Radar Assistive System for People with Neurodegenerative Disorders Through Head Motion and Eyes Blinking Detection

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***Abstract*—The world is witnessing a dramatic increase of the number of neurodegenerative pathologies along with improving living conditions and increasing life expectancy. One of the main consequences of neurodegenerative diseases consists of making the patient paralyzed and finally unable to communicate with others. An accepted solution to enable the communication is based on the detection of a body part motion which can be interpreted as a command. In this paper, a microwave Doppler radar is employed to accurately detect specific and intentional movements of the body, in detail head motion and eyes-blinking. Both displacement and micro-Doppler signature measurements are exploited to accurately recognize intentional motions to send commands. A suitable solution to avoid motion artifacts due to the physiological movements of the subject is shown. This work will demonstrate the effectiveness of radar-based solutions as assistive systems for enabling the patients to express their basic needs.**

***Keywords*— microwaves, Doppler radar, dementia, neurodegenerative diseases, assistive devices, biomedical applications.**

I. Introduction

The number of people affected by neurodegenerative disorders is dramatically increasing in the last decades. As an example, people affected by dementia pathologies are estimated at 55 million in 2019, with an expected increase to 139 million in 2050, according to the World Health Organization (WHO) report drawn up in 2022 [1]. This can be probably attributed to the improvement of the life conditions and the related increase of the life expectancy. Such a kind of condition has profound physical, psychological, social, and economic impacts, not only for the subjects, but also for relatives and caregivers [2, 3]. One of the main consequences related to both the neurons death and the progressive paralysis of the body, concerns the inability of the subject to communicate by speaking. This is of course a very critical aspect, not only for the act of communicating in itself, but also to express basic needs as the feeling of hunger and thirst.

This scenario has fueled the research activities to find new solutions for making the subjects able to communicate. A limited number of products are already available on the market or within the scientific literature, but the field is far from being mature and a great scientific effort is still required. All the assistive devices are based on the consideration that the last part of the body being paralyzed is the head. Therefore, one of the most employed strategies consists of detecting the intentional movement of a body part, e.g., head motion or eyes-blinking, and translating the movement to a command for an assistive system [4]. A movement can be coded to be considered intentional and not due to the normal physiological motions, e.g., two or three consecutive eyes-blinking can be easily separated from a single physiologic eye-blinking.

To this purpose, different existing systems are based on acquiring and analyzing images with cameras or exploiting electrooculography (EOG) and electroencephalography (EEG) to analyzes the brain signals, as it is the case of the eye movement tracking [5, 6]. However, they are affected by a large probability of error and low immunity to surrounding conditions. As an example, it is well-known that camera-based systems are characterized by a strong dependence on the light conditions [7]. Moreover, they can raise privacy concerns, making this technology barely appealing for domestic environments. EOG- and EEG-based systems have the peculiar capability to recognize the ocular movement by exploiting brain signals, but they require contact electrodes placed on the head of the subject. For this reason, such contact sensors are considered quite invasive for the user's comfort.

In this context, we are assisting to an impressive growth of biomedical applications developed by exploiting radar systems [8-10]. Among the main known advantages of the radar technology, it is possible to mention the capability to provide advanced features as measuring sub-millimeter displacements and micro-Doppler signatures. These tasks can be accomplished with high accuracy, by preserving the privacy of the user, and ensuring a high integrability with the standard technologies. Finally, radar systems are very robust and reliable against different light and weather conditions [11]. Some examples of radars employed to recognize eyes-blinking and above all head movements can be found in the scientific literature [12-16]. As an example, the head motion detection is exploited to recognize inattentive driver behaviors, [15], [16].

In this contribution, the authors propose a radar-based system able to detect intentional head movements and eyes-blinking performed by users affected by neurodegenerative pathologies [17]. These movements can be interpreted as intentional commands for an assistive system. This task is fulfilled by measuring the micro-Doppler signature and displacement resulting from the activity of the subject and by subsequently recognizing the movements of interest. The immunity of the solution from the physiological activity is analyzed to demonstrate the effectiveness of such a kind of technology in real applications.

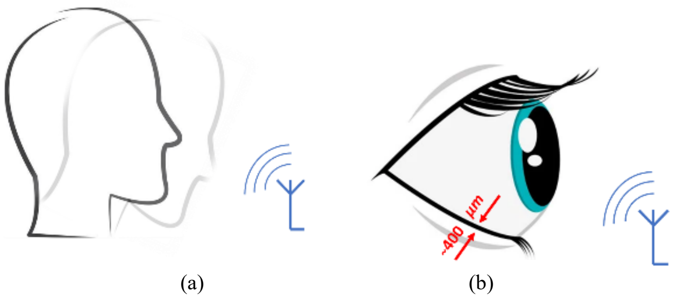


Fig. 1. Graphical representation of the movement of interest, in detail: (a) head motion and (b) eye-blinking.

