Internet of Things (IoT) for Healthcare Application: Wearable Sleep Body Position Monitoring System using IoT Platform

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ABSTRACT

People with health conditions such as dementia often face problems sleeping, experience wake-rest routine changes and suffer from emotional disturbances amid sleep disorders. Caregivers, such as family members, of dementia sufferers face great challenge in taking care of such patients at night as it takes a toll on their own sleep quality resulting in sleep deprivation and other issues. The goal of this work, presented in this paper, is to develop a wearable body position monitor that can detect user's body position and keep online records during sleep; provide light when data shows the user is not asleep, aid user to fall asleep with audio assist feature, and if necessary, activate emergency alert call to caregivers when the patient remains seated or stands for longer durations (e.g. more than 20 minutes) at night. Main system components of the developed prototype include MySignals HW Complete Kit (e-health medical development platform), Arduino Uno microcontroller, LEDs, speakers, micro SD card, micro SD card reader, SPI interface and esp8266 module. Real-time transmission, data analysis and visualization and remote data storage has been realized. The plan for the next phase of this work will include application of sleep pattern recognition and machine learning techniques on large datasets and real biometric measurements.

KEYWORDS

Internet of Things for Healthcare, Wireless network, Arduino, Wearable, e-health, Sleep disorder

1. Introduction

Dementia is a syndrome or a series of syndromes related to cognitive impairment, associated with several series of mental and behavioral symptoms including depression, hallucination, sleep disturbance etc. [1,2] The trigger of dementia is not totally clear but confirmed with multiple causes, most prevalent as Alzheimer's disease and dementia with Lewy bodies (DLB)[1]. Among several common syndromes, sleep disturbance is one of the most common problems for people with dementia for people with dementia. Investigation of Alzheimer's Disease (AD) shows that people with AD tend to have longer portion of sleeping time staying awake at night and taking more naps during the day than usual leading to a disorganized life routine [3,4]. It is also possible for them to lose track of time during night causing confusion of sleep routine. Night time activities are unsafe for the elderly dementia patients due to lack of light, higher risk of fall and difficulty in accessing caring support. Not only does dementia put large number of people affected at physical and psychological risks, but also puts an extra burden on their families and caregivers [5]. Dealing with sleep disturbances, non-pharmacologic strategies probably having least side-effects are always encouraged to be the first therapy for patients with slight or severe signs or symptoms [6]. Neef and Larson[7] suggest that patients should be helped in developing regular sleep hygiene and limiting their daytime napping [8]. Researchers in various fields have deployed approaches to solve diverse problems associated with sleep disturbance from different angles at different levels. Professional researches usually involve polysomnography method which records a variety of human bio-signals during sleep such as brain functioning (electroencephalography (EEG)), muscle activity (electromyography (EMG)), respiratory record, heartbeat (electrocardiography (ECG)), oximetry. Chesson et al [9] thoroughly reviewed the use of multi-channel physiological data acquisition to study sleep disorder and its related syndromes. Although clinical methods ensure the precision of collected data, practical problems such as its complexity and financial cost needs to be considered before conducting rigorous investigations in clinical settings. Recently, the growing popularity of healthcare related digital devices provides the opportunity to improve caring support of people with dementia and elderly people. Tabakis et al [10] designed a wearable system with Android application which keeps track of the location and health related data of patients to help care providers and clinics know patient's conditions. Zeng and Chang [11] realized the estimation of sleep status with wearable free passive infrared-red (PIR) devices and Support Vector Machine (SVM) trained data. Undoubtably caregivers and doctors would benefit from data analysis and monitoring. However, few studies focus and stress on the need to develop control devices for helping patients. More physical assistance can be achieved if the collected data can be used to control actuators.

For these aforementioned reasons, this paper presents an IoT enabled wearable sleep body position monitoring device that focuses on wireless data collection and device control. This system has three main functions: 1) measure user's body position and store this useful data online for users, family and doctors to better understand patients' sleep patterns; 2) provide essential light as per user's position (seated or standing)and play audio activated guide to assist the user to sleep during night; 3) automatically contact caregivers if patients' wakefulness state is detected. Body position is detected by MySignal HW Complete Kit, which is processed by Arduino UNO microprocessor and uploaded via Wi-Fi module ESP8266 to the online dashboard (Ubidots). The LED light and a speaker with micro SD card are the two controlled devices used to help user fall asleep.

