Proof of the Accuracy of Measuring Pants to Evaluate the Activity of the Hip and Legs in Everyday Life

Khalil Niazmand, Ian Somlai, Slim Louizi, and Tim C. Lueth

MiMed, Department of Micro Technology and Medical Device Technology
Faculty of Mechanical Engineering, Technische Universität München
Boltzmannstraße 15, D-85748 Garching
khalil.niazmand@tum.de

Abstract. In this paper, an innovative measuring platform for the detection of movements of legs and hips is presented and tested. The system consists of washable pants with built-in acceleration sensors and control and evaluation electronics and is powered by detachable, rechargeable batteries. It measures acceleration at the hip and legs in three directions in space. The movement detection is based on recognizing, by means of the sensors, the posture and acceleration magnitudes usually associated to a specific movement. The raw sensor data are saved on the integrated MicroSD card for posterior analyze in a computer. With the help of mathematical functions presented in this paper, the timely occurrence of a specific movement can finally be detected. The whole system (pants, sensors and electronics) is washable due to component's encapsulation. Thanks to an optimized production process, the system can be affordably reproduced in low volume productions and can be adjusted for multiple purposes.

Keywords: accelerometer / pants / movement.

1 Introduction

Demographic change represents a high burden on the society in Germany and other industrialized countries. The associated costs increase for the social health system might be diminished by means of newly developed assistance systems that focus rather on prevention than on cure.

An important component of Pervasive Care is to collect and analyze health-related data in everyday life. Besides the usual vital parameters, there are also data that permit to get conclusions about the movements of the supervised person.

Sensors for motion detection are continuously becoming smaller, cheaper and more accurate. The evaluation of the data delivered by these sensors is also becoming easier.

By integrating these sensors in garments and subsequently analyzing the data obtained from them, the movements recorded for the user can be detected and documented. Collecting these data over a long period of time allows to characterize the movement habits of the person. Unexpected changes to these patterns can then be used for early detection of potentially disease-related behaviours. As a result, it is possible to initiate appropriate therapy measures.

J. Lin and K.S. Nikita (Eds.): MobiHealth 2010, LNICST 55, pp. 235–244, 2011.
© Institute for Computer Sciences, Social Informatics and Telecommunications Engineering 2011

2 State of the Art

Intelligent assistance systems are already used in telemedicine in the tertiary prevention for the monitoring of chronically ill people. The future of such systems lies in a better integration into daily life and easier usability, so that they can also be implemented for early detection of diseases and for the reduction of risk factors. In 1990, many leading groups in the area of portable integrated sensors predicted the growing integrity of wireless communication as well as the sensor system in everyday clothing [1]. According to [2], the applications of wearable sensors can be divided into six areas: military, civilian (home care and sports), aerospace, public safety (fire fighting), hazardous applications (mine action) and universal (portable mobile applications).

Nowadays, accelerometers are among the most used sensors for these applications. In [3], accelerometers are used in garments in order to carry out localization as well as activity measurement. In [4], acceleration sensors included in garments are used for rehabilitation scopes, where the movements of the upper part of the body are registered and assigned to a particular movement. The same kind of sensors, also attached to the upper part of the body, can be used for respiratory and heart rate measurements [5, 6]. Furthermore, different temperatures can be classified by recognizing tremor [7]. The position of the sensors on the body is of great importance. In [8], 30 accelerometers were distributed all over the body. It became obvious that not only the number of sensors but also their dependence on each other is very important. The challenge of building sensors in garment is that the electronics can't disturb the user and, on the other hand, to provide the necessary stability, so that the electronics aren't harmed during normal daily life movements. This leads to the conclusion that the integrated sensors should not be tight-fitting to the body. In [9], the influence of loose-fitting sensing garments is described in terms of measurement accuracy when a movement is being detected. A comparison of different systems is portrayed in table 1.

Most of the presented systems do not integrate sensors in garments [8, 10], applying them directly on the body. They either have to be attached each time with hook-and-loop fasteners at certain spots or are built in specific, tight-fitting vests. The wearing comfort isn't taken into account.

In order to warrant a long-term recording of data, the measurement garment must be washable, making its production more complicated. There is, on one hand, the possibility of using washable and conductive sensor textiles [11, 4], which increases

Table 1. Summary of the state of the art

Ref.	Sensor	Application	Washable
[1]	NM	None	Yes
[4]	AC	Rehabilitation	Yes
[5]	AC	Heart frequency	No
[6]	AC	Respiration rate	No
[7]	AC	Temperature	No
[8]	AC	Movement	No
[10]	AC	Movement	No
[11]	AC	Movement	Yes

the production costs tremendously. On the other hand, there is the option of an external wiring that has to be removed before washing, which complicates the implementation of such systems in everyday life.

