Designing a Smart Pillow for Sleep Quality Remote Monitoring

VINICIUS OLIVEIRA (viniciusuchoa@ua.pt)
Instituto de Telecomunicações
Felisberto Pereira
Instituto de Telecomunicações https://orcid.org/0000-0002-1416-4191
Nuno Carvalho
University of Aveiro https://orcid.org/0000-0002-7402-2099
Sérgio Lopes
Polytechnic Institute of Viana do Castelo

Article

Keywords: sleep quality, IoT, NodeMCU, healthcare, force sensing resistor

Posted Date: January 6th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1188952/v1

Designing a Smart Pillow for Sleep Quality Remote Monitoring

Vinicius Oliveira *†, Felisberto Pereira*, Nuno B. Carvalho*†, Sérgio Ivan Lopes *‡

* IT - Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
† DETI, Departamento de Eletrónica, Telecomunicações e Informática, Universidade de Aveiro, 3810-193 Aveiro, Portugal
‡ ADiT - Instituto Politécnico de Viana do Castelo, 4900-348 Viana do Castelo, Portugal
† Corresponding Author: viniciusuchoa@ua.pt

***Abstract*—This paper proposes a low cost IoT solution to detect head movements and positions of a patient by means of Force Sensing Resistors positioned on a pillow and connected to a micro-controller collecting patient data anytime, when sleeping, sending it to the cloud and making it available to healthcare professionals. The impact of this work is focused on monitoring sleep quality, using low-cost and easy to use pillows in an ambulatory scenario, without the need of expensive and dedicated sleeping rooms for sleep monitoring, which most of the times affect patient sleep and degrades the quality of the measurement.In this case it is possible to monitor the patient's behavior throughout the entire sleep, important for detecting factors causing minor head and neck injuries and even checking for events of long pauses in respiratory rate.**

***Index Terms*—sleep quality, IoT, NodeMCU, healthcare, force sensing resistor**

I. Introduction

Sleep is one of the main human needs. It is responsible for physical and energy restoration, memory processing, learning and brain development and so on [1]. Poor quality sleep can lead to psychological as well as physiological illnesses or disturbances that degrades quality of life. Usually the acquisition of parameters related to sleep quality is expensive and requires the use of bulky devices in sleep labs (not at patient home) and affects comfort and quality of sleep, appealing for cost-effective, non-intrusive, efficient and portable solutions and Internet of Things (IoT) emerges as solution [2].

The IoT is an extensive open network of smart devices with ability to share resources, data, self-organize, to act and react to changes in the dynamic environment. It is a novel computing and telecommunications technology arose from Radio Frequency Identification (RFID) and Wireless Sensor Networking (WSN) meeting [3].

The rapid growth of IoT allied with others technologies like Cloud Computation, Big Data and the reach of portable devices are changing the relationship between patients and health providers [4]. COVID-19 pandemic accelerated the needs for ubiquitous health, telemedicine, remote patient monitoring and wearable devices [5]. Along with an aging population that has increased the demand on the healthcare sector, technology that optimizes the availability of doctors and healthcare professionals becomes even more paramount.

According to the American Academy of Sleep. the gold standard to measuring sleep is the polysomnography [6] [7]. It is performed in laboratory and followed by sleep technologists. At least seven different parameters are obtained while the patient sleeps in the laboratory.

Other less complex methods can help measure sleep quality, one of them is Actigraphy. It is based on body movements to estimate sleep or wake periods [7]. Commonly is performed with a wearable on patient's limbs, for example, wristbands, smartwatches that stores the data of sleep pattern [8] [9]. Although it is not a complete test, it provides important data that can serve for longitudinal study.

Other reported sleep-related health problems is craniocervical pain, fatigue, headache, typically caused by bad posture when sleeping and can also be monitored by the pressure

