Personalized health service in assistive environments and telemonitoring of sleep patterns*

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***Abstract*— assistive environments are entering our homes faster than ever. However, there are still various barriers to be broken. One of the crucial points is a personalization of offered services and integration of assistive technologies in common objects and therefore in a regular daily routine. Recognition of sleep patterns for the preliminary sleep study is one of the health services that could be performed in an undisturbing way. This article proposes the hardware system for the measurement of bio-vital signals necessary for initial sleep study in a non-obtrusive way. The first results confirm the potential of measurement of breathing and movement signals with the proposed system.**

I. Introduction

Health and care services based on AAL technologies are being the topic for the investigation for a long time, yet they have barely made it into patients' homes. Some of the barriers are technological and are due to the lack of integration of device data (including heart rate, heart signals, blood oxygen saturation, breathing, muscle movement, temperature, falls, sleep patterns). As a rule, they only offer isolated solutions. Integrated use of the data, which is hardly taking place at the moment, would result in great potential.

Sustainable health services should be comprehensive and accompany the user throughout the full cycle:

- consulting,
- planning,
- implementation,
- operation,
- support.

Such services are always provided by individuals and performed using AAL technologies. Sustainability is strongly influenced by user acceptance, but also by economic implementation and cost models.

Recognition of sleep patterns is one of the areas of home health services with the detection of sleep stages as its essential part. Performing this task in a non-obtrusive way is the main topic presented in this article work.

II. State of the Art

The analysis of sleep patterns is a subject of many scientific articles [1, 2, 3]. In this summary, only a few relevant publications are mentioned.

The article [4] presents an approach for the identification of awake and sleep stages using the ECG signal and a neural network-based algorithm. For the evaluation of the proposed algorithm, 16 PSG data sets from the MIT-BIH database were used. The heart rate variability (HRV) was calculated from the output signal for further processing with a neural network algorithm of Extreme Learning Machine using a single hidden layer [5]. The results after the training achieved an accuracy of about 90%.

As in [6] presented, the algorithm based on multinomial logistical regression has achieved 72% of accuracy recognizing Wake, NREM, and REM stages. Ten derived from breathing, heart rate, and movement signal parameters were used as the input for the software system. These signals can be obtained in a non-invasive way, for example, using the sensors under the bed mattress [7,8].

There is also a high amount of investigations dedicated to sleep study using the signals, which actually cannot be obtained in a non-obtrusive way (e.g., EEG [9]), but these publications are out of scope of this work, as in this article the main accent is done on sleep study using the contactless sensors.

III. Methodology

The presented State of the Art articles confirm the potential of sleep stage classification using the breathing, heart rate, and movement signals. Obtaining these signals in a non-obtrusive way is one of the main aims of the presented in this manuscript method.

As signals should be obtained during the sleep without any direct contact with a human's body, the bed itself could be used for placing the sensors. Force sensing resistors (FSR) sensors were chosen in this work to obtain signals from the human body.

In contract to many other approaches, the sensors are placed under the mattress and connected to sensor nodes,

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which give an individual address to each sensor and convert a signal from analog to digital. The placement of sensors under the mattress ensures the unnoticeability of the system for the users. All sensor nodes are connected to a computational unit, which executes the preprocessing and storing of the obtained from sensors data. It can be reached via a Wi-Fi connection to download and process the stored data. In this work, both Intel Edison and Raspberry Pi were used as a central computational unit but other or similar embedded systems can be used as well. As a backend, a web server was running on it for easy access to the stored data.

The hardware structure of the bed installation is presented in Fig. 1. The setup is not different from a commonly used bed. The only attribution are the sensors that are placed on top of the bed's frame support, and therefore, below the mattress. Following components are forming the system:

1. bed structure
2. bed frame
3. computational unit
4. FSR sensor
5. sensor node
6. cable connection
7. mattress

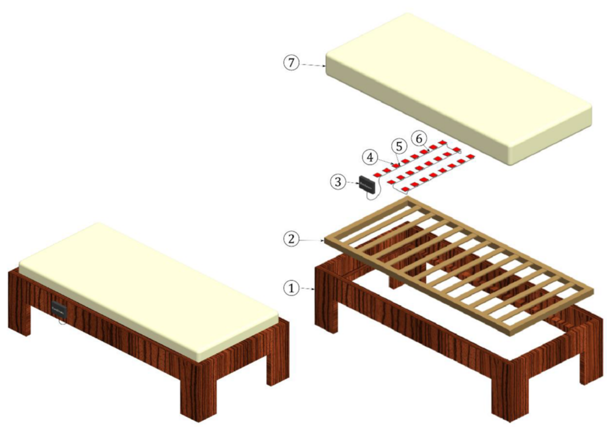

Figure 1. Bed's system structure

IV. Results

For the evaluation of system work, some experiments have been executed. Sixteen sensors have been placed under the bed mattress and connected to the computational unit. The study was performed with three test persons with the age of 26 ± 4 years old and weight 65 ± 7 kg. The frequency of sending sensors' signals to the computational unit is 1Hz. The results of system work are represented in Fig. 2. For the clearness of the visualization, the signals of only three sensors are displayed.