3 Task and Approach

By means of acceleration sensors integrated in a pair of pants, the movements of the hip and legs should be detected. The collected data should be stored on a removable storage medium and analyzed by the user. The electronics should be encapsulated inside a washable unit and the system's power supply should be provided by rechargeable batteries. It is very important that the whole system doesn't hinder the movements of the user while wearing it. The accuracy of such a garment to determine movements has to be proven. By building this system, the basis for long-term recording and analysis of transaction data is created.

4 Dynamic System Concept Description

The pants (Fig. 1, 1) don't differ from a normal garment externally. In its interior, there are five acceleration sensors (2), which measure the movements of the hip and the legs.

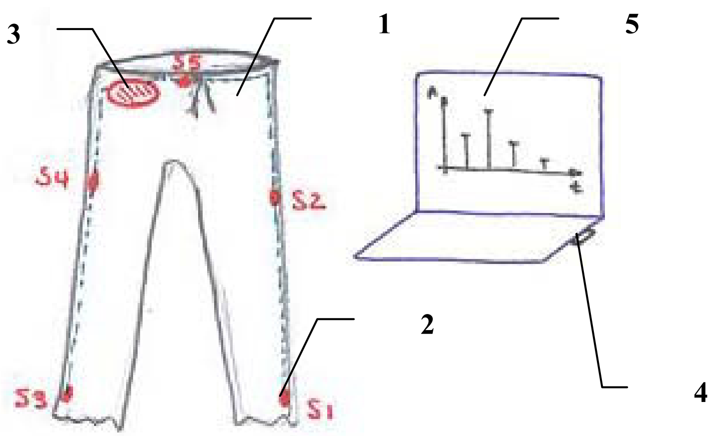

Fig. 1. Description of the system's parts and interfaces

The system is powered by a detachable, rechargeable battery box and the electronics installed in the garment are not easily noticeable by the user. The sensors are made washable thanks to encapsulation and connected with a shielded cable network with the electronics unit, which is built in a washable housing and hidden in a pocket. As a result, the measuring pants can be washed whenever necessary without concerns of damaging the integrated electronics.

The pants are dressed just as any other normal ones. The data recording settings, such as time, measurement duration, number of readings per second and software version, are entered in form of a text file on the storage medium (MicroSD card) directly on a computer. The MicroSD card is then inserted into the electronic unit. After the power supply has been ensured by fixing the battery box, the electronic unit reads the saved settings and accordingly sets the desired configurations. The data recording begins then corresponding to the entered settings and the information delivered by the sensors is read and stored on the MicroSD card. At the end of the experience, the battery box is detached and the storage unit can be removed. The data contained in the MicroSD card is subsequently read on a computer, where an algorithm to evaluate the activity of the hip and legs in everyday life can be developed and tested.

The system is characterized by a simple and universal application and a fast and economical production. Additionally, the user is not hindered by the measurement system in his daily life and has the opportunity to wash the garment when needed.

5 Evaluation

5.1 Materials and Methods

In order to define the location of the sensors on certain parts of the body and to protect the cable network, a protective bag made of fabric was sewn in by a tailor along the seam on the garment's inner side. The 3-Axis acceleration sensor (SMB380, Robert Bosch GmbH) delivers digital values that are read over an SPI-interface. Its measuring range can be set to ±2g, ±4g or ±8g. The five sensors are connected to the electronics unit through a cable network (cross section: 0.1 mm² with PVC isolation).

The electronics unit consists of a nanoLOC module (microcontroller and radio transceiver, Nanotron Technologies GmbH) (Fig. 2, 1), a RV-8564-C2 real-time clock (Micro Crystal AG) (3), a MicroSD-card slot (4), a status LED and the necessary components for power management (2).

The electronics unit is integrated in a washable housing (Polar Electro Oy). The original electrical connections of the housing (press-buttons) are used for plugging the battery-box. The connection between the cable network and the electronics unit is sealed by an encapsulation.

The electronics in this system requires a voltage between 3.5 and 4.5 V. It is provided by a rechargeable battery box (5) that consists of an accumulator with a capacity of 350 mAh, a MAX1555 charging chip (Maxim Integrated Products, Inc.), a USB socket for charging the battery and a charge-status LED.