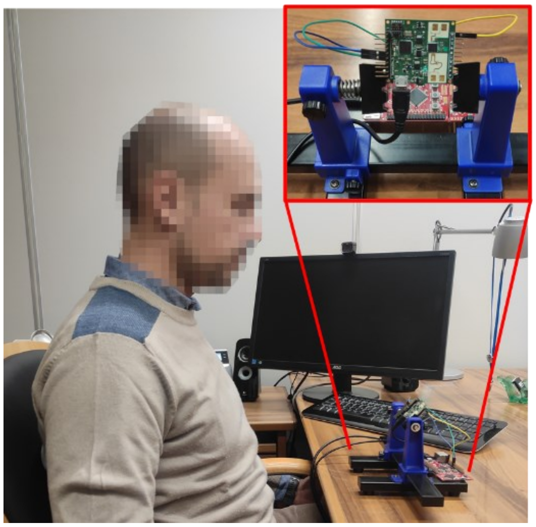


Fig. 2. Picture of the measurement setup.

The immunity of the solution from the physiological activity is analyzed to demonstrate the effectiveness of such a kind of technology in real applications. A cost-effective 24 GHz Doppler radar is exploited to test the proper operations of the system without requiring expensive hardware components. As an example, camera-based solutions usually require very high-performance cameras to obtain a proper resolution.

The reported tests show the successful detection of both the range shift due to the head motion and the eyelid thickness, that usually range up to tens of centimeters and hundreds of micrometers, respectively.

The applicative field of this system can be also extended to other human-computer interaction applications where radar-based systems compete with camera-based devices. In the field of healthcare services, contactless commands based on the body motion can be exploited to allow a paralyzed subject lying on the bed to switch off/on the light or remotely control the electric shutters or to ask for help.

II. System Working Principles

The main purpose of this contribution consists of detecting intentional movements performed by the user to be interpreted as commands. As graphically represented in Fig. 1, the movements of interest are the head motion and the eyes-blinking.

Doppler and frequency-modulated continuous-wave radars are among the most employed radar techniques for short-range applications. Since the range information are not of interest in this context, the Doppler radar technique has been selected, due to its great sensitivity and effectiveness for very small displacement detection [18]. Doppler radars often exploit an In-phase and Quadrature (*I/Q*) demodulator. The expression of the beat signal $s_{\mathrm{b}}(t)$ at its output is reported in (1).

$$s_{\mathrm{b}}(t) = \sigma_R \, e^{j\left(\phi_1 \pm \frac{4\,\pi x(t)}{\lambda}\right)}. \tag{1}$$

where σ_{R} is the signal amplitude, $x(t)$ is the range shift due to the relative radial motion between the radar and the object, λ is the wavelength calculated at the radar operating frequency and ϕ_1 is the residual phase which can be calculated as in (2).

$$\phi_1 = \frac{4\,\pi\,R_0}{\lambda} + \phi_0. \tag{2}$$

where R_0 is the range of the target and ϕ_0 is the initial phase.

By exploiting (1), it is possible to extract the term $x(t)$ which can be exploited to estimate the range shift due to the head motion or eyes-blinking. Moreover, the phase of the beat signal can be employed to obtain the micro-Doppler signature. This can be accomplished by implementing the Short-Time Fourier transform (STFT) on the received data, i.e., performing different FFTs on the range matrix within short and overlapped time windows. Both the range shift and the micro-Doppler signature might be exploited in this context. However, in Section 3, the pros and cons of each solution will be highlighted, depending on the case of interest.