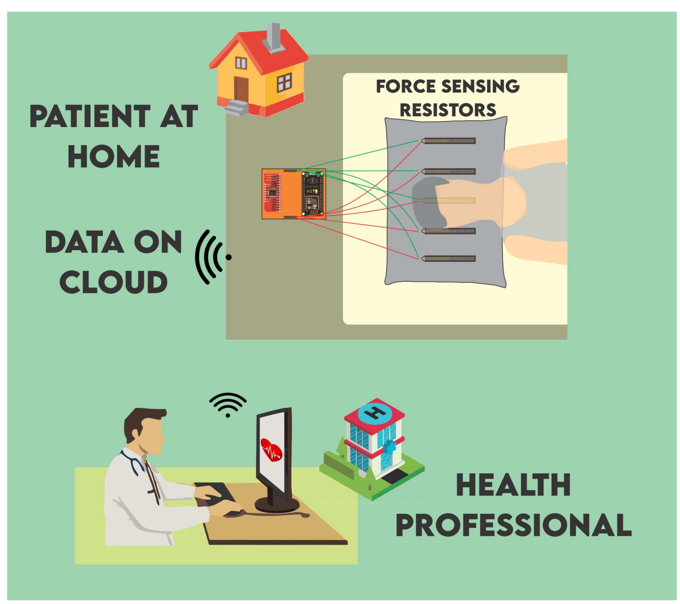

Fig. 1. System for remote sleep monitoring implementation.

sensors [10] [11] [12].

Entering even further in the domain of patient care, they can be also monitored by a wide range of sensors in wearable devices transmitting information about health status at real time. E-health is a reality and the trend is for the mobile phone to be the greatest ally of people's health extending the reach of care, enabling personnel and "predictive maintenance" for humans [13] with sensors capturing health signals, storing and transmitting to professionals.

Great efforts are needed to make the service network viable, so that the available health resources and the various medical services could be interconnected through the definitive applications of Internet-based devices. The importance of Internet of Health Things (IoHT) concepts is mainly manifested when medical services need to be attended to in some remote areas. It is an intelligent technology that combines the Internet with medical equipment, including domestic ones, being able to monitor patients at home remotely and in real time for chronic diseases [14]. Vital signs in real time of inpatients, like body temperature (BT), respiratory rate (RR), heart hate (HR), blood pressure (BP), glucose level, EEG, ECG, SpO2 can be made available for medical team remotely by IoHT.

The choice for FSR sensors was due to their robustness, low cost and ease of integration. FSR strip is flexible, thin and human-friendly and can detect movements even if placed at soft surface as a foam pillow. The intention is to detect the presence, position, and movement of a lying or bedridden patient. The collected data is stored and sent at real time to the cloud and viewed by the health professional anywhere and at any time. In this project ThingSpeak IoT service was chosen. It is an IoT service suitable for collect, view, and evaluate real-time data flow in the cloud. Since it offers easy integration with Matlab, data can be mathematically handled online and in real time.

According to the arrangement of the weight of the head and neck on the sensors, it is possible to identify the sleep position, verifying how long it lasted, and also detect the lack of lung expansion and retraction movements, which can alert to the risk of sleep apnea. Other environment disturbances can also affects sleep quality (e.g. light, noise, temperature, humidity), then other sensors can be inserted due to the presence of the multiplexer.

This paper presents such a solution for day to day care, and it is divided as follows, section II, presents previous works on this topic, section III presents the proposed system to be developed and corresponding prototype construction and section IV presents the obtained results.

II. Related Works

In the following a state-of-the-art and an overview on solutions for sleeping monitoring will be presented.

Pressure sensing mechanisms have been develop rapidly and are widely employed and composes the major part of works related. Park and Shin proposed a respiratory monitoring using strip-type FSR [15]. Kuramoto et al. [16] has built a control intelligent bedding system (pillow + mattress) with FSR sensors to detect body posture and airbags as actuators to redistribute patient position at real-time. Lokavee at al. [17] used an array of FSR embedded on a pillow to detect thorax movements and evaluate patient's quality of breathing and sleep. Discrete force-sensitive sensor-strips placed under patient bed in specifics zones can detect its position according to Qidwai et al. [18]. Diao et al. showed that a considerable quantity of FSR can be embedded to a mattress to acquire a pressure distribution [19]. Matar et al. used a manufactured mattress by Sensor Products to acquire patient's pressure distribution and proposed a neural network to identify the actual position, for example, supine, prone or fetus [20]. Hudec et al. [21] presented 64 force-sensitive resistor embroidered in a textile with conductive thread and Velostat, a material that changes its resistance due to pressure. The setup can notice caregivers to chance the position of patient to prevent bedsores. Since rigid PCB circuitry in wearables are not comfortable, Peng et al. [22] has built electrodes in a band with flexible silver fiber conductive embedded in patient mattress. Along these lines, a PCB circuit in a patch embedded with pressure, humidity, temperature sensors, and Bluetooth Low Energy to communicate with a single base station was made by Sen at al. [23].

III. System Design

This section presents the system developed for the quality of sleep monitor and its corresponding prototype manufacturing.

