Optimized Sleep Apnea Detector using UWB Signals

Jesús G. Servín-Aguilar[a], Jorge A. Pardiñas-Mir[b] and Luis Rizo-Dominguez[c]
Department of Electronics, Systems and Informatics, ITESO University, Tlaquepaque, Mexico

Keywords: Sleep Apnea, UWB Technology, Optimization, Parametric Multidimensional Search, eHealth.

Abstract: Sleep apnea is a syndrome defined as the pause of breathing for more than 10 seconds while the patient remains asleep. Diseases such as strokes, coronary heart attacks or diabetes could be associated with an untreated sleep apnea. UWB is an alternative technology to help treat this condition. It is a non-invasive technology, with low power and low radiation. In this article we present a system based on UWB signals to detect sleep apnea. It is shown that the proposed algorithm correctly detects apnea. Once this is done, an experimental optimization is performed to find the parameters that produce the best results.

1 INTRODUCTION

The main cause of death in the world is chronic diseases (WHO, 2014). 70 % of deaths in the world are diseases like diabetes, heart diseases, strokes, or cancer (WHO, 2018). Half of these deaths correspond to people over 70 years old (WHO, 2014). It is expected that between 2000 and 2050 the population over 60 years old will increase from 11% to 22% with respect to the world population (WHO, 2015). This data indicates that the world population has become old. If we focus on elderly people, we find that most of our seniors prefer to live alone in their own homes, than living with their families or in a care center (Hou, 2009). The risk is that, if they live alone, they may have an accident caused by a health problem and there would be no one around to help them. Therefore, the time it takes a family member or medical assistant to know that the elderly have had an accident can be too long and can cause irreversible damage.

Another alarming problem around the world is the overpopulation of hospitals. A solution to reduce the number of patients attending hospitals every day is to design a system to monitor vital signs and send the information to a remote database. From there, doctors can review, make a diagnosis, and give or modify the treatment of a patient via internet. This could be in fact a remote medical appointment (Hou, 2009). This situation has represented in the last years a good opportunity for research work aimed to develop solutions in this area. In this scope, Wireless Sensor Networks (WSN) and Wireless Body Area Networks (WBAN) have been considered to be applied to monitor patient vital signs constantly like the patients' breathing to detect sleep apnea.

The sleep apnea (SA) is a syndrome which affects at least 6% of the adult population (WHO, 2017). SA is the breathing pause for 10 seconds or more while the patient is asleep. Occasionally, a normal person can have apnea. However, a health damage is considered when the patient has at least 300 sleep apneas per night or its duration is around 5 minutes (Varady, 2003), (AASM, 2017), (Guyton, 2011). SA is caused by the obstruction of the airways [8] and it is divided into two types: central sleep apnea (CSA) and obstructive sleep apnea (OSA). In the CSA, the nervous central system does not send the impulse information to the airway muscle and they block the air conduct in the pharynx. On the other hand, the OSA is caused by soft tissues of muscle that block the airway conduct (Varady, 2003), (Guyton, 2011). In both cases, it could be accompanied by loud snoring (WHO, 2017). After that, the snore is interrupted by a long silence. Finally, the brain sends an impulse to the patient to open the airway or move the body to continue breathing (Guyton, 2011). A patient with SA could present different symptoms such as feeling sleepy or sleep during the day, be forgetful, having strong headaches, fall asleep while the patient is

[a] https://orcid.org/0000-0002-1908-3171
[b] https://orcid.org/0000-0002-0972-3980
[c] https://orcid.org/0000-0001-9393-5320

Servín-Aguilar, J., Pardiñas-Mir, J. and Rizo-Dominguez, L.
Optimized Sleep Apnea Detector using UWB Signals.
DOI: 10.5220/0007931103610369
In *Proceedings of the 16th International Joint Conference on e-Business and Telecommunications (ICETE 2019)*, pages 361-369
ISBN: 978-989-758-378-0

watching TV, working, driving, reading, or waking up tired in the morning (MedlinePlus, 2017).