The rest of this paper is organized as follows: Section 2 describes the system architecture and detailed designs of the system's prototype. Section 3 illustrates the related work. Section 4 presents the analysis of the system's performance and presents data visualization, followed by conclusion in section 5 and brief discussion on future work in section 6.

2. Related work

Rapid development of digital devices and wireless communication technologies provides extensive range of possibilities to support people suffering from dementia. In this section, a few comparable systems related to sleep tracking and for safety of people suffering from sleep disorders are introduced and compared with our developed sleep body position monitoring device.

Mat-On-Guard® [12], a wireless pressure pad that perceives the patient's weight once the patient walks on it and notifies caregivers with a portable receiver with 200-meter range and adjustable volume control. It has received some good reviews from customers about its ease of use, sensitivity and user-friendly receivers. However, scalability is one of the foremost apprehensions due to its inability to add more pads to the system and relatively limited size of the pad, allowing the system only to operate in a relatively small area.

The pervasive monitoring system designed by Friedrich Hanser et al. [13] has more functions including location tracking, measurement of patient's vocal interaction and sleep. The system consists of an ultra-wide-band (UWB) radio receiver and transmitter that defines user's indoor location, microphones that collects user's sound information and bed mounted accelerometers that records patient's sleep movement during night. The system shows strengths in multi-channel and data, while its function is limited due to lack of flexibility and in-depth data analysis due to fixed sensors and lack of direct data visualization.

Irene-Maria Tabakis et al. [10] presented the idea of a wearable monitoring system with Android application. It is basically a wristband that can track and transmit user's location, heartbeat and hand movement data. It has the merits of portability and well-constructed data protection, but on the other hand it is relatively weak in terms of operational lifetime with complexity of usage and unclarity of data accuracy.

In comparison to the aforementioned systems, the system presented in this paper demonstrate primacy in terms of the following criteria: 1) inclusion of both user-friendly alert and data visualization; 2) portability since it does not require any fixed sensors; 3) massive online data storage; 4) scalability provided by MySignal multi-channel board. However, the sleep body position device has the weakness as: 1) its unavoidable cost of MySignal board and other components at this stage of development; 2) the wired connection between body position sensor and the system's core; 3) perhaps a little uncomfortable experience of wearing sensors; 4) insufficient classification of user's sleep status. In future, we plan to focus on these design challenges by further enhancing the developed prototype and also seeking required ethical and legal permissions to perform experimental and clinical trials.

3. Method

3.1 System Architecture

3.1.1 Components. The components used to build the sleep body position monitor include:

1. MySignal HW Complete Kit (with body position sensor)
2. Arduino UNO
3. ESP8266
4. Micro SD card with micro SD card reader SPI interface
5. LEDs

3.1.2 MySignal HW Complete Kit. MySignal HW Complete Kit is a e-health medical development platform for Arduino UNO launched by Libelium Company, which can measure more than 20 biometric signals including heart rate, blood pressure, body position and so on. In this study, body position sensor has been used, which is a triple axis accelerometer offering acceleration of three perpendicular acceleration distinguishing five positions: supine, left lateral recumbent, right lateral recumbent, prone and standing or sitting as following table 1.

Position	Number	x-axis acceleration	y-axis acceleration	z-axis acceleration
Prone	1	/	/	>0.12
Left lateral	2	/	>0.12	/
Right lateral	3	/	< -0.12	<-0.12

Supine	4	/	/	/
Sit or stand	5	< -0.12	/	/
Else	6	/	/	/

Table 1. Detectable body positions and their corresponding number and accelerations

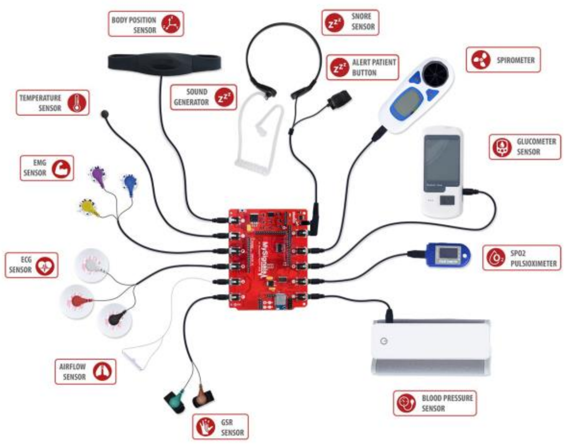

Figure 1. MySignal eHealth and Medical IoT Development Platform for Arduino [14]

3.1.3 ESP8266 and Unidots. ESP8266 is a cost-efficient Wifi microchip with TCP/IP stack produced by Espressif Systems. It can be used as stand-alone microcontroller or as Wifi adapter to any other microcontroller as logger. Ubidots is an online IoT platforms where developers can quickly build web applications to communicate and control hardware wirelessly. It is accessabile via mutiple devices and protocols.

