THE PUBLISHING HOUSE
OF THE ROMANIAN ACADEMY

PROCEEDINGS OF THE ROMANIAN ACADEMY, Series A,
Volume 17, Number 1/2016, pp. 90–98

A WEARABLE SYSTEM FOR TREMOR MONITORING AND ANALYSIS

Marius HAGAN[1], Oana GEMAN[2]

[1] SC Flow Meter SRL, R&D Department, Iaşi, Romania
[2] "Stefan cel Mare" University of Suceava, Department of Health and Human Development, Romania
Corresponding author: Marius HAGAN, E-mail: marius.hagan@gmail.com

Abstract. This paper presents results demonstrating the usefulness of intelligent clothes in tremor analysis. A dedicated robe with a recently proposed capacitive sensor suite was designed in order to gather tremor data of the neck movements, inserting capacitive electrodes in the collar of the robe. The tremor data were sent in real time via an RF connection to a computer and processed. An accelerometric sensor mounted in the cervical zone in the robe produces supplementary information. The FFT analysis revealed the presence of the tremor in the spectrum.

Key words: intelligent clothes, tremor analysis, capacitive sensors, FFT analysis, capacitive to number convertors, neurological disorders, painted sensors.

1. INTRODUCTION

Neuropsychological dysfunction affects more than 160 million Europeans, representing 38% of the population, according to the report presented by National Parkinson Foundation (NPF) [17] and WHO [29]. Parkinson's and Alzheimer's diseases cause important disabilities [29]. According to NPF [17], in the United States, 50,000–60,000 new cases of Parkinson's disease (PD) are diagnosed each year, adding to the one million people [16] who currently have Parkinson's disease. The Centre for Disease Control evaluated complications from PD as the 14th leading cause of death in the US [16]; worldwide, it is estimated that four to six million people suffer from PD. It is estimated that in Romania there are approximatively 75.000 patients with PD.

Establishing an accurate diagnosis in the early stages of PD is difficult. Less than 75% of patients are correctly diagnosed with PD within a few years since the onset, the rest being diagnosed too late or undiagnosed [29], hence the importance of new, affordable tools for early diagnostic, as the one proposed in this paper. Keeping the patient under observation for a certain period of time to evaluate the severity of symptoms helps the differential diagnosis between Parkinson's disease and other similar diseases. An early sign that may indicate PD is invisible hand tremor. The tremor is often most prominent when the affected person is active or is maintaining a particular posture. Cerebellar tremor may be accompanied by other manifestations of ataxia, including dysarthria (speech problems), nystagmus (rapid, involuntary rolling of the eyes), gait problems and postural tremor of the trunk and neck [17].

Numerous researchers have contributed to the development of devices and tools for analysis and early diagnostic of movement disorders such as those resulting from Alzheimer, PD, and epilepsy, with the purpose of improving the coordination of movements. This research topic is already several decades old [27], yet no satisfactory progress has been made. In the treatment direction, mainly that of invasive prostheses, Deep Brain Stimulation (DBS) and the related signal processing methods to support DBS involved numerous techniques [7–11] and has seen significant progresses in efficient treatment. In a newer direction, wearable devices were developed especially for tremor monitoring (see the reviews [18, 20, 5, 21, 22] and the critical assessment of the state of the art by [19]) and for monitoring various other parameters, such as the patient body position and ECG signals [14]. Various solutions were proposed for monitoring tremor, most of them based on accelerometers and gyroscopes placed on the limbs [15, 3, 23]. While accelerometers are nowadays very small and can easily be incorporated into clothes, they have the disadvantage, when included in the clothes, of measuring the clothes movements, instead of determining the displacement of the limbs inside the clothes. This produces large errors when the clothes are not tight on the body. The use of accelerometers placed directly on the body, on the other side, is obtrusive, for example when the monitored part of the body is the head. Other solutions [4, 5] used combinations of "wireless IR motion sensors network distributed in the room of the patient" in combination with accelerometric modules fixed on the skin to monitor abnormal movements and falls. The system is costly, obtrusive, and not appropriate for PD monitoring. Other approaches used intricate combinations of accelerometers, IR sensors and ultrasonic sensors [5]. This unsatisfactory situation in the field of tremor sensing conducted to research in other types of sensors that overcome these disadvantages. In [24], a new wearable capacitive sensor was proposed, which can be included in the clothes and indicate the relative displacement between the body parts and the sensor. That type of sensor is also suitable to operate in conjunction with new capacitance-voltage converters, as demonstrated in [13]. However, the realization of that sensor in the version described in [24, 13] proved to be unreliable, with the conductive paint used to make it producing faults after a few weeks of operation. In addition, the circuit solutions presented in [24, 13] are too simple for advanced tremor monitoring, which requires networks of sensors instead of single ones and improved precision.

