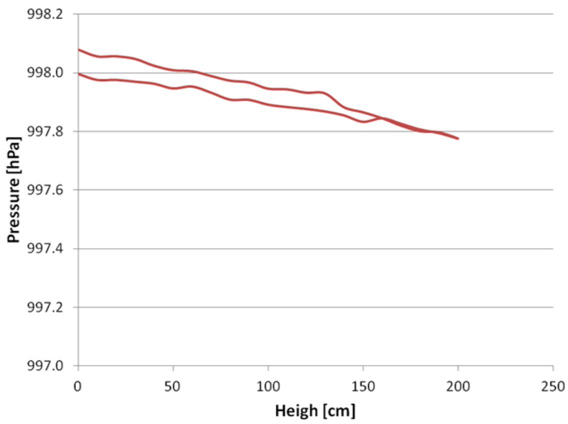

Fig. 5. Experimental results.

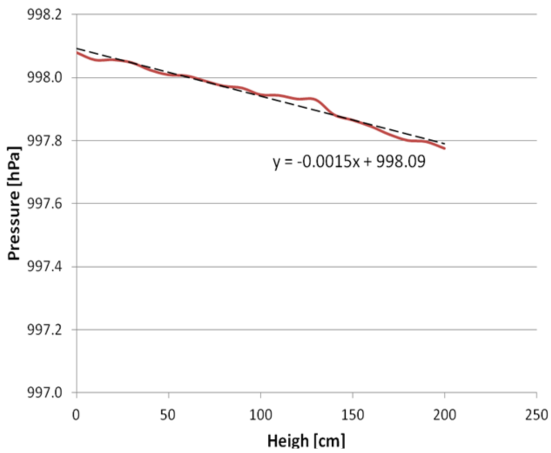

Fig. 6. Experimental data in ascending and descending order, to highlight hysteresis errors.

In the situation where the sensor has reached the alarm state, the data to be read and passed through the same process are no longer taken into account, the alarm representing the most important point at which a reading can reach. The alarm condition lasts until cleared by resetting the sensor and repeating all of the above steps, or lasts up to five minutes if not cleared by restarting the calibration process. After the five minutes in which the alarm is not turned off by anyone, it will be recorded on the application with the date and time it occurred, even if it will no longer be in an alarm state, so that it can be viewed at a later time.

V. Results and Comments

After fully understanding the operation of the sensor and the variation of pressure with height, measurements were made readings every 10 cm until 200 cm, Fig. 5. The actual value that the sensor reads to observe the rise and fall of pressure, at different heights, was obtained by averaging, the sensor being influenced by events such as sudden movements, gusts of wind, etc.

From these experimental results became, by linear regression, an ideal characteristic, presented on the same picture, Fig. 5. This can be useful when develop application, to increase estimation of events occurs. The presence of the hysteresis error was also analyzed, Fig. 6.

As can be seen, this is present especially towards the initial value (0 cm) from where the evaluation is made. The pressure drop with height is not smooth, due to various factors (the sensor provides a very good resolution on 24 bits of the pressure measurement, which causes excessive sensitivity to any influence such as air movement or positioning accuracy in front of the landmark). Arithmetic average is the most suitable because it can be easily seen that although different phenomena occur, it is kept as correct, there is the possibility of events that change the pressure at a certain height especially during normal walking, events such as sudden movement or walking more quickly and this leading to an error in the measurements. A series of averages were done to see which one is the most suitable, such as shifting average which is the calculation method that is based on consecutive values.

Another possible formula is the statistical average, which selects the median value of the entire data read. A possible comparison between these values leads to improved performance by choosing the best averaging method. Hysteresis error uses the classic formula, applied in the worst case (here at 0 cm height), (1). Hysteresis error occurs when the measured value (such as pressure) is increasing or decreasing and may not be the same in both directions, [11], [12], [13]. In this case, this error is about 27%. Even this error is significant, it can be reduced, but it is also useful to avoid any false alarm (decreased sensitivity).

$$\varepsilon h\ [\%]=|p\_mM-p\_mm|/|p\_max-p\_min|*100 \qquad (1)$$

The explanations of quantities are: |p_mM-p_mm| is the absolute maximum difference of pressure, observed from the graphic representation; |p_max-p_min| represents absolute difference between maximum and minimum pressure for which the variation characteristic was established.

Experimental setup consists of a measuring tape, Raspberry Pi Zero W to which the pressure sensor is connected, a plier set that allows positioning (from 10 by 10 cm) on the measuring tape, Fig. 7.

Data acquired use two relation to make mean of measured pressure: median (statistical) and average (arithmetic) formulas, Table I.

There is some difference between results because mean formula is different.

Fig. 7. Aspect of experimental setup, to establish pressure vs. height correlation

Also was use relative pressure because this value is used by algorithm to make decision.

TABLE I.
SOME SAMPLES OF DATA ACQUIRED

Height [cm]	Pressure [hPa]			
	Statistical	Relative statistical	Average	Relative average
100	997.9746	0.217674	997.9463	0.170828
110	997.9578	0.200874	997.9440	0.168592
120	997.8901	0.133167	997.93256	0.157092
130	997.9107	0.153807	997.9302	0.154794
140	997.8777	0.120766	997.8826	0.107219
150	997.8836	0.126652	997.8656	0.090145

Considering a pressure sensor, hysteresis would be the error in the measured value immediately after pressure is applied to the sensor, before the system responds. Once the pressure sensor eventually reaches a steady state, the error is reduced. This error can be reduced in this application by increasing the interval between readings, the measurement time, but this may affect the response time. The sooner the occurrence of an event in which a difference in a patient's posture is observed, the better the delayed intervention of the medical staff will be avoided. The device can be made in a more compact way, using the smallest representative of the Raspberry Pi family, the Raspberry Pi Pico. Components of entire equipment are reasonable in terms of weight and sizes, Fig. 8, Fig. 9, Fig. 10.