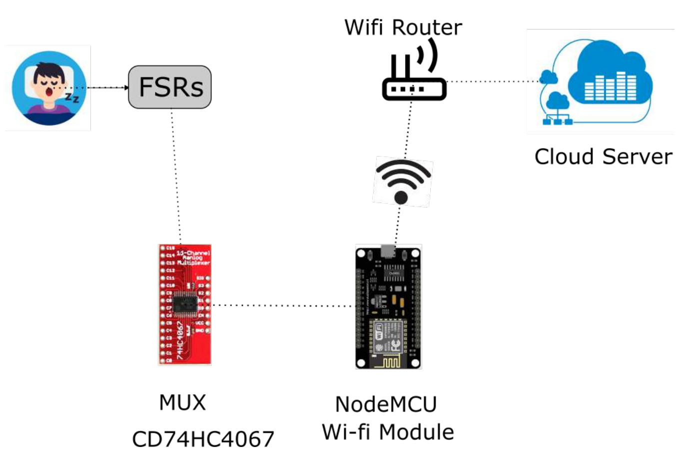

Fig. 2. System architecture.

A. Architecture

The original concept is presented on Fig.1, the pillow is filled with FSR's creating a matrix of sensing devices that can be measured by evaluating its impedance using a digital unit, implemented using a micro-controler. In this case the NodeMCU micro-controler was used, it is a low cost, and small size device widely used for IoT solutions. It features the advantage of having native support for Wi-fi networks with 802.11 b/g/n standards, being open source. Since it has only one analog input, a multiplexer is required to allow the use of several sensors. In this work a Sparkfun 16 Channel Multiplexer module (chip CD74HC4067) was employed. It works as a rotary switch routing the common pin to one of 16 channels according to a combination of selectors pins (S0-S3) and can be used for both digital and analogue signals. In this work, NodeMCU takes advantage of the existing Wi-fi infrastructure in the user's home to send information to the Cloud Server, adequate for collect, handle data at real-time due to its easy integration with Matlab.

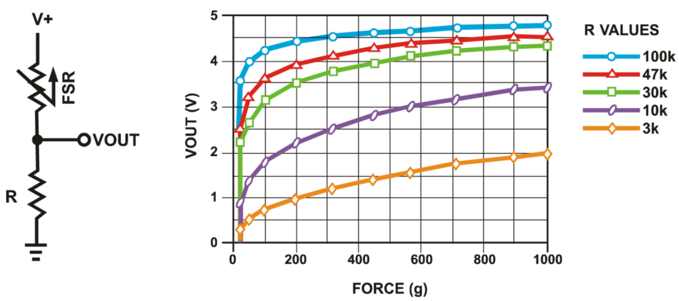

Fig. 3. Voltage divider schema and curves for FSR calibration.

B. Prototype

The second step includes the construction of a prototype. In order to proceed with this approach a strip-type FSR was used, which, given its elongated shape, was able to vary its resistance by means of deflection, and proved suitable for our application. To develop the solution we started by characterizing an FSR strip to understand its response and choose the best components (resistors) cf. Fig.3.

After a first successfull test, the resolution was increased to five units on the pillow (Fig.4) in order to detect various sleeping positions and improve the accuracy of user behavior. Each sensor has two electrodes. One is connected to 5V supplied by NodeMCU and the other is connected to a grounded resistor making up a voltage divider assembly to report the acquired pressure to the multiplexer which selects at a preset time which sensor signal will be read by the NodeMCU's analog port. A set of five strip FSR (from Interlink Electronics) is distributed on a pillow and connected to a PCB, cf. Fig.5

Fig. 4. Distribution of the five FSRs on the pillow.

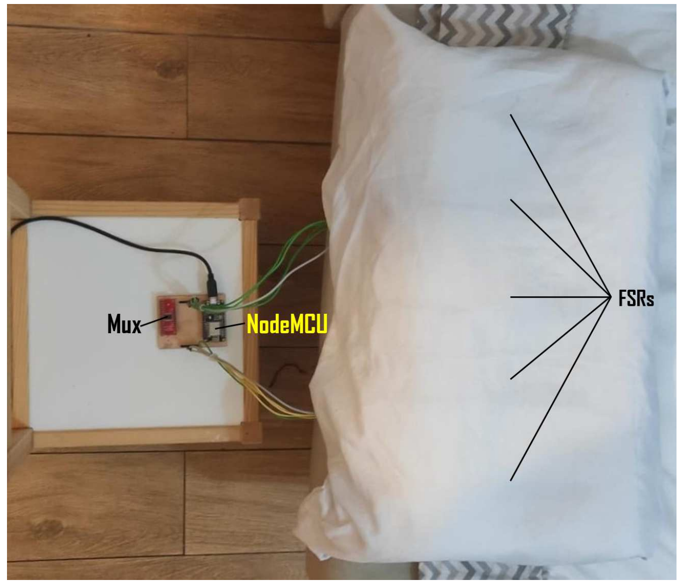

Fig. 5. Smart Pillow System Prototype in use.

that accommodates the multiplexer and NodeMCU designed for this application.