To acces network, ESP8266 module requires Internet connection and commands to send or post data from its logger Arduino UNO. Firstly, ESP8266 and Arduino needs to be assigned Wifi SSID password, and Ubidots TOKEN and Ubidots-esp8266-serial library. Specified in codes, the monitor is able to conncet Ubibots via internet. Secondly, Arduino takes the responsibility to read sensor data, construct command in TCP and send it to ESP8266 serially every few seconds. After Recieving command, ESP8266 sends data to Ubidots which can now be accessed and analysed on Ubidots platform. In this study TCP has been used as the communication protocol. For the host and port configuration, it is specified with URL things.ubidots.com and ports 9012. With Ubidots library, payload format is designed as:

USER_AGENT/VERSION|METHOD|TOKEN.

Specifically, to send data the payload is

{USER_AGENT}|POST|{TOKEN}|{DEVICE_LABEL}:{DEVICE_NAME}@{GLOBAL_TIMESTAMP}=>{VARIABLE_LABEL}:{VALUE}${CONTEXT_KEY_1}={CONTEXT_VALUE}${CONTEXT_KEY_2}={CONTEXT_VALUE}@{VARIABLE_TIMESTAMP}|end,

which is wrapped up as command by Arduino UNO and sent to ESP8266 every 5 seconds. With these configurations, user's body position data will be observable on Ubidots online dashboard

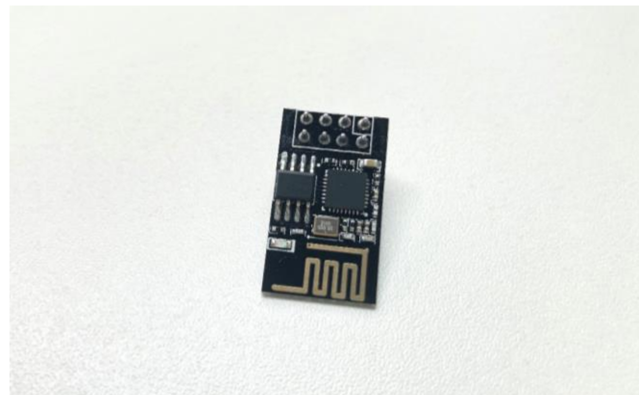

Figure 2. ESP8266

3.1.4 System framework. Figure 3. shows the overview of the system design. We used MySignal HW Complete kit as body position sensor, which contains a wearable belt and a circuit board connected between belt and Arduino UNO. LEDs are the light source and speaker offers audio guidance to patients in which the voice messages are stored in SD card with SPI reader in the system. Arduino UNO is the only microprocessor which deals with almost all data work, such as receive, determine and send. ESP8266 acts as a Wi-Fi telemetry of Arduino UNO which connects the system with internet, transmits body position to Ubidots online dashboard during night, and initiates emergency call to the registered caregiver if patient is detected sitting or standing up for 20 minutes.

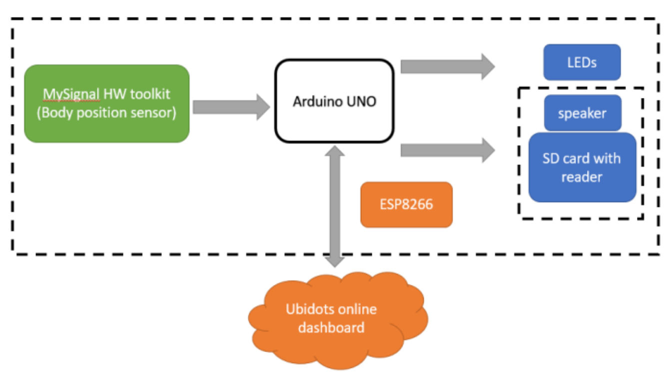

Figure 3. An overview of system design

3.2 System events and functions

System functions such as turn on the speaker, turn off the light and give emergent calls are triggered by several cases, which let the microprocessor to determine whether to conduct functions. The followings are specific events and their corresponding possible triggered functions:

1. If the system is powered on, ESP8266 will automatically search the wireless network pre-registered in code; once it is connected with Internet, body position data will be uploaded every 5 seconds.
2. If user is detected as sitting or standing up, LEDs will be on and voice messages will be played once be speaker to encourage users to go to sleep.
3. Once the user lies down, the light will turn off automatically, meanwhile the position data is still uploaded continuously with timestamp.
4. If time is recognized as night time, the patient is detected as sitting and standing up for more than 20 minutes, and this event is enabled before, Ubidots event function will be triggered and make voice call to the phone number registered on dashboard.

3.3 System events and functions

The software configuration is presented in Figure 4. Once the system is connected to power, ESP8266 module will automatically search for network connection. At the same time, MySignal e-health medical shield and SPI reader will be initiated. Light will be on at first. After initialization, user's body position is measured and wrapped up as command transmitted to ESP8266 by serial port, which will be uploaded then. If the user is detected sitting up or standing up (measured as same position), light will stay on and voice message *"It's night time, please go to sleep"* will be played once. After the user lies down, the light will automatically turn itself off. The voice call event is construction trough event functions of Ubidots, as is shown in Figure 5., that if the body position is equal to 5 (sit or stand up position) for more than 20 minutes, with the time range limit from midnight (12:00 p.m.) to morning (8:00), voice call with the content will be acted.

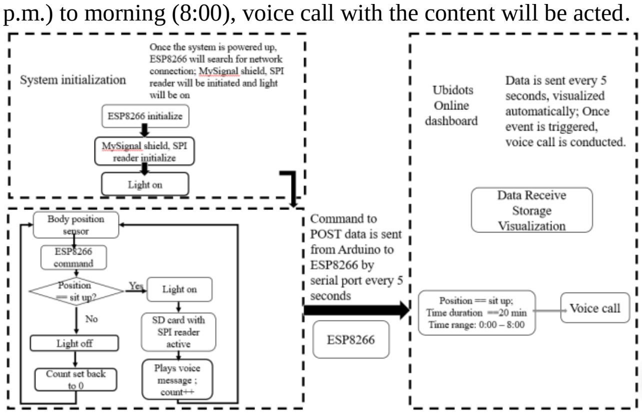

Figure 4. Software configuration

In addition, MySignal libraryassigns several different positions with numbers from 1 to 6: number 1 stands for Supine position; number 2 stands for Left lateral decubitus; number 3 stands for Right lateral decubitus; number 4 stands for Prone position; number 5 stands for Stand or sit position; number 6 stands for unknown positions. The system transmits number and presents the changes of numbers through the night for convenience and for the smaller size command package

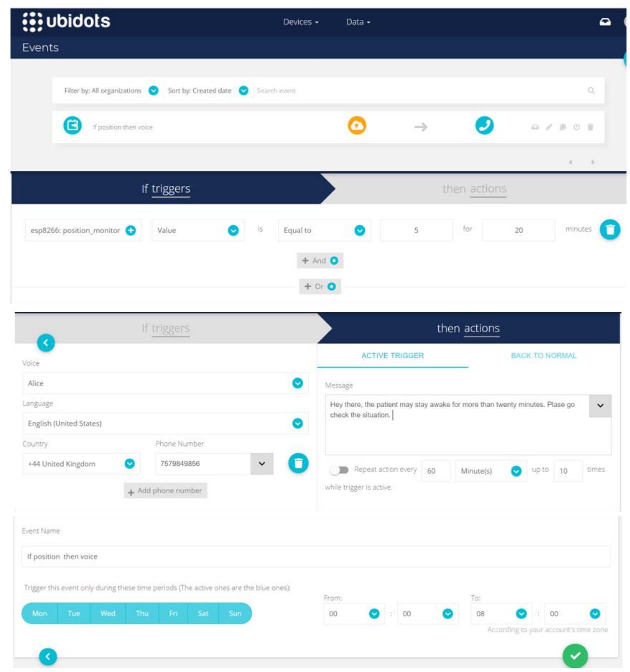

Figure 5. Ubidots event function

4. Results and discussion

4.1 Physical configuration

The system is configured as depicted in Figure 6. The system can be powered by 5V voltage supply. Arduino UNO is connected with MySignal HW toolkit where the UNO board pins is still accessible via the extension on shield. A belt is with body position senor which is part of MySignal HW Kit is connected to the main system. The ESP8266 module and SPI reader module with SD card are powered by Arduino UNO board and communicated via SPI and UART interface respectively. Speaker and LED light are connected to digital pins on the Arduino UNO, controlled by its output signals.