Currently, the medical method to diagnose sleep apnea is performed with a polysomnography (AASM, 2017), (Guyton, 2011), (MedlinePlus, 2017). In this technique, an oxygen mask is placed on the nose and mouth of the patient while sleeping. Then, the device records the patient's breathing and it detects when the sleep apnea occurs, as well as its duration. There are other complementary tests that confirm SA, such as electrocardiography (ECG), echocardiography, thyroid test, or arterial blood test (MedlinePlus, 2017). Also, a non-invasive technique to detect sleep apnea is to measure the patient chest movements. For example, pressure transducers are placed on the patients' bed. When the patient inhales or exhales, the pressure exerted on the bed changes. When a sleep apnea occurs, the pressure of the body on the bed is still for more than 10 seconds (Waters, 2019). However, the patient must be in a specific position for the breathing frequency detection. Another technique is the Doppler radar, which measures the distances between the radar and the chest of the patient. If distances don't change for more than 10 seconds, then the sleep apnea alert is activated. Unfortunately, this technique, in some cases, tends to be inaccurate (Lai, 2011). Recent experiments show that sleep apnea can be detected using the Ultra-Wide Band (UWB) technology (Fedele, 2015). UWB signals are used to measure the distance between the target and the device and the variations caused by the breathing movement, (Abib, 2014), (Muller, 2015). An advantage is that the power required to send a UWB pulse is lower than other technologies (Muller, 2015). In these papers, the method to detect sleep apnea is through the detection of the breathing signal of the patient. It is analyzed, and the sleep apnea is detected. This process could be optimized in order to reduce the time consumption of the process.

In this paper, a methodology to detect sleep apnea is proposed using UWB signals without the need of first obtaining the breathing signal. The rest of the paper is divided as follows: Section II shows an overview of the UWB technology to detect SA in patients. Section III describes the proposed methodology to detect sleep apnea. Section IV presents the optimization of the proposal. Finally, section V remarks some conclusions.

2 UWB TECHNOLOGY AND BREATHING SIGNAL

The Federal Communications Commission (FCC) of the United States of America (USA) defines UWB technology as that employing devices that transmit very short pulses that result in very wide transmission bandwidths (Waters, 2009), (Pardiñas, 2017). Typically, the largest pulse length considered as a UWB pulse is on the order of nanoseconds. The received energy signal is spread from close to dc to a few GHz (Pardiñas, 2017). Another advantage of this technology is that multipath effects can be diminished, and it can penetrate through materials such as walls, doors, and windows (Pardiñas, 2017).

When a signal is transmitted in an ideal environment from point *A* to point *B* and is reflected back to point *A* in a direct path without additional reflections, it is called the direct path. The total traveling time is known as time of flight T_R. In a real environment, the signal that arrives at point *B* is composed of the direct path plus additional signals reflected from different objects, as seen in Figure 1, traveling longer paths and lasting for more than $T_R/2$ seconds.

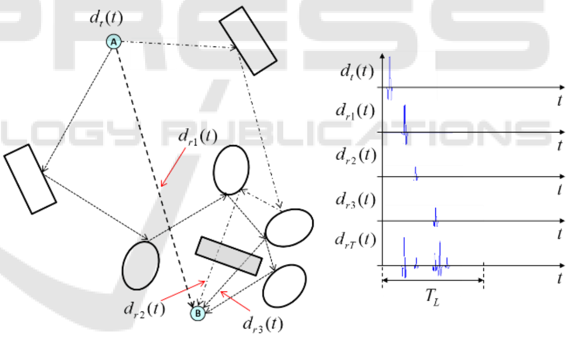

Figure 1: Received signal constructed from reflections of the original signal off of scatterers.

Figure 1 shows the way that the received signal, $d_{rT}(t)$, is constructed from different reflected signals or paths $d_{r1}(t)$, $d_{r2}(t)$, $d_{r3}(t)$, etc. In the case of a transceiver acting as a radar, the signals at point *B* are reflected and redirected to point *A*, where they are collected. This kind of UWB radar can be used to obtain a breathing signal of a person, as shown in Figure 2.

The transceiver targets the person and sends one pulse, recording the reflected signal, called a realization, for T_L seconds, ensuring that all paths have arrived. Doing this very fast and as many times as needed, a signal representing the breathing can be obtained. Figure 3 shows the waveform of a UWB

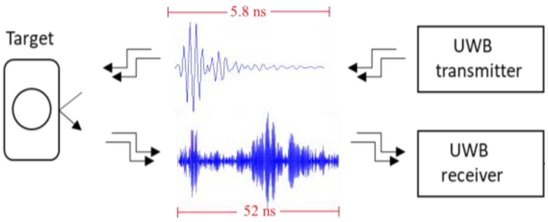

Figure 2: UWB system targeting a patient.

pulse transmitted and Figure 4 shows the received signal, called realization, of around 52 nanoseconds long.