In this paper, we propose a system using a network of sensors of the type described in [13] with improved performances and high reliability and analyze in detail the system characteristics. The sensor network includes several capacitive sensors and an accelerometer; it achieves good reliability and precision and large enough bandwidth for quality acquisition. This study performs a thorough analysis of the properties of the wearable sensors, including the determination of perturbations picked up during normal operation on clothes. The paper is organized as follows. In Section 2, the design of the wearable sensors and acquisition system are explained. Section 3 presents examples of sensor operation analysis and results of operation. The last section discusses the results and presents conclusions.

2. DESIGN OF THE MONITORING DEVICE

2.1. MONITORING WEARABLE DEVICE CONFIGURATION

Medical wearable devices have applicability in preventive medicine, health supporting monitoring and individual "coaching" [1–6], being used in a daily activity. The wearable devices, used as discrete objects being attached on human limbs or body, are widely encountered as results of research activities as experimental models or prototypes. The PERFORM System, described in [3] is such example representing a platform dedicated for PD remote monitoring and management. A drawback of this system is that the sensors are mounded individually on the person's limbs and for head tremor monitoring, it is difficult to attach a sensor on the neck. SDAND (System Dedicated to Assess some Neurological Disorders) [12] is another example of device that acquires the tremor of the hand; it uses tremor correlation with the palmar pressure [13]. We propose to remove such disadvantages proposing a sensors network based on the interdigital capacitive sensor demonstrated in [13, 24]; that type of sensor is easily and unobtrusively incorporated in the clothes.

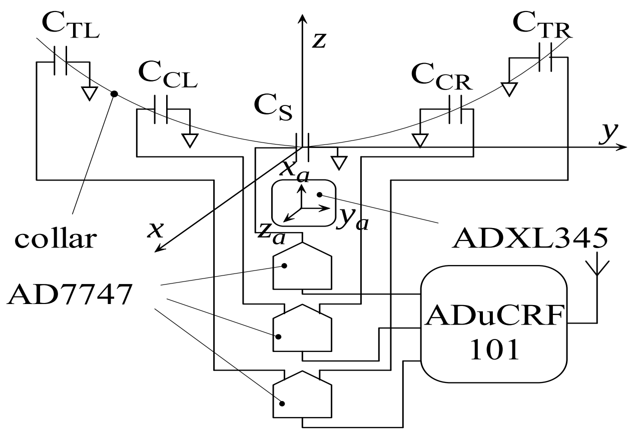


Fig. 1 – Wearable devices block scheme.

Intelligent clothes are the most convenient way of monitoring the movement and tremor of the human body, unobtrusively. We name intelligent clothes those incorporating wearable sensors, interfaces, processing units and communication peripherals that can communicate with other systems, possibly connect to IoT (Internet of Things) networks [6]. The human body parts which could be monitored for PD with the proposed sensor network are the hands, the legs, the trunk and the neck.

The capacitances electrodes are painted directly on the collar with a dye based on silver, in a first experimental model implementation. The capacitances are converted in numerical values through AD7747 capacitance-to-number convertors. The capacitance arrangements are configured in order to detect neck rotations in a Cartesian coordinates system: *Cs* detects head rotation in the sagittal plane; CCL – CCR is a differential capacitance and it detects head rotation in the frontal plane; CTL – CTR is a differential capacitance and it detects head rotation in the transversal plane (Fig. 1). The AD7747 capacitance-to-number circuit measures the capacitance value taking the ground as a reference. We adopted this solution instead of AD7746 to avoid the influence of an active reference on the increasing of measurement nonlinearity [2].