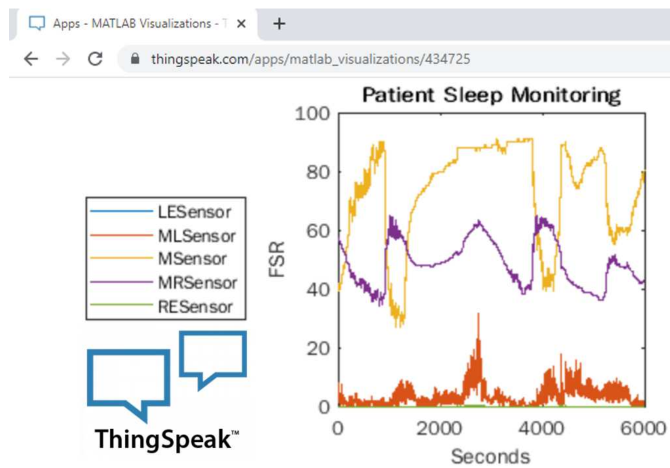

Fig. 6. Running visualization on ThingSpeak IoT.

With the help of the WiFi module of the NodMCU card and a WiFi connection at home, the data is sent directly to the ThingSpeak cloud, cf. Fig.6.

IV. Results

Using the previous developed prototype (Fig.5), a routine was followed to verify the correct detection by the sensors of the head movement when sleeping. A volunteer lying in supine position rests his head on the center of the pillow, then turns his head to the right, and then turns to the left. Next the same individual positions himself in lateral decubitus to the right, rotates his head to the center, and then positions himself in lateral decubitus to the left. Each position is held for approximately 15 s. The behavior is checked by means

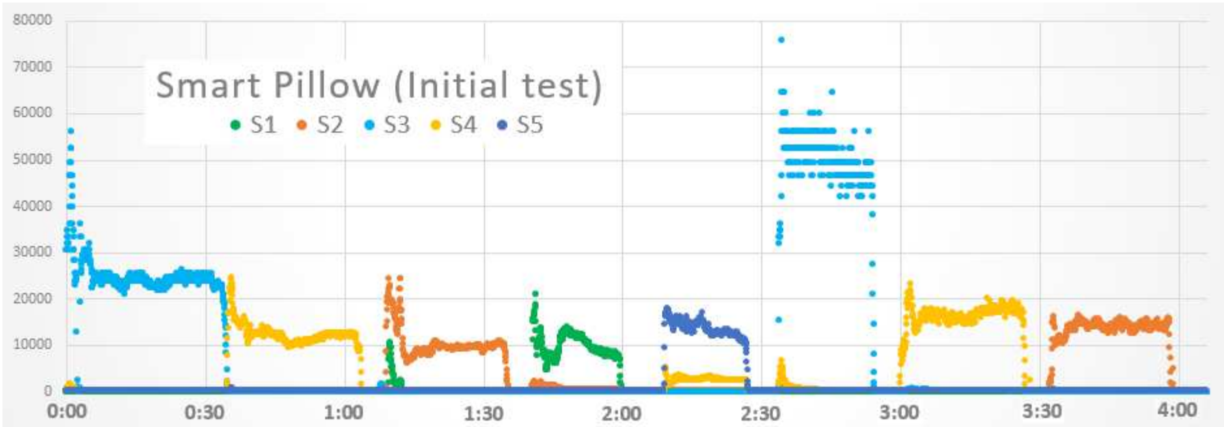

Fig. 7. Initial test for data acquisition at various sleeping positions.