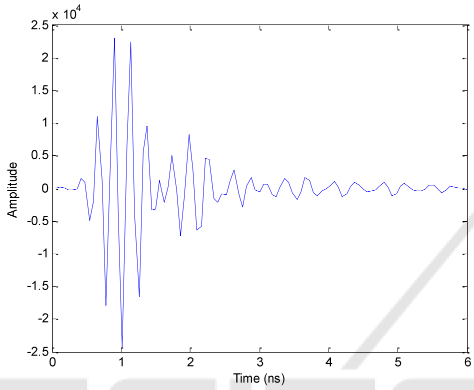

Figure 3: The waveform of an UWB pulse produced by the transmitter.

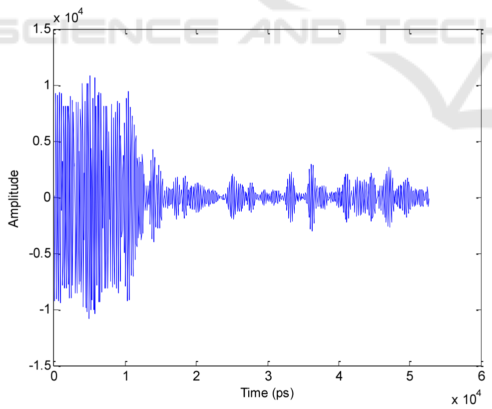

Figure 4: Waveform of a realization collected from a range of 15.6 meters using the UWB device.

The time T_L is dependent on the longest distance to the object on which the signal is reflected. Hence, T_L corresponds to the time of flight of the longest signal path, so the maximal distance d_{max} that the transceiver can detect is half of that time:

$$d_{max} = \frac{T_L}{2} V_p \qquad (1)$$

where V_p is the velocity of propagation. For example, a typical value of T_L for the transceiver used during the experiments presented in this document is 54 ns, so the maximum distance at which a target can be from the transmitter for being recorded is around 8 meters. As stated before, in order to detect the cycle of the breathing signal of a person, it is necessary to analyze the signals corresponding to several cycles of breathing, which means a set of many realizations. The aim is to identify, in those signals, the information associated with the x axis value to the time position that indicates where the target is positioned. In order to standardize the identification concept, this method will be called the target position.

The analysis of the target position is made through all realizations. The normal breathing frequency of a patient is approximately 12 times per minute, which means that the patient inhales and exhales every 5 seconds. However, the breathing frequency could change according to the patient and his status, where the minimum breathing frequency to live for a short time is 2 times per minute and the maximum is 40 times per minute (Guyton, 2011).

According to the sampling theorem, the minimum sampling frequency must be at least twice the frequency of the signal. In this case, the breathing frequency is 0.2 Hz and the sampling frequency is normally set to 8 Hz, which is the repetition transmission frequency of the set of pulses produced by the UWB system. One set usually consists of 20 realizations in order to detect one respiratory cycle of around 5 seconds. Figure 5 illustrates three realizations from a set, where the time between them is 0.125 s.

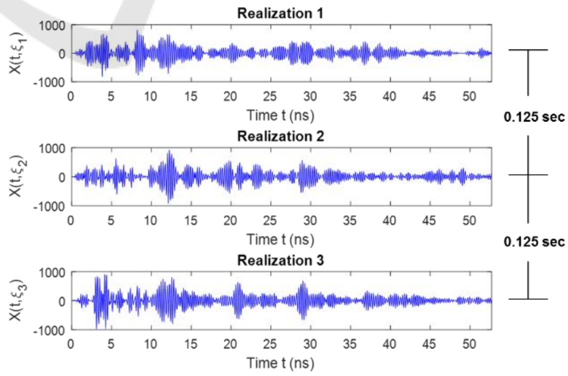

Figure 5: Three realizations from a set of signals from the UWB system.

3 APNEA DETECTOR PROPOSAL

The method presented in this section is based on a UWB transceiver acquiring the reflected signals from a human body.

3.1 Detection Methodology

Instead of trying to identify the breathing cycle, the received signals (realizations) are processed to detect signal variations corresponding to a change of breathing. This is made by computing its variance and comparing the values from one realization to the next one, no matter at what point in the signal this variation occurs. While a person is breathing, the variance of realizations does not change suddenly, but when the person stops breathing, the variance has a big change, signalling that apnea has occurred if it lasts for more than 10 seconds. Note that the breathing frequency of a patient is around 0.2 Hz or a breathing period of 5 seconds. The flowchart of this method is shown in Figure 6.