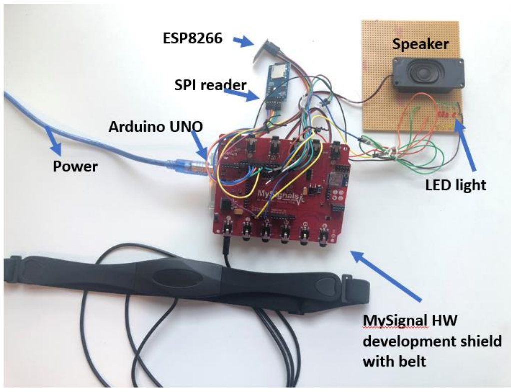

Figure 6. System construction

4.2 Wireless communication

In this work, wireless data transmission and analysis plays the crucial role. In order to realize the designs, it is meaningful to test the functionality of the network connection and remote presentation.

4.2.1 Wi-Fi connection. The performance and stability of the of the connection was tested through 10 experimental runs and its stability was found to be good with 100 percent successful connection, each test took 2 to 3 seconds to establish connection.

4.2.2 Online presentation. Firstly, data transmission detail is available for users on Ubidots platform, where the data with specific timestamp is kept and stored at backend. As mentioned above, transmitted number represents the corresponding body position, preset by MySignal library. We designed to send a new value every 5 seconds. It has been verified that every new data point is received in 5 or 6 seconds, which is quite accurate considering transmission delay.

Secondly, we built an online dashboard. As is shown in Figure 7, the dashboard provides user with current position data, average position value, and a line graph, which updates a couple of times within a minute, as long as the system is on. A text description is added additionally to help users understand data. With the visualization, the patient as well as the caregivers are able to monitor patient's night time sleep-and-wake states easily. Through the line graph, users can know when their movement is most frequent, when they sit or stand up, and how long they lie on the bed while through the average value, users can know what kind of position they usually keep during sleep, which might also affect their sleep quality.

According to Table 2, simulation data was successfully recorded on April 17, 2020. The device started to work at 0:00. From the table, it is obvious that 6 position-changes are detected. From 1:00 to 4:00, we collected date for 2 to 3 different positions each hour, representing the possible cases that the real user experiences during deep sleep and reduced movement. From 4:00 to 7:00, light sleep was simulated by increasing frequency of position changes. The number of times with different positions was set to 9 and was recorded successfully both in back-end data storage and on dashboard. Analogous cases are shown in the next 2 hours when 4 and 6 separate postures were precisely detected and registered in online cloud.

Figure 7. presents the measurement more clearly. The line graph in Figure 7. is more visual to observe the various sleep patterns, including the wakefulness in the first half hour at 00:00, the deep sleep pattern from 00:30 to 4:00, and light sleep status at dawn. Also, we can know from the graph and the average position value that the majority of collected data was 4 (supine position). As a result, the simulation proved the monitor's function of data collection, real-time transmission, data analysis, visualization and data storage.

Lastly, the voice call functionality of the developed prototype was conducted, tested and verified successfully. After remaining in sitting position for more than 20 minutes at night, an auto voice call was made through the registered phone.

Time period	Times of changing positions
00:00 to 1:00	6
1:00 to 2:00	3
2:00 to 3:00	3
3:00 to 4:00	2
4:00 to 5:00	9
5:00 to 6:00	4
6:00 to 7:00	6

Table 2. Frequency of changing body position in each hour, from 00:00 to 7:00 17, April, 2020

Figure 7. Ubidots online dashboard.

5. Conclusion

The objective of this work is to develop a wearable sleep body position monitoring device for people with dementia to help them stay safe when awake at night. This device is also expected to help caregivers of sleep disorder sufferers to keep track of online record acquired wirelessly. The device transmits position data to an online platform, provides simple guidance assist when a patient sits or stands up during the night, and automatically contacts registered caregiver(s). In order to realize these functions, Arduino UNO was used as a microprocessor, MySignal HW shield as sensor, ESP8266 module as telemetry unit and LED, speaker with SD card as controlled components. The event function of Ubidots platform was utilized to make phone calls. The light and speaker related functions are designed properly; the system can be connected to the Internet within 3 seconds once it is powered up with 100 percent success rate; data transmission works accurately and with slight time delay; online monitor manages to present data in various forms and gives an idea about user's sleep status. Phone calls are conducted automatically once the patient-wakefulness event is triggered. As dementia grows common worldwide and IoT technology develops, technology should be used by fully considering both patients and caregivers' needs and practical requirements to provide latest smart solutions to try and address the challenges in a futuristic manner.