The device can be used alone or expanded with the sampling of other signals, outline more complex equipment for patient monitoring.

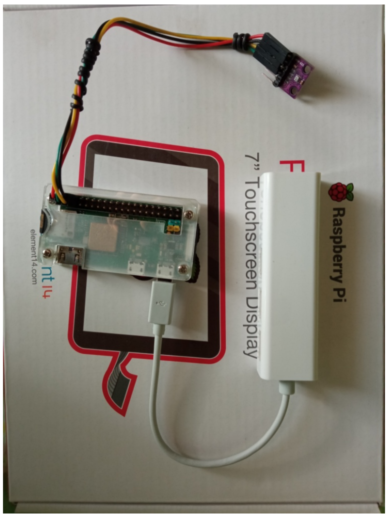

Fig. 8. Sensors, Raspbery Pi Zero and power bank.

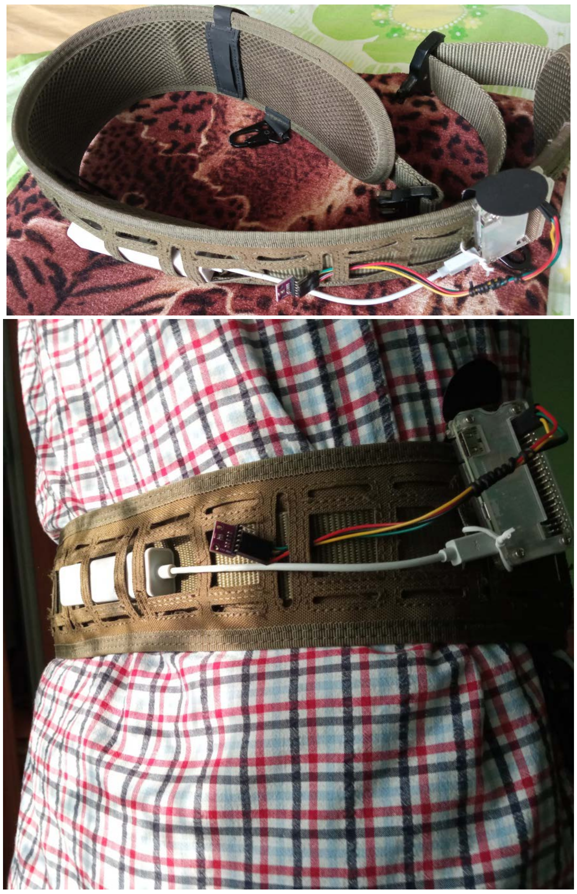

Fig. 9. Fixing the equipment on the belt.

The entire equipment can be carried in the pocket, belt or bracelet. The power bank supply with 5 V the equipment and ensure an operating time according with its capacity. According with specifications Raspberry Pi Zero consumption is about (various versions and situation): idle - ~65 mW, W idle - ~0.6 W, 2 W idle - ~1.4 W, stressed - ~1 W, W stressed - ~1.85 W, 2 W stressed - ~2.9 W. If go further we have possibility to use Raspberry Pi Pico, and in this case we have, at power supply of 3.3 V, the following results: WiFi connected: 43 mA, WiFi connected and answering remote ping requests: around 60mA.

Fig. 10. Bracelet version of balance monitoring device.

For example, a power bank of 5000mAh can be use in condition of 1.5 W consumption (intensive use of Raspberry PI Zero board) almost 24 hours (ideal condition and not complete discharge the power bank because this operation can damage it). In case of using Raspberry Pi Pico, three weeks is operating time. An optimization is needed between operation time, charging of battery, and weight of equipment.

Because of low-voltage operating (3.3 – 5 V), the equipment is safe in operation. To avoid short circuit between sensor pads and GPIO pins, or bending them, the hardware components must be fixed in a box.

VI. Conclusions

Equipment developed use low-cost components and software application use friendly programming IDE (Python). Also the design of the equipment took into account that it should be robust and accurately signal any event that indicates an important change in a patient's posture.

Was choosing Python for integrated web framework; more than two possibilities to use this facility: Django and Flask. Django is high-level, full-stack framework used for quickly developing clean-looking apps. Flask is a micro web framework written in Python. It is classified as a micro framework because it does not require particular tools or libraries.

To detect changes in distance to the ground, pressure sensors was chosen, because has been exploited the gradient of pressure vs. the height (altitude). In the development of the algorithm, situations that can generate false alarms were taken into account, such as climbing stairs and occasional pressure variations (such as those due to opening a door). This differentiation between the situations that appear was solved by means of mediation, repeating data reading and counting operations. Quantitatively, these operations were established experimentally.

Remarkable is the accuracy of pressure sensors SPL06-001; actually was necessary to decrease this accuracy (24 bits) because o stability of readings.

Also a hysteresis error was noted, but is beneficial in this case because for small variation (e.g. for stepping movement), the signal is more stable.

Developments of the application can be considered the possibility of adjusting the parameters in the program interface, the possibility of presenting events in the form of a diagram, and the extension of the application to mobile devices.

To increase duration of operation it is possible to deactivate some unnecessary peripheral like LED indicator on Raspberry Pi board, or use Wi-Fi connection only when is needed. Also it is possible to use idle facility of Raspberry Pi board, and in this case operation time can increase significant (one week in case of Raspberry Pi Zero).

Entire developed equipment is a starting point for improvements.

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