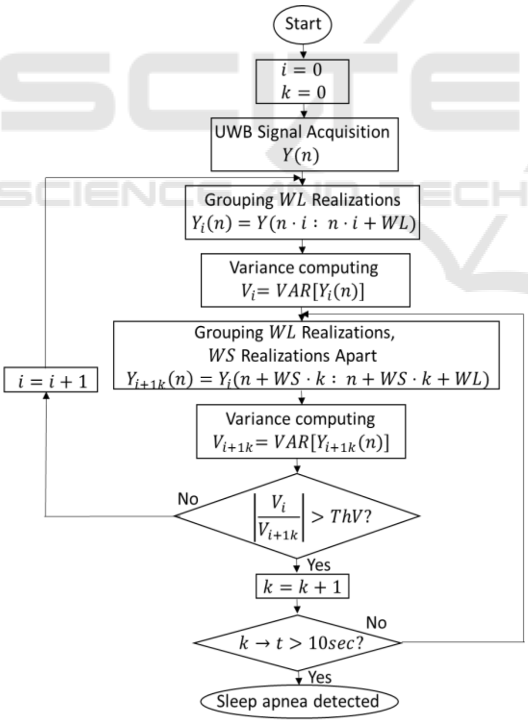

Figure 6: Flowchart of sleep apnea detection using the variance of realizations.

The variance of a signal, as used in this work, provides a measure of the amplitude dispersion of the signal with respect to its average in a determinate time (Leon-Garcia, 2008), and is given by:

$$VAR[X(t)] = \int_{-\infty}^{\infty} \left(x - m_x(t)\right)^2 f_{x(t)}(x)dx \qquad (2)$$

where $m_x(t)$ is the mean function of the random process $X(t)$, and $f_{x(t)}(x)$ is the probability density function (PDF) of $X(t)$.

For signal processing, a set $Y_1(n)$ consisting of a certain number of realizations, *WL*, is grouped into a "window" and its variance V_1 is calculated. A new window $Y_2(n)$ is analyzed by grouping other *WL* realizations located *WS* realizations apart from the start of the previous window: $Y_2(n) = Y_1(n+WS)$. Its variance is V_2. *WS* corresponds to the number of realizations or window step where the new window is defined. Construction of the grouping of realizations and window step is illustrated in Figure 7.

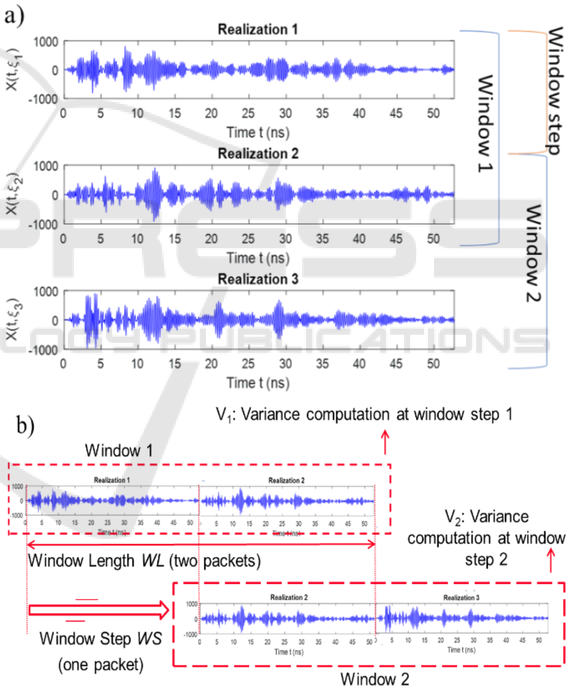

Figure 7: Construction of realization windows and definition of window step: a) Three consecutive realizations. b) Windows shifting.

This procedure, computing the variance of shifted windows, is executed continuously. The result is a signal containing the amplitude of variances, as it is shown in Figure 8.

In this figure, note that there is a time interval when breathing ceased, and the amplitudes of the variances decreased abruptly. A comparison between consecutive variance amplitudes is also continuously

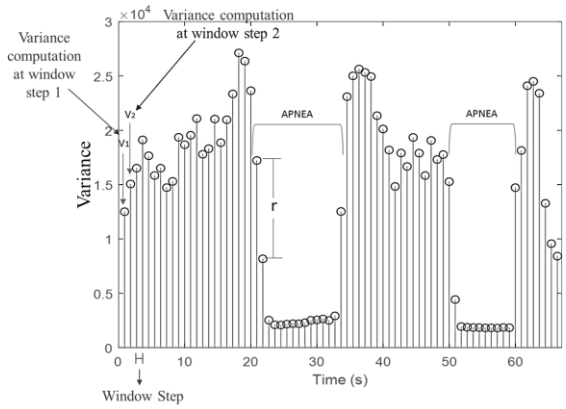

Figure 8: Elements of variance computation by windows.

computed, searching for this abrupt change by calculating:

$$r = \frac{V_1}{V_2} \tag{3}$$

When the relation r between them is greater than a threshold value *ThV*, this point of time is considered as a potential start of apnea. Then, if the relation between subsequent variance amplitudes and the one at the start point is kept greater than the threshold value for more than 10 [Guyton-11], [Servin-Aguilar-18], apnea is declared. Computation of the relation factor *r* for a signal lasting 60 seconds and apnea at 25 seconds is shown in Figure 9.