2.2. THE CAPACITIVE SENSORS

An interdigital configuration was adopted in order to realize a capacitance that is applied directly on the textile. These types of sensors have already been used in the experimental stage as movement sensors, being manually painted with a paint based on graphite and water solvent as described in [3]. According to [24, 28], the capacitance of the interdigital capacitors is given by the approximate formula

$$C[pF] = \frac{\varepsilon_r + 1}{W} \cdot l \cdot \left[(N-3)\cdot A_1 + A_2\right], \tag{1}$$

where $A_1 = 8.85 \cdot 10^{-12} w$, $A_2 = 9.92 \cdot 10^{-12} W$, W is the overall width of the electrodes (*i.e.*, $N(s+w)$), and l is the lengths of the digits, both measured in centimeters. The formula is not appropriate for the case we discuss, because it assumes very thick substrates h compared to the distance between digits (strip spacing), s, $h/s > 100$. The formula also assumes very small values of s, of the order of microns. A more precise formula is given by Bahl [2] (equ. 7.7b). For details on the behavior of the sensor at low frequencies, see [24].

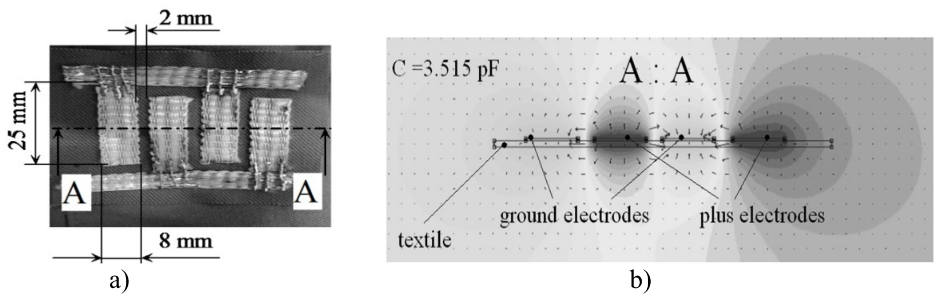


Fig. 2 – Interdigital capacitive sensor; implemented version with metallic braid (a) and electric field intensity of the sensor electrodes – simulated with Beladraw™ 1.0 software (b).

In the first experimental model, the interdigital capacitive sensor was realized with a paint based on silver, as in [12, 13, 24]. A drawback of this sensor is the rigidity of the paint layer that determines the interruption of conductivity when the sensor is bent. In another experimental model, a metallic braid was glued on the textile in an interdigital configuration. In this case, an elastic and robust sensor resulted (Fig. 2a).

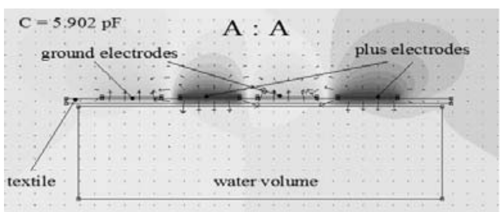


Fig. 3 – The capacitive sensor detection of an object with water in its composition (Beladraw 1.0 simulation).

Unlike the plane capacitor, where the electrodes are positioned in parallel planes, in case of interdigital capacitor the electrodes are placed in the same plane, its longitudinal axes being parallel. The electrodes are intermediaries one by one with different polarity, between two adjacent electrodes is generated an irregular electric field (Fig. 2b), the electrical field lines cross the environment around the electrodes. The capacitance value is determined by the electrodes surfaces, by the distance between electrodes, by the number of electrodes and by the environment electric permittivity. When an object is close to the sensor the capacitance value is increasing proportional with the electric permittivity of the object. A simulation of the interdigital capacitive behavior was performed using Beladraw™ 1.0 software (**B**asic **El**ectrostatic **A**nalysis software package). The configuration of the capacitor presented in figure 2a was modeled, respecting the dimensions. The value of the capacitor resulted as 3.515 pF (Fig. 2b), the environment of the capacitor being the air.