6. Future work

The research work presented in this paper focuses on the realization of a prototype. There is a need for conducting more studies and trials on real dementia sufferers in order to validate and come up with a near-perfect solution. Therefore, we plan to get the required ethical and legal approvals to perform experimental and clinical trials.

In addition for improvement of the data analysis phase, more work will be done in order to detect and analyze user's sleep status and give better and smart control of assist technology by applying sleep pattern recognition algorithm(s) and machine learning techniques once larger datasets are developed.

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REFERENCES

[1] S. Gale, D. Acar and K. Daffner, "Dementia", The American Journal of Medicine, vol. 131, no. 10, pp. 1161-1169, 2018. Available: 10.1016/j.amjmed.2018.01.022

[2] C. Lyketsos, M. Steinberg, J. Tschanz, M. Norton, D. Steffens and J. Breitner, "Mental and Behavioral Disturbances in Dementia: Findings From the Cache County Study on Memory in Aging", American Journal of Psychiatry, vol. 157, no. 5, pp. 708-714, 2000. Available: 10.1176/appi.ajp.157.5.708.

[3] S. McCurry et al., "Characteristics of Sleep Disturbance in Community-Dwelling Alzheimer's Disease Patients", Journal of Geriatric Psychiatry and Neurology, vol. 12, no. 2, pp. 53-59, 1999. Available: 10.1177/089198879901200203.

[4] R. Postuma, J. Gagnon, M. Vendette, M. Fantini, J. Massicotte-Marquez and J. Montplaisir, "Quantifying the risk of neurodegenerative disease in idiopathic REM sleep behavior disorder", Neurology, vol. 72, no. 15, pp. 1296-1300, 2008. Available: 10.1212/01.wnl.0000340980.19702.6e.

[5] Alzheimer's Disease International. 2019. World Alzheimer Report 2019: Attitudes to dementia. London: Alzheimer's Disease International.

[6] G. Cipriani, C. Lucetti, S. Danti and A. Nuti, "Sleep disturbances and dementia", Psychogeriatrics, vol. 15, no. 1, pp. 65-74, 2014. Available: 10.1111/psyg.12069.

[7] D. Neef and D. Larson, "Sleep and Quality of Life in Alzheimer's Disease and the Dementias", Sleep and Quality of Life in Clinical Medicine, pp. 155-160. Available: 10.1007/978-1-60327-343-5_18.

[8] D. Forbes et al., "Light therapy for managing cognitive sleep functional behavioural or psychiatric disturbances in dementia", *Cochrane Database of Systematic Reviews*, vol. 7, no. 4, 1999.

[9] A. L. Chesson et al., "The indications for polysomnography and related procedures", *Sleep*, vol. 20, pp. 423-487, 1997.

[10] I. Tabakis, M. Dasygenis and M. Tsolaki, "A monitoring system for people living with Alzheimer's disease," 2017 Panhellenic Conference on Electronics and Telecommunications (PACET), Xanthi, 2017, pp. 1-4.

[11] Y. Zeng and W. Chang, "Estimation of sleep status based on wearable free device for elderly care," 2016 IEEE 5th Global Conference on Consumer Electronics, Kyoto, 2016, pp. 1-4.

[12] "Mat-On-Guard - Dementia Care at Home", Matonguard.co.uk. [Online]. Available: https://www.matonguard.co.uk/index.php/en/. [Accessed: 27- Apr-2020].

[13] F. Hanser, A. Gruenerbl, C. Rodegast and P. Lukowicz, "Design and real life deployment of a pervasive monitoring system for dementia patients", 2008 Second International Conference on Pervasive Computing Technologies for Healthcare, 2008. Available: 10.1109/pcthealth.2008.4571090.

[14] https://www.cooking-hacks.com/mysignals-hw-v1-ehealth-medical-biometric-iot-platform-arduino-tutorial/index.html#img_3. 2020.