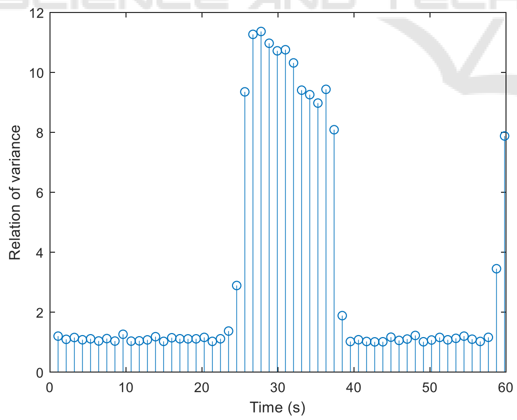

Figure 9: Relation of variance amplitudes with a sleep apnea at 25 seconds.

Finally, when the relation *r* is lower than the threshold, then the patient is breathing again. This process is repeated until the complete signal is analyzed.

3.2 Detection Results

In order to evaluate the performance of the algorithm, we analysed signals corresponding to two environments: a laboratory and a dormitory. We used a UWB monostatic radar module (MRM) model 410 from PulsOn which works in a frequency band between 3.1 and 4.8 GHz, transposing the UWB pulse to a center frequency of 4.3 GHz. This device has two antennas (Tx and Rx) in the same package. The UWB transmitter sends a pulse of 5.6 nano-seconds every 0.125 seconds targeting directly the chest of a patient.

In a first experiment, the laboratory environment is analysed. The distance between the patient and the UWB transceiver is varied from 20 cm to 100 cm. Some results are presented in Figure 10 for values of comparison factor *r*.

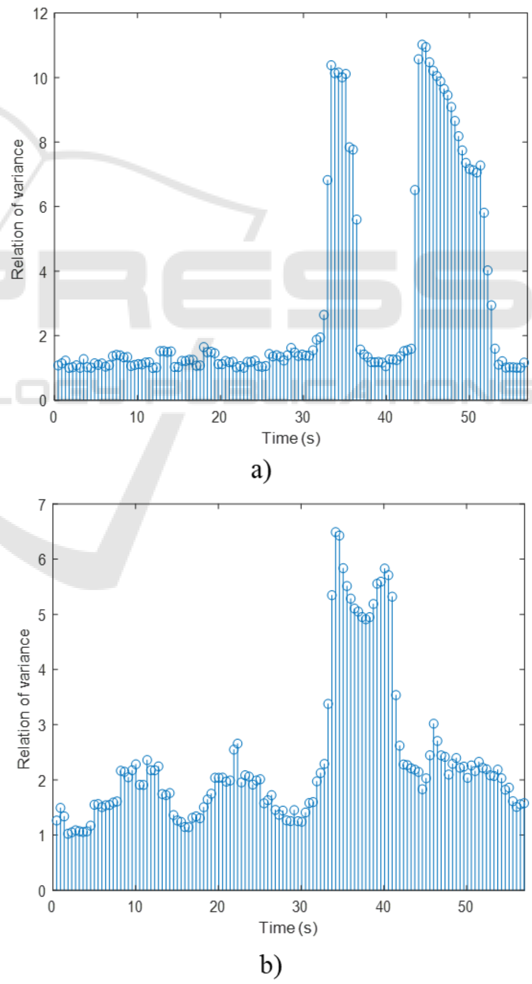

Figure 10: Relation of variance amplitude for signals at different distances between the UWB device and the patient: a) 20 cm and b) 80 cm.

Here, a threshold *ThV* of 5 is chosen. We correctly detected apnea at distances of 20 cm, 60 cm, 80 cm, and 100 cm. For distances greater than 100 cm, the signal is not suitable for processing.

When the threshold value *ThV* is changed to 2, sleep apnea is wrongly detected at 50 seconds. If distance between the UWB device and the patient is grater, then the threshold *ThV* must be lower to detect sleep apneas, because the amplitude of variances are lower.