III. Experimental Setup and Results

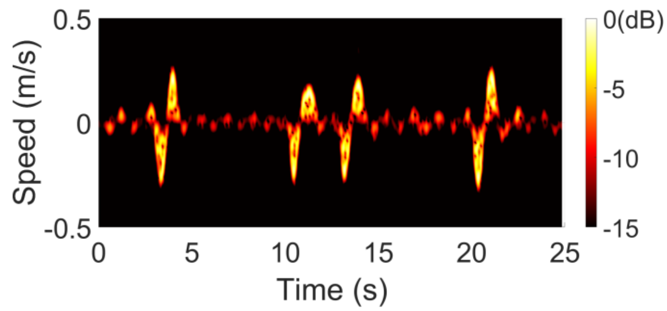
To investigate the system effectiveness, the experimental setup shown in Fig. 2 has been set. The radar system is placed at the distance of 40 cm from the subject and points towards his head and works in Doppler mode within the 24 GHz ISM band. It is composed by a commercial microwave board based on the Infineon BGT24MTR11 transceiver [19]. The board includes also the antennas, the low-frequency amplification stages and a microcontroller unit (MCU) able to set the main radar working parameters and to perform the analog-to-digital conversion (ADC) of the raw I/Q data. Even though the board is equipped with an UART interface able to send the data to the laptop, its maximum throughput seriously limits the maximum detectable speed v_{max}, according to (3).

$$v_{max} = \frac{\lambda}{4\,T_m} \tag{3}$$

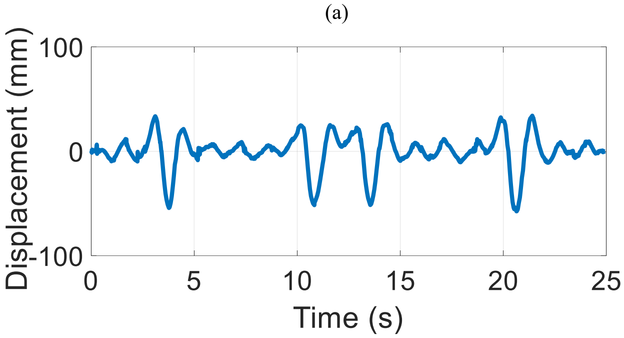
where T_m is the time interval between two measured I/Q couples.

Therefore, the built-in interface has not been used. To improve the maximum detectable speed, a custom ADC interface has been developed by exploiting an MCU board based on the Infineon XMC4500 ARM® Cortex™-M4F microcontroller [20]. With the current system setup, it allows to measure target speeds up to 31 m/s.

As anticipated, the main task of the system is to measure intentional head movements and eyes-blinking to be translated into commands. Separating the subject's physiological activity from the movements of interest is one of the main challenges to be addressed.



(a)



(b)

Fig. 3. (a) Micro-Doppler signature and (b) displacement associated to the head motion.

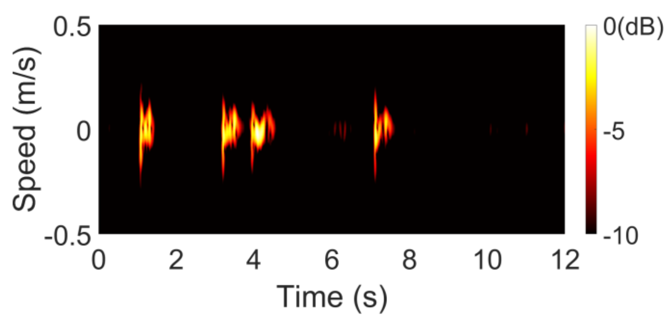


Fig. 4. Micro-Doppler signature due to the eyes-blinking during diaphragmatic breathing.

The respiratory act of a healthy subject breathing normally is called diaphragmatic breathing. It is a mode of breathing that requires the diaphragm contraction. As a consequence of the diaphragm relaxation, the air passively comes out of the lungs. This kind of breathing mode is also known as deep breathing. During diaphragmatic breathing, the head should not move at all as a consequence of the respiratory activity and all the related body movements should be confined to the chest level.

On the other hand, a healthy subject might also have a costal breathing and requires the contraction of the intercostal muscles in addition to the diaphragm. In this case, the air leaves the lungs because of the intercostal muscle relaxation. This kind of breathing mode is also known as shallow breathing.

In this case, the head moves as a consequence of the intercostal muscle movements, and the effect of the breathing activity during the head motion detection is clearly visible. This circumstance can be observed from Fig. 3a, where the micro-Doppler signature due to both the breathing activity and the head movement can be clearly recognized. In detail, the head motions, i.e., the head moving toward and away from the radar, are visible at 4 s, 11 s, 14 s, and 20 s. The two head movements in the middle of the figure are intentionally consecutive, thus they can be separated from the non-intentional head motions due to other factors. However, due to the larger effects of the head moving forward and backward, the alternating positive and negative Doppler signature due to the respiratory activity does not affect the effectiveness of the measurement.

