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Abstract

Embedded Sensing System for Wireless Sleep Apnea Monitoring †

Gabriel Rodriguez Gutierrez [1], Chenchen Shen [1], Daniel Rau [2], Alvaro Ortiz Perez [1], Jürgen Götze [2] and Stefan Palzer [1,*]

[1] Professorship for Sensors, Department of Electrical Engineering and Information Technology, TU Dortmund, 44227 Dortmund, Germany; gabriel.rodriguezgutierrez@tu-dortmund.de (G.R.G.); chenchen.shen@tu-dortmund.de (C.S.); alvaro.ortiz@tu-dortmund.de (A.O.P.)
[2] Information Processing Lab, Department of Electrical Engineering and Information Technology, TU Dortmund, 44227 Dortmund, Germany; daniel.rau@tu-dortmund.de (D.R.); juergen.goetze@tu-dortmund.de (J.G.)
* Correspondence: stefan.palzer@tu-dortmund.de
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Abstract: Sleep apnea syndrome is a breathing disorder with a prevalence exceeding 20% in the overall population, and it can seriously affect health and well-being. However, this condition usually remains undetected because suitable monitoring solutions are lacking. This contribution presents an approach to facilitate apnea diagnosis using a battery-powered, wireless, miniaturized sensing system embedded in a patient's mask. It combines a photoacoustic-based carbon dioxide detector with temperature and humidity sensors as well as embedded algorithms to automatically detect apnea episodes. The results show the feasibility of detecting apnea using an easily deployable analysis system.

Keywords: embedded sensor systems; health monitoring; wireless communication; chemical sensing; data classification

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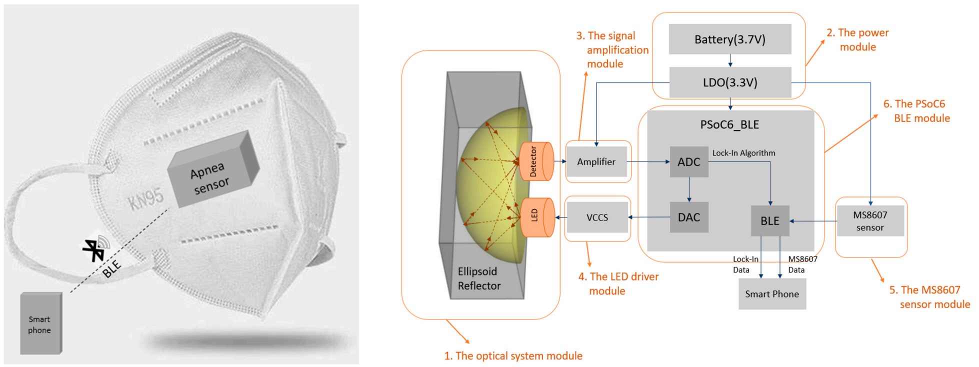
1. Introduction

Among the various types of sleep apnea syndromes, so-called obstructive sleep apnea (OSA) is the result of a relaxation of the soft palate and tongue muscles and may lead to restricted airflow during breathing. The timely diagnosis of this condition leads to a significant reduction of adverse health effects, which include high blood pressure, diabetes, and cerebrovascular disease [1]. While dedicated, highly effective medical equipment like polysomnography (PSG) is able to reliably detect this condition, it is almost exclusively employed in hospital settings [2].

The widespread occurrence of OSA in combination with its serious adverse health effects make the development of easy-to-use, reliable, and low-cost diagnostic instrumentation for its detection desirable. To this end, efforts have included determining intraocular pressure as it correlates with the occurrence of OSA [3], changes in ambient air humidity using surface acoustic wave sensors [4], and methods detecting breathing movements [5]. However, monitoring the exhaled levels of carbon dioxide has the potential to increase the reliability of apnea diagnostic tools.