In a second experiment, the signal processed corresponded to a patient wearing two different clothes: a shirt and a jacket. In order to illustrate the results, we present in Figure 11 the relation of variance amplitude at a distance of 60 cm from the patient.

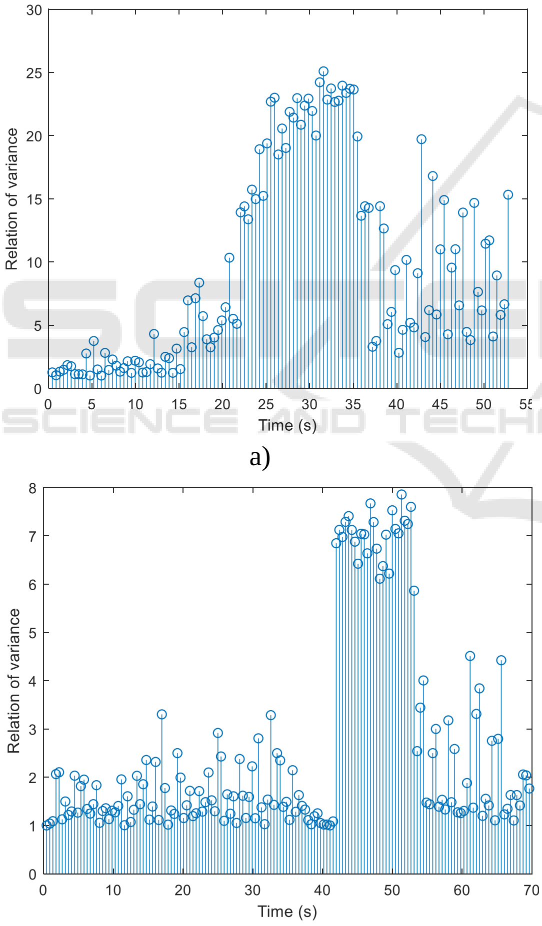

Figure 11: Relation of variance amplitudes for signals in two scenarios: a) the patient is wearing a shirt, b) the patient is wearing a jacket.

When the patient wears a shirt, a sleep apnea occurring at 23 seconds is correctly detected using a *ThV* equal to 10, while when the patient wears a jacket, a sleep apnea at 42 seconds is correctly detected with a threshold *ThV* equal to 3. The range of values is different for each case, so the amplitudes must be normalized to achieve a reliable threshold regardless of, in this case, the type of clothing that the patient uses.

In a third experiment, the signal to process is acquired in a dormitory, where the patient is laying down on his side in a bed. The UWB device is directed toward to the chest of the patient. Two scenarios are considered: the patient wearing a shirt and the patient covered with a thick blanket. In this case, an apnea present at 45 seconds for the patient wearing a shirt is detected correctly, while for the patient with a thick blanket, an apnea present at 47 seconds is correctly detected but another non-existent is detected at 75 seconds. Once the proof of concept of the method has been carried out, it is necessary to optimize it to detect apnea with greater precision.

4 DETECTION OPTIMIZATION

In order to find the conditions with the best performance of the proposed apnea detection method, the main parameters involved in the computation are changed in a series of executions of the algorithm. The targeted parameters are the window length, *WL*, the shift or step between consecutive windows, *WS*, and the threshold value, *ThV*.

4.1 Optimization Methodology

The experiments, carried out with a UWB signal corresponding to the chest movement of the patient, have two main objectives. First, is to evaluate the parameters that produce the best accuracy of the apnea detection method. Second, is to identify the parameters with shortest processing time.

The proposed optimization methodology essentially consists of a parametric multidimensional search based on actual physical measurements. Each execution of the searching process begins with the values of two parameters fixed, *WL* and *WS*, and the threshold value varied. Once the whole process of detection over the signal is carried out, a new execution is run by fixing *WL* and *WS* to new values and then varying *ThV*. The executions are repeated by modifying the parameters until their ranges of variation are covered. For each execution, the values of the parameters, the number of detected apneas, and the processing time are saved.

4.2 Optimization Results

The set of experiments are performed over five signals presenting different characteristics. Each signal corresponds to a series of around 750 realizations, lasting 94 seconds in total. As a reference for the experiments, the average breathing frequency of a patient is considered to be 0.2 Hz or 5 seconds. Parameter ranges considered are: for the window length *WL*, from 4 realizations, which represents 0.5 seconds, to 128 realizations, corresponding to 16 seconds; for the window step WS, from 1 realization to the maximum length of the window; and for the threshold value *ThV*, from 1 to 10. This makes a total of 18,544 combinations of parameters tested for each signal.