Each set of data is stored in an individual text file with the name DD_HH-MM.txt, where DD represents the current day of the month, HH the hour and MM the minutes of the measurement recording time. The configuration parameters of the measurement are saved in another file with the name config.txt, where the device number, software version, time, date and number of recordings per second can be set. For this reason, this configuration file has to be updated before valid data recording.

Fig. 2. Left side: Pants being used. Right side, above: electronics unit. Right side, below: battery.

For this experiment, the pants with the number "1" were chosen. The configuration file was set so that the five acceleration sensors should be read 10 times per second with a resolution of ± 4g. In addition, data should be stored every two minutes in a newly generated text file. The obtained raw data in text format could be directly imported into a spreadsheet application such as Microsoft Excel.

Five calculations are then implemented to analyze it. These are:

- Absolute resulting acceleration:

The resulting magnitude of the three coordinates (x, y and z) is calculated as follows:

$$|a| = \left| \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \right| = \sqrt{a_x^{\,2} + a_y^{\,2} + a_z^{\,2}}$$

- Normalization according to Earth's gravity:

The value of Earth's gravitation, g, according to the sensor resolution, is subtracted:

$$(\pm 4g = -512 \ldots +512 \rightarrow +g \cong 128)$$

$$X = |a| - g$$

- Data average:

The average of the 10 recorded data (recording 10 times per second, T_0=100ms) is generated as follows:

$$n = 10 \cdot T_0$$

$$\overline{X_{10}}[k] = \sum_{n=k}^{n=k-9} X[k] \Big/ 10$$

- Average difference:
For each value the difference to its corresponding average is calculated:

$$\Delta X[k] = X[k] - \overline{X}[k]$$

- Noise filtering:
A noise threshold value is experimentally determined and applied:
Noise value = 5 ≙ 0.04 g

$$X = \begin{cases} X & \rightarrow |X| \geq 5 \\ 0 & \rightarrow |X| < 5 \end{cases}$$

By means of this procedure, it can be calculated if an acceleration value resulting from a movement is larger than the noise value. In this case, a movement can be correctly detected.

5.2 Experiment

An experiment is performed in order to confirm the hypothesis that, by means of the measuring pants, it is possible to detect the occurrence in time of daily life movements of the hip and legs. To assess the effectiveness and accuracy of the proposed method, further experiments with more volunteers are being planned.

A person (male, 30 years old) carried out the following activity five times, after having washed the pants once in a washing machine with a protective laundry bag (Wash settings: 30°C (86°F), max spin cycle 900 rpm). First, the person left the pants on the table for 10 seconds. Next, he puts them on and sits on the chair for another 10 seconds. After this, he stands up, walks slowly for 10 seconds and then stands still for five seconds. Next, he runs for 10 seconds and then stands still again for five seconds. After this, he lies down on the bed for 20 seconds and, finally, sits on the chair for ten seconds.

5.3 Result

The time progression of the gathered data, after being processed with the 5 mentioned calculations, can be seen in fig. 3.

The noise threshold value has to be chosen in such a way so that daily life movements can still be recognized. If it is too high, the movements of the legs aren't detected. If the noise value is too low, a great amount of disturbing additional information is being transferred besides the useful movements. In all five attempts, an alteration of the movement pattern could be detected with every single sensor. In fig. 4, the diagram of sensor SBV (waist in the front) is analyzed as an example.

All signal changes could be attributed to the respective activity. A histogram of the evaluated data confirms that when choosing the noise value, no crucial information that is important for the detection of movements goes astray (fig. 5).

Applying the Fast Fourier Transformation to the analyzed data, it is claimed additionally that a recording frequency of 6 times per second would provide all relevant information.