2. Materials and Methods

The use of indirect, photoacoustic-based non-dispersive infrared spectroscopy sensors enables the construction of selective, sensitive gas sensors for carbon dioxide (CO_2) [6] and enables the design of a miniaturized apnea sensor with low-power consumption. To this end, a sensor system was embedded into a mask to determine the most important parameters for a diagnosis of apnea. The system design concept is shown in Figure 1. It is controlled via an Infineon (Neubiberg, Germany) PSoC6 Bluetooth-low-energy system-on-chip, where all system control and analysis algorithms have been implemented and which is used to communicate with users' smartphones. The overall size of the embedded device is (3.6 × 2.6 × 4.6) cm^3.



(a) (b)

Figure 1. (**a**) Schematic overview of the wireless, embedded system design for apnea diagnosis. (**b**) The system concept including a highly selective, miniatured CO_2 sensing module.

3. Discussion

Using the system, apnea events were reproduced, and the time evolution of the corresponding sensor signal was analyzed. Using the time evolution of the CO_2 concentration data, the breathing status of test persons was analyzed in real-time, as shown in Figure 2.

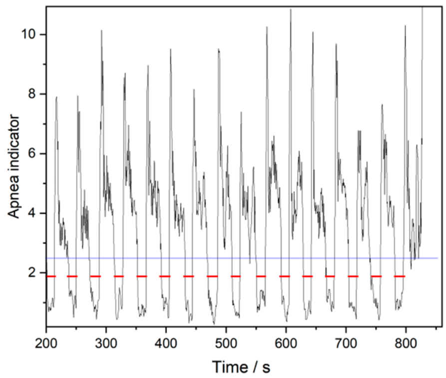


Figure 2. The real time values of the apnea indicator (black line) during a laboratory test and simulated apnea events. The system's algorithm reliably detected patterns in line with OSA. The blue line represents the threshold value under which an apnea episode is detected, the red lines are time intervals in which a simulated apnea event occurred.

Author Contributions: C.S., A.O.P. and G.R.G. built the sensing system and performed the experiments. D.R., J.G. and G.R.G. performed the data analysis. S.P., G.R.G., J.G. and D.R. wrote and edited the manuscript, S.P. and G.R.G. devised the experimental setup. All authors have read and agreed to the published version of the manuscript.

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References

1. Fletcher, E.C. The relationship between systemic hypertension and obstructive sleep apnea: Facts and theory. *Am. J. Med.* **1995**, *98*, 118–128. [CrossRef]
2. McGregor, P.A.; Weitzman, E.D.; Pollak, C.P. Polysomnographic Recording Techniques Used for the Diagnosis of Sleep Disorders in a Sleep Disorders Center. *Am. J. EEG Technol.* **1978**, *18*, 107–132. [CrossRef]
3. Carnero, E.; Bragard, J.; Urrestarazu, E.; Rivas, E.; Polo, V.; Larrosa, J.M.; Antón, V.; Peláez, A.; Moreno- Montañés, J. Continuous intraocular pressure monitoring in patients with obstructive sleep apnea syndrome using a contact lens sensor. *PLoS ONE* **2020**, *15*, e0229856. [CrossRef]
4. Jin, H.; Tao, X.; Dong, S.; Qin, Y.; Yu, L.; Luo, J.; Deen, M.J. Flexible surface acoustic wave respiration sensor for monitoring obstructive sleep apnea syndrome. *J. Micromech. Microeng.* **2017**, *27*, 115006. [CrossRef]
5. Hashizaki, M.; Nakajima, H.; Tsutsumi, M.; Shiga, T.; Chiba, S.; Yagi, T.; Ojima, Y.; Ikegami, A.; Kawabata, M.; Kume, K. Accuracy validation of sleep measurements by a contactless biomotion sensor on subjects with suspected sleep apnea. *Sleep Biol. Rhythm.* **2014**, *12*, 106–115. [CrossRef]
6. Scholz, L.; Ortiz Perez, A.; Bierer, B.; Eaksen, P.; Wollenstein, J.; Palzer, S. Miniature Low-Cost Carbon Dioxide Sensor for Mobile Devices. *IEEE Sens. J.* **2017**, *17*, 2889–2895. [CrossRef]