Table 1: Number of combinations of parameters that produced correct detections.

Signal Characteristics		Number of Correct Detections
Number of Apneas	Distance between the UWB Transceiver and the Patient (cm)	
0	60	17,731
1	20	1,291
1	30	2,383
2	30	1,564
1	80	866

The difference between the signals used in the experiments are the number of apneas and the distance between the UWB transceiver and the patient. Table 1 shows the characteristics of the signals and the number of combinations of parameters that presented a correct detection out of the 18,544 possible combinations. We analysed all the results for each signal, and compared them in order to identify the ranges of common values of combinations of parameters that presented correct detections.

The first signal used had a length of 85.63 seconds with zero apneas and a distance between the UWB device and the patient of 60 cm. A total of 17,731 combinations correctly detected the absence of apneas. The highest number of correct results were produced for combinations of parameters that comprise the following values: *WL* from 16 to 40 realizations, *WS* varying from 10 to 27, and *ThV* from 1.5 to 10.

The second signal used had a length of 81.3 seconds with one apnea and a distance of 20 cm. The number of combinations that detected correctly the apnea is 1,291. Table 2 shows, as an example, a subset of the parameters with the highest number of correct detections. It is seen that the range for the *WL* parameter is from 8 to 40 realizations, the *WS* range is from 8 to 19, and the value of *ThV* varies from 1 to 10.

The third signal had a length of 113.4 seconds. It has one sleep apnea and an acquisition distance of 30 cm. The number of correct detections is 2,383 combinations. The subset of parameters with the highest number of correct detections has a value range of *WL* from 16 to 40, the *WS* range is from 11 to 15, and the *ThV* maximum range is from 1 to 10.

The fourth analyzed signal had a length of 89.5 seconds, with two apneas, and an acquisition distance of 30 cm. The total number of combinations producing correct detections is 1,564 (see Table 1). In this experiment, the subset of parameter combinations with the highest number of correct detections corresponds to *WL* with a range from 16 to 40 realizations, *WS* from 9 to 17, and *ThV* with a variation from 1.5 to 8.

Finally, the fifth signal had a length of 118.3 seconds, with one apnea, and an acquisition distance of 80 cm. In this experiment, the total number of correct detections is obtained from 866 combinations. The range of *WL* is from 48 to 72 realizations, *WS* varies from 8 to 40 realizations, and the *ThV* range is from 1.5 to 6. In this case, it is found that the ranges of parameters values stepped away from the group of values obtained in the previous results.

The few coincident results of the fifth signal, in comparison with the first four signals, show that the distance has an important effect in the detection algorithm. In addition, it is also observed that the number of correct detections decreased by half. In this case, we cannot define a range of parameters values good enough for all tested signals. We conclude that the signal tested at a distance of 80 cm is not suitable for the proposed algorithm, since it makes the algorithm unreliable.

Taking into account the results obtained for the first four signals, we can determine an appropriate set of reliable values, valid for all four signals. This set comprises a *WL* equal to 24, a *WS* ranging from 12 to 15 realizations and a *ThV* range from 2 to 4.5. This means that these selected values can be used for the detection of apneas within the first four signals. On the other hand, it can easily be found that, for a fixed value of parameter *WL*, the minimum number of operations to be computed is obtained when the value of *WS* is the largest. We can then define that the WS value to be used for all tested signals is 15. In summary, we conclude that a set of values that allows the detection algorithm to have a good performance with the least number of calculations, is a *WL* of 24, a *WS* of 15 and a range *ThV* from 2 to 4.5.

Table 2: Detection results for several parameters using a signal with one apnea, acquisition distance = 20 cm, and length = 81.3 seconds.

PARAMETERS		
WL	*WS*	*ThV* Range
8	8	2.5 – 10
16	8	6 – 10
16	9	3.5 – 4.5
16	10	1 – 9
16	11	1 – 4.5
24	12	1 – 4.5
24	13	1 – 6.5
24	14	1 – 6
24	15	1 – 5
24	16	1 – 5.5
32	13	1 – 5
32	14	1 – 5
32	15	1 – 4.5
32	16	1 – 4.5
32	17	1 – 2.5
40	15	1 – 4.5
40	16	1 – 4
40	17	1 – 3.5
40	18	1 – 4.5
40	19	1 – 4

5 CONCLUSIONS

An algorithm to detect sleep apnea using the relation of the variance of signals obtained from a UWB transceiver was presented in this paper. It was demonstrated that the algorithm detects sleep apnea with a maximum distance of 100 cm between the UWB device and the patient. The experiments also showed that the algorithm is able to detect sleep apnea considering different scenarios, with some limitations.