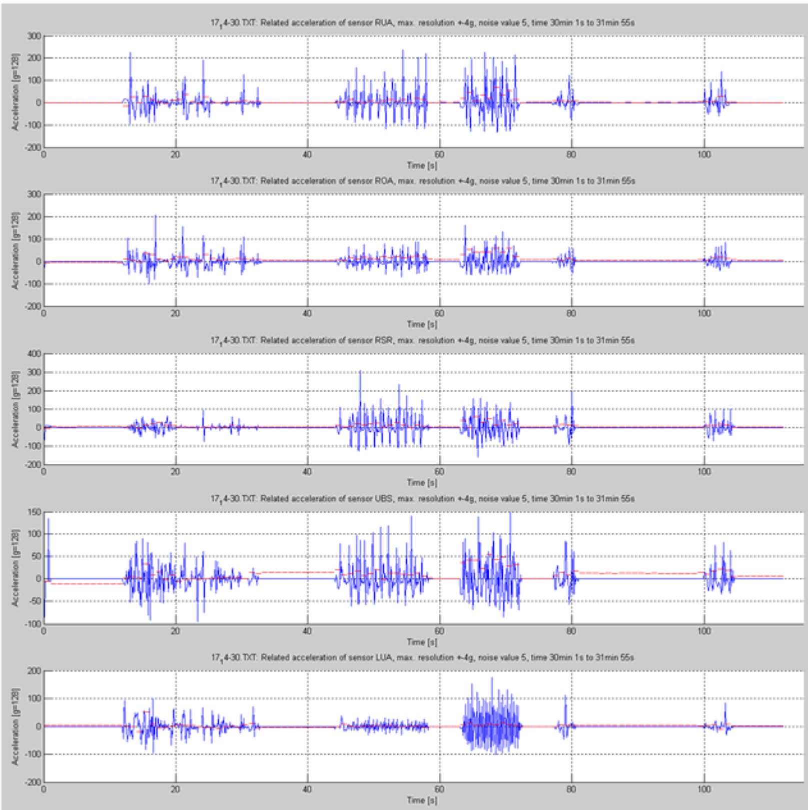

Fig. 3. The recorded data are portrayed according to the sensor location. From the top: RUS= right lower thigh, ROS=right upper thigh, LOS= left upper thigh, LUS= left upper thigh, SBV= waist in the front. The x-axis represents the time in seconds after the beginning of the recording and the y-axis is the registered acceleration amplitude (128 ≙ 1g).

The hypothesis "With the measuring pants, the time occurrence of daily life movements of the hip and legs can be detected" was confirmed in this experiment. The recorded data was subject to five analysis calculations and the obtained values were portrayed in a diagram over the time. The actions carried out in the experiment could be correspondingly assigned in time to the observed data. It was observed that, merely for movement detection, one single sensor (SBV) would be sufficient. However, with five sensors, respective movements of the single body parts can be compared with each other.

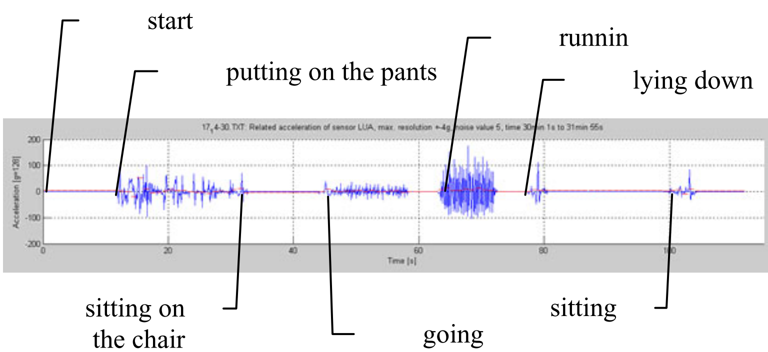

Fig. 4. Analyzed data of sensor SBV (waist in the front) are portrayed over time

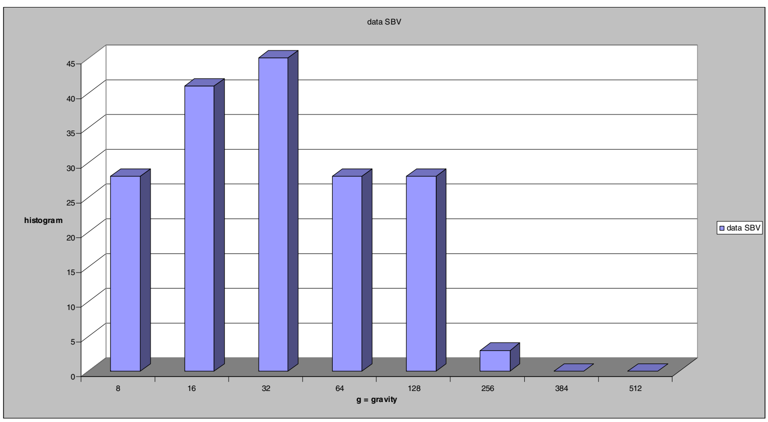

Fig. 5. Histogram of the calculated data of SBV sensor. It is obvious that due to the movements, accelerations up to 2 g can occur. With the elimination of all acceleration values lower that 0,04 g, no crucial information goes astray. If the movements are very slow, usually acceleration sensors from 0,1g up to 0.6 g occur. The x-axis represents the acceleration (128 = g) and the y-axis shows the histogram of the acceleration values in the recorded signal.