In Fig. 3b, the related measured displacement is reported. It is possible to observe the different range shifts due to the head and chest motion. Also from this figure, the head motions can be clearly recognized. More challenging is the case of the eyes-blinking detection, whereby the different range shift due to the eyelid thickness when the eyes are closed compared to the case of open eyes should be measured. In Fig. 4, the eyes-blinking detection during diaphragmatic breathing is shown. Since in this case the effects of the breathing activity on the head motion are very limited, the eyes-blinking at 1 s, 3 s, 4 s and 7 s can be clearly recognized. Once again, the eyes-blinking are repeated twice at 3 s and 4 s, to simulate an intentional command.

On the other hand, it is worth investigating if costal breathing can affect the eyes-blinking detection. Indeed, the extent of the head motion as a consequence of the breathing, can be higher than the eyelid thickness. This issue is even more relevant for this specific application, where the subjects are affected by body paralysis. Indeed, a subject affected by neck and upper limb musculoskeletal disorders, as it is the case of this contribution, can lose the natural supporting function of the neck, thus making the effect of the breathing activity on the head more evident. Costal breathing, e.g., arising either from costal respiration or musculoskeletal disorders, can seriously affect the measurement. As it can be inferred from Fig. 5, in this case performing a displacement measurement is not a proper choice to detect the eyes-blinking. Indeed, Fig. 5 shows the displacement related to a measurement whereby eyes-blinking are present at 2 s, 6 s, 7 s and 10 s, as indicated by the red arrows. However, the different displacement due to the eyelid thickness cannot be recognized in the figure, due to the greater extent of the range shifts compared to the breathing activity. As a matter of fact, the expected eyelid thickness is in the order of hundreds of micrometers, usually 300 µm-500 µm.

On the other hand, it is interesting to observe that, despite the low thickness of the eyelids, the eyes-blinking is characterized by higher peak Doppler speeds compared the breathing activity. This can be very beneficial to separate the eyes-blinking from the breathing activity by exploiting the micro-Doppler analysis. The detection effectiveness can be verified from Fig. 6, where different micro-Doppler components due to the eyes-blinking during costal breathing can be recognized due to the longer Doppler strips. The white arrows indicate the eyes-blinking at 2 s, 6 s, 7 s and 10 s. This is a very interesting result, since demonstrates that the micro-Doppler signature can be exploited to detect both the head motion and the eyes-blinking as key elements to make a user able to communicate.

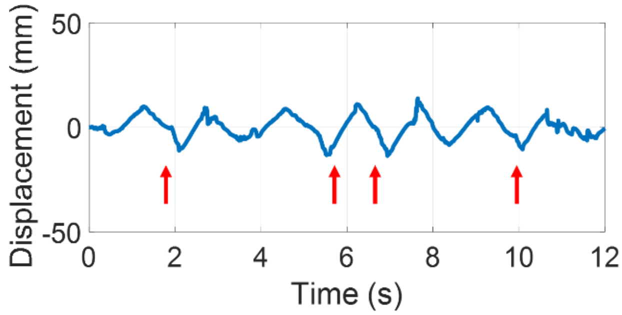


Fig. 5. Displacement due to costal breathing and eyes-blinking during. It is not possible to notice the eyes-blinking occurring in the points indicated by the red arrows, at 2 s, 6 s, 7 s and 10 s.

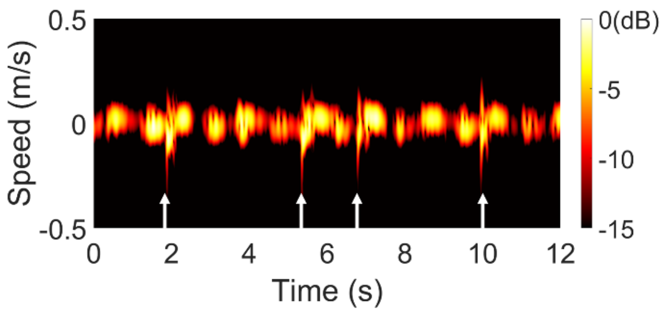


Fig. 6. Micro-Doppler signature due to the eyes-blinking during costal breathing. The white arrows indicate the eyes-blinking at 2 s, 6 s, 7 s and 10 s.

IV. Conclusion

In this paper, a 24-GHz Doppler radar has been exploited as assistive device for people affected by neurodegenerative disorders. In detail, the micro-Doppler signature and the displacement related to the head motion and eye-blinking have been exploited. The user can take advantage of the detection of these intentional movements to communicate needs or to send commands to an assistive device. The reliability of the system in presence of unwanted head movements due to costal breathing activities has been demonstrated, identifying the micro-Doppler signature detection as the best technique to obtain the desired information in such a delicate context.

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