An optimization methodology to improve the detection was also presented. The experimental evaluation allowed the identification of the combinations of parameters that produce the best results and the smallest number of operations. The parametric optimization of the algorithm showed that the best detection results were achieved by using a *WL* of 24 realizations, *WS* of 15 realizations, and a *ThV* between 2 and 4.5. It was also found that the detector was not accurate at a distance of 80 cm between the UWB device and the patient.

ACKNOWLEDGEMENTS

This work was supported in part by CONACYT (Consejo Nacional de Ciencia y Tecnología, Mexican Government) through a scholarship granted to J. G. Servin-Aguilar.

REFERENCES

World Health Organization (2014. Nov. 03), *Chronic diseases and health promotion*. [Online]. Available: http://www,who.int/chp/en

World Health Organization (2018. Jul. 30), *Noncommunicable diseases and their risk factors.* [Online]. Available: http://www.who.int/ncds/en.

World Health Organization (2015. Jan. 29), *Datos interesantes acerca del envejecimiento.* [Online]. Available: http://www.who.int/ageing/about/facts/es/.

Hou, H., Xu, Y., Yan, H., Mubben, S., and H. Zhang, 2009. An elderly health care system using wireless sensor networks at home. In *SENSORCOMM Conf*. Glyfana, Athens.

World Health Organization (2017, Mar. 10), *Obstructive sleep apnoea syndrome.* [Online]. Available: htttp://www.who.int/respiratory/other/Obstructive_sleep_aponea_syndrome/en.

Varady, P., Bongar, S., and Benyo, Z., 2003. Detection of airway obstructions and sleep apnea by analyzing the phase relation of respiration movement signals. In *IEEE transactions on Instrumentation and Measurement*.

American Academy of Sleep Medicine (2017, Mar. 10), *New guideline for diagnostic testing for adult sleep apnea.* [Online]. Available: http://www.aasmnet.org/articles.aspx?id=6792.

Guyton, A.C., and Hall, J. E., 2011. *Tratado de Fisiología Médica, doceava edición*, México: Elsevier Sauders.

MedlinePlus (2017, Mar. 10), *Sleep Apnea*. [Online]. Available: https://medlineplus.gov/sleepapena.html.

Waters, J. R., and LaCourse, J.R., 2009. Unconstrained and non-invasive respiration monitoring for obstructive sleep apnea prevention. In *2009 IEEE 35th Annual Northeast Bioengineering Conference*, Boston, MA.

Lai Eason, J. C. Y., Xu, Y., Gunawan, E., Chua, E. C-P, Maskooki, A., Guan, Y. L., Low, K-S., Soh, C. B., and Poh, C-L, 2011. Wireless Sensing of Human Respiratory Parameters by Low-Power Ultrawideband Impulse Radio Radar. In *IEEE Transactions on Instrumentation and Measurement*.

Fedele, G., Pittella, E., Pisa, S., Cavagnaro, M., Canali, R., and Biagi, M., 2015. Sleep-Apnea detection with UWB Active Sensors. In *2015 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB)*, Montreal, Canada.

Abib, G. I., Muller, M., Seoane-Gomez, C., and Fernandez-Sepulveda, P., 2014. Ultra-Wideband Radar system for range measurement. In *2014 IEEE International Conference on Ultra-WideBand (ICUWB)*, Paris, France.

Muller, M., and Abib, G. I., 2015. Ultra WideBand Radar system for human chest displacement. In *2015 IEEE 13th International New Circuits and Systems Conference (NEWCAS)*, Grenoble, France.

Pardiñas-Mir, J. A., 2012. Contribution à l'etude de la detection des signaux UWB. Etude et implementation d'un récepteur ad hoc multicapteurs. Applications indoor de localisation, These de Doctorat, EDITE de Paris, Paris, France.

Taylor, J. D., *Ultra-Wideband Radar Technology*, 2000. US: CRC Press.

Leon-Garcia, A., 2008. *Probability, Staticstics, and Random Process for Electrical Engineering*, Third Edition, US: Pearson Prentice-Hall.

Servin-Aguilar, J. G., Muller, M., Abib, G. I., Pardiñas-Mir, J. A., and Rizo-Dominguez, L., 2018. System to Detect Sleep Apnea Syndrome Using the Signal Similarity. In *Int. Conf. Electrical, Electronics, Computers, Communication, Mechanical, and Computing (ECCMC)*, Tamil Nadu, India.