As the pants aren't essentially tight-fitting, the sensors don't have an absolute position in terms of the skin surface. Since accurate detection of an activity, such as sitting on a chair, standing or lying, depends largely on the position of sensors, no reliable detection can be implemented applying only one single sensor. An intelligently designed spatial distribution of several sensors could then decrease the error rate and lead to a feasible detection, broadening the field of application.

6 Conclusions

The first prototype of a movement detection system based on measuring pants was presented. It differs from other systems as the sensors are unobtrusively built in the pants and is completely washable. Furthermore, data can be saved on a removable MicroSD card. Functions have been introduced to detect hip and legs movements with a resolution of 0,04g exclusively by means of acceleration sensors. The algorithm was validated in concluding experiments, whose satisfactory results revealed that detection of the timely occurrence of movements is possible with the pants. It was found out that, although the pants are loose-fitting, one single sensor would be sufficient for the detection of movements. However, combining several distributed sensors, certain movements such as e.g. lying, sitting and standing can be detected immediately. Further experiments involving a greater number of volunteers are being planned, in order to assess the effectiveness and accuracy of the proposed method.

Acknowledgment

Within the research consortium of the Bavarian Research Foundation (BFS) „*FitForAge*“ a team of scientists and engineers affiliated to 13 departments of the Bavarian universities Erlangen-Nürnberg, München, Regensburg and Würzburg works together with 25 industrial partners on the development of products and services for the aging society.

The scope of the research consortium is to develop technology based solutions which will help elderly people in their future living environment comprising home and workplace as well as in communication and transportation. Eventually not only elderly people but also all social groups should profit from these solutions.

References

1. Iso-Ketola, P., Karinsalo, T., Myry, T., Hahto, L., Karhu, H., Malmivaara, M., Vanhala, J.: A Mobile Device as User Interface for Wearable Applications, PERMID Munich. LMU Munich, Germany (2005)
2. Sungmee, P., Jayaraman, S.: Enhancing the quality of life through wearable technology. IEEE 22(3) (2003)
3. Lukowicz, P., Junker, H., Stäger, M., von Büren, T., Tröster, G.: WearNET: A Distributed Multi-sensor System for Context Aware Wearables. In: Borriello, G., Holmquist, L.E. (eds.) UbiComp 2002. LNCS, vol. 2498, pp. 361–370. Springer, Heidelberg (2002)
4. Harms, H., Amft, O., Roggen, D., Tröster, G.: Smash: A distributed sensing and processing garment for the classification of upper body postures. In: Third Interational Conference on Body Area Networks (2008)
5. Yoshimura, T., Yonezawa, Y., Maki, H., Ogawa, H., Ninomiya, I., Caldwell, W.M.: An ECG electrode-mounted heart rate, respiratory rhythm, posture and behavior recording system. In: Proceedings of the 26th Annual International Conference of the IEEE EMBS San Francisco, CA, USA, September 1-5 (2004)
6. Reinvuo, T., Hannula, M., Sorvoja, H., Alasaarela, E., Myllyla, R.: Measurement of Respiratory Rate with High-Resolution Accelerometer and EMFit Pressure Sensor. In: SAS 2006 – IEEE Sensors Applications Symposium Houston, Texas USA, February 7-9 (2006)
7. Sung, M., DeVaul, R., Jimenez, S., Gips, J., Pentland, A.S.: A Shiver Motion and Core Body Temperature Classification for Wearable Soldier Health Monitoring Systems. In: IEEE International Symposium of Wearable Computers (2004)

8. Van Laerhoven, K., Schmidt, A., Gellersen, H.-W.: Multi-Sensor Context- Aware Clothing. In: Sixth International Symposium on Wearable Computers, ISWC 2002, pp. 49–57. IEEE Press, Los Alamitos (2002)
9. Harms, H., Amft, O., Troster, G.: Influence of a loose-fitting sensing garment on posture recognition in rehabilitation. In: Biomedical Circuits and Systems Conference (2008)
10. Guler, M., Ertugrul, S.: Measuring and Transmitting Vital Body Signs Using MEMS Sensors, RFID Eurasia, 1st Annual, September 5-6, pp. 1–4. IEEE, Los Alamitos (2007)
11. Noury, N., Dittmar, A., Corroy, C., Baghai, R., Weber, J.L., Blanc, D., Klefstat, F., Blinovska, A., Vaysse, S., Comet, B.: VTAMN - A Smart Clothe for Ambulatory Remote Monitoring of Physiological Parameters and Activity. In: 26th Annual International Conference of the IEEE EMBS San Francisco, CA, USA, September 1-5 (2004)