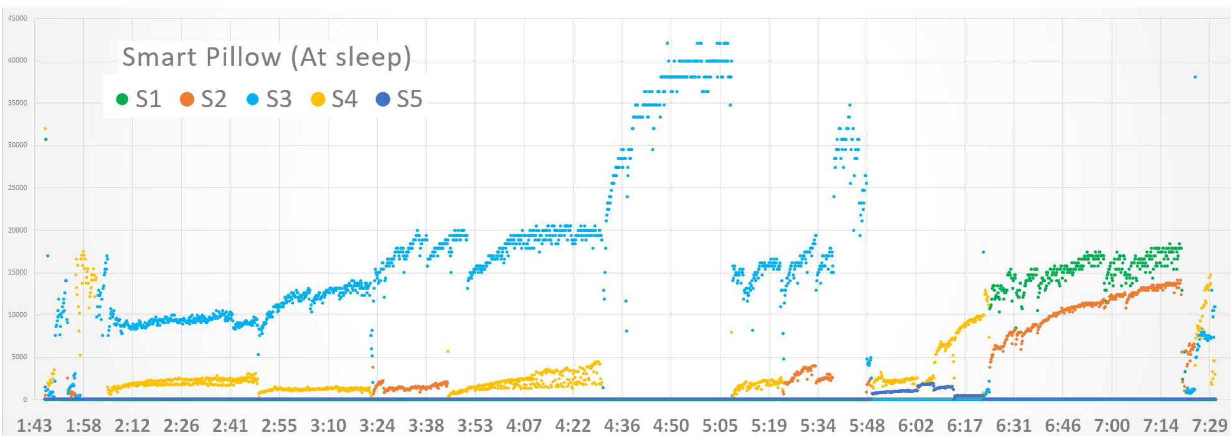

Fig. 8. Data acquisition of volunteer while sleeping.

of the force sensors collecting data every 0.1 s as depicted in Fig.7. It is possible to verify that, according to the volunteer's position, a different area of the pillow is pressed and detected by one or more sensors that cover that area.

Measurements are then taken while an individual sleeps. On this occasion data was collected while sleeping every 10 s. The results are shown in Fig. 8. On top of identifying head movement, it was also possible to detect Heart and Respiration Rate using Low-pass filters.

V. Conclusion

A smart pillow embedded with FSRs for sleeping quality was designed, and built. These sensors are cost-effective, easy to integrate, requires simple electronics and does not affect the comfort of users. Strip-type FSRs are well suited for monitors presence, motion and position, helping caregivers and healthcare professionals to manage their patients, preventing bedsores, mild spinal and neck injuries. After tests, the obtained results are satisfactory in this respect. The collected data can be easily transmitted in real time to professionals via wireless technologies directly to the cloud and the large amount of data stored by the professional can be handled with the help of Big Data and Machine Learning. On top of this it was also visible that these sensors could potentially be used to heart and respiratory rate, but that would be the objective of a future work.

Acknowledgment

This work is a result of the project CoViS - Contactless Vital Signs Monitoring in Nursing Homes using a Multimodal Approach, with references POCI-01-02B7-FEDER-070090 and LISBOA-01-02B7-FEDER-070090, under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF).

References

[1] D. Cai and H.-L. Chen, "Ergonomic approach for pillow concept design," *Applied ergonomics*, vol. 52, pp. 142–150, 2016.

[2] G. S. Aujla and A. Jindal, "A decoupled blockchain approach for edge-envisioned iot-based healthcare monitoring," *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 2, pp. 491–499, 2020.

[3] L. Catarinucci, D. De Donno, L. Mainetti, L. Palano, L. Patrono, M. L. Stefanizzi, and L. Tarricone, "An iot-aware architecture for smart healthcare systems," *IEEE internet of things journal*, vol. 2, no. 6, pp. 515–526, 2015.

[4] D. C. Yacchirema, D. Sarabia-Jácome, C. E. Palau, and M. Esteve, "A smart system for sleep monitoring by integrating iot with big data analytics," *IEEE Access*, vol. 6, pp. 35 988–36 001, 2018.

[5] A. A. Hussain, O. Bouachir, F. Al-Turjman, and M. Aloqaily, "Ai techniques for covid-19," *IEEE Access*, vol. 8, pp. 128 776–128 795, 2020.

[6] S. Y. Y. Tun, S. Madanian, and D. Parry, "Clinical perspective on internet of things applications for care of the elderly," *Electronics*, vol. 9, no. 11, p. 1925, 2020.

[7] D. J. Jaworski, A. Park, and E. J. Park, "Internet of things for sleep monitoring," *IEEE Instrumentation & Measurement Magazine*, vol. 24, no. 2, pp. 30–36, 2021.