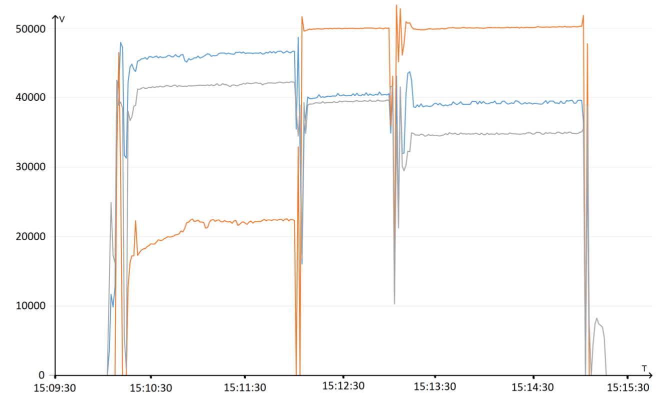

Figure 2. Visualization of signals from 3 sensors

Three visualized sensors are placed under the mattress under the chest in the middle (orange line), on the left (blue line) and right (grey line) sides of the bed frame. X-axis represents the time of measurement and Y-axis shows the output voltage of the sensors. All movements of the person can be clearly recognized in the presented chart as changes in the output voltage over time. Furthermore, zooming in the obtained throughout the measurement signal, breathing can be distinctly recognized as a periodical signal. A similar level of accuracy was reached for all three test persons.

V. Conclusion

The proposed in this manuscript approach confirms the potential of non-invasive measurement of necessary bio-vital signals for telemonitoring of sleep patterns. The results have indicated, that movement and respiration monitoring in a conventional bed can be performed without any contact to the human's body and therefore without influencing the usual sleep flow. Further work will be concentrated on the improvement of signal frequency and herewith on recognition of the heartbeat signal. Furthermore, the connection of developed hardware system with the software algorithm [6] for the classification of sleep stages as a part of the personalized health system in the assistive environment is one of the principal aims for the future research.

References

[1] Y. Kurihara and K. Watanabe, "Sleep-Stage Decision Algorithm by Using Heartbeat and Body-Movement Signals," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans,* vol. 42, no. 6, pp. 1450-1459, 2012, doi: 10.1109/TSMCA.2012.2192264.

[2] X. Long, J. Foussier, P. Fonseca, R. Haakma, and R. M. Aarts, "Analyzing respiratory effort amplitude for automated sleep stage classification," *Biomedical Signal Processing and Control,* vol. 14, pp. 197-205, 2014/11/01/ 2014, doi: 10.1016/j.bspc.2014.08.001.

[3] A. Tataraidze, L. Anishchenko, L. Korostovtseva, B. J. Kooij, M. Bochkarev, and Y. Sviryaev, "Sleep stage classification based on respiratory signal," in *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 25-29 Aug. 2015 2015, pp. 358-361, doi: 10.1109/EMBC.2015.7318373.

[4] W. Hayet and Y. Slim, "Sleep-wake stages classification based on heart rate variability," in *2012 5th International Conference on BioMedical Engineering and Informatics*, 16-18 Oct. 2012 2012, pp. 996-999, doi: 10.1109/BMEI.2012.6513040.

[5] G.-B. Huang, Q.-Y. Zhu, and C.-K. Siew, "Extreme learning machine: Theory and applications," *Neurocomputing,* vol. 70, no. 1-3, pp. 489-501, 2006, doi: 10.1016/j.neucom.2005.12.126.

[6] M. Gaiduk, T. Penzel, J. Antonio Ortega, and R. Seepold, "Automatic sleep stages classification using respiratory, heart rate and movement signals," *Physiological Measurement,* vol. 39, no. 12, p. 124008, Dec 2018, Art no. 124008, doi: 10.1088/1361-6579/aaf5d4.

[7] M. Gaiduk, B. Vunderl, R. Seepold, J. A. Ortega, and T. Penzel. *Sensor-Mesh-Based System with Application on Sleep Study*, vol. 10814 LNBI, pp. 371-382, 2018. doi: 10.1007/978-3-319-78759-6_34.

[8] E. R. de Trujillo, R. Seepold, M. Gaiduk, N. Martínez Madrid, S. Orcioni, and M. Conti, "Embedded system to recognize movement and breathing in assisted living environments", vol. 550, S. Saponara and A. De Gloria Eds.: Springer Verlag, 2019, pp. 391-397. doi: 10.1007/978-3-030-11973-7_46.

[9] F. Karimzadeh, R. Boostani, E. Seraj, and R. Sameni, "A Distributed Classification Procedure for Automatic Sleep Stage Scoring Based on Instantaneous Electroencephalogram Phase and Envelope Features," *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 26, no. 2, pp. 362-370, 2018, doi: 10.1109/TNSRE.2017.2775058.