[8] X. Long, P. Fonseca, J. Foussier, R. Haakma, and R. M. Aarts, "Sleep and wake classification with actigraphy and respiratory effort using dynamic warping," *IEEE journal of biomedical and health informatics*, vol. 18, no. 4, pp. 1272–1284, 2013.

[9] M. Angelova, C. Karmakar, Y. Zhu, S. P. Drummond, and J. Ellis, "Automated method for detecting acute insomnia using multi-night actigraphy data," *IEEE Access*, vol. 8, pp. 74 413–74 422, 2020.

[10] F. Fazli, B. Farahmand, F. Azadinia, and A. Amiri, "The effect of ergonomic latex pillow on head and neck posture and muscle endurance in patients with cervical spondylosis: A randomized controlled trial," *Journal of Chiropractic Medicine*, vol. 18, no. 3, pp. 155–162, 2019.

[11] J. Son, S. Jung, H. Song, J. Kim, S. Bang, and S. Bahn, "A survey of koreans on sleep habits and sleeping symptoms relating to pillow comfort and support," *International journal of environmental research and public health*, vol. 17, no. 1, p. 302, 2020.

[12] S. Kiatkulanusorn, N. Luangpon, and K. Tudpor, "Increased upper and lower trapezius muscle activities during rest in side-lying position in young adults with forward head posture," *Website: www. ijpot. com*, vol. 14, no. 02, p. 2266, 2020.

[13] H. Zhu, C. K. Wu, C. H. Koo, Y. T. Tsang, Y. Liu, H. R. Chi, and K.-F. Tsang, "Smart healthcare in the era of internet-of-things," *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26–30, 2019.

[14] T. Adegbija, A. Rogacs, C. Patel, and A. Gordon-Ross, "Microprocessor optimizations for the internet of things: A survey," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, vol. 37, no. 1, pp. 7–20, 2017.

[15] S. Park and H. Shin, "Feasibility study for unconstrained respiration monitoring based on multi-way approach using an acceleration and force sensing module," *IEEE Sensors Journal*, vol. 17, no. 11, pp. 3482–3489, 2017.

[16] A. Kuramoto, W. Inoue, Y. Otake, H. Kimura, N. Inou, T. Ichikawa, H. Ono, and N. Sekiyama, "Development of intelligent integrated bedding system transformable pillow and mattress with multiple flexible actuators," in *IECON 2016-42nd Annual Conference of the IEEE Industrial Electronics Society*. IEEE, 2016, pp. 5885–5890.

[17] S. Lokavee, W. Suwansathit, V. Tantrakul, and T. Kerdcharoen, "Unconstrained detection of respiration rate and efficiency of sleep with pillow-based sensor array," in *2014 11th international conference on electrical engineering/electronics, computer, telecommunications and information technology (ECTI-CON)*. IEEE, 2014, pp. 1–6.

[18] U. Qidwai, S. Al-Sulaiti, G. Ahmed, A. Hegazy, and S. K. Ilyas, "Intelligent integrated instrumentation platform for monitoring long-term bedridden patients," in *2016 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES)*. IEEE, 2016, pp. 561–564.

[19] H. Diao, C. Chen, W. Yuan, A. Amara, T. Tamura, J. Fan, L. Meng, X. Liu, and W. Chen, "Deep residual networks for sleep posture recognition with unobtrusive miniature scale smart mat system," *IEEE Transactions on Biomedical Circuits and Systems*, vol. 15, no. 1, pp. 111–121, 2021.

[20] G. Matar, J.-M. Lina, and G. Kaddoum, "Artificial neural network for in-bed posture classification using bed-sheet pressure sensors," *IEEE journal of biomedical and health informatics*, vol. 24, no. 1, pp. 101–110, 2019.

[21] R. Hudec, S. Matúška, P. Kamencay, and M. Benco, "A smart iot system for detecting the position of a lying person using a novel textile pressure sensor," *Sensors*, vol. 21, no. 1, p. 206, 2021.

[22] S. Peng, K. Xu, S. Bao, Y. Yuan, C. Dai, and W. Chen, "Flexible electrodes-based smart mattress for monitoring physiological signals of heart and autonomic nerves in a non-contact way," *IEEE Sensors Journal*, vol. 21, no. 1, pp. 6–15, 2020.

[23] D. Sen, J. McNeill, Y. Mendelson, R. Dunn, and K. Hickle, "A new vision for preventing pressure ulcers: wearable wireless devices could help solve a common-and serious-problem," *IEEE pulse*, vol. 9, no. 6, pp. 28–31, 2018.