An object that has water in its composition placed near to sensor at a distance of about 2 mm (Fig. 3) significantly increases the electric permittivity value of the sensor environment and has as effect the increasing of the interdigital capacitor value (C = 5.902 pF). The measurement of the interdigital sensor was performed connecting it to the positive input of AD7747 CDC, the negative input remaining disconnected. The measured capacitive value is 3,645 pF that is very close to the capacitive value resulted from simulation (3.515 pF, Fig. 2b). With the sensor mounted on the collar, when the robe was worn, the maximum capacitive value was measured, with the head thrown back (in sagittal plane), this value being 5.134 pF, also very close to the capacitive value resulted from simulation that is 5.902 pF (Fig. 3).

2.3. MONITORING WEARABLE DEVICE IMPLEMENTATION

The capacitive sensors were painted directly on [24] or attached to the collar of the robe (Fig. 4 and Fig. 5) and were connected to the inputs of capacitive to number convertors. The sensor 3 detects the neck movement in the sagittal plane. The sensors 1 and 5 are connected in differential mode and so they are able to detect the neck movement in the transversal plane. The sensors 2 and 4 are also connected in differential mode and are dedicated to neck movement in the frontal plane.

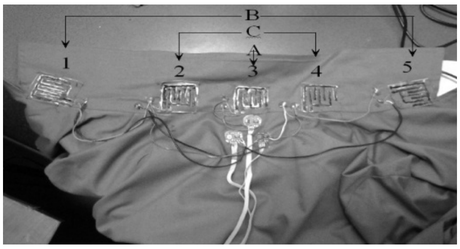


Fig. 4 – Wearable devices implementation example: an experimental model shown with the sensors exposed.

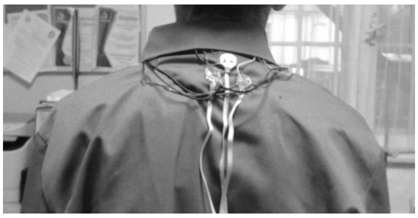


Fig. 5 – Robe being worn by a human subject, shown with the sensors and circuitry exposed.

Capacitive and accelerometric data are gathered through I2C interface in the local RAM memory vectors of the microcontroller; afterwards, the data are sent by the RF module to a concentrator which is connected to a computer, being saved in a text file on six columns. The data rate is 30 SPS being limited by the RF baud-rate. In parallel with capacitive data also the accelerometric data are gathered from ADXL345 accelerometric sensor, following the method in [26]. The objectives of the experiments are to determine the response of the sensors while a person is wearing the robe. The first case of data acquisition was performed with the robe standing on a table in order to detect sensor noise. After that, the data was gathered with the robe being worn by a human subject for several cases: in a standing position, moving the head in three planes (sagittal, frontal and transversal), and moving the hands in the frontal plane.

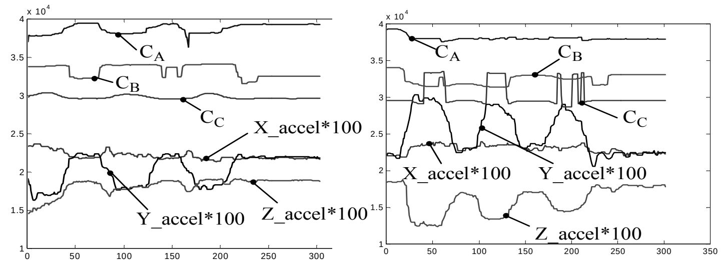
3. RESULTS

3.1. ROLL-PITCH-YAW NECK MOVEMENTS

The capacitive sensors network should be able to detect the individual rotation of the neck: pitch-roll-yaw, respectively: the pitch movement – the rotation of the neck in the frontal plane, the roll movement – neck rotation in the transversal plane and the yaw movement – neck rotation in the sagittal plane. The acceleration sensor is responsible for the trunk position and movement but it will also detect neck movement as an effect of trunk movement.

3.2. DETECTION OF THE LIMB MOVEMENTS

Hands movements and walk are perceived by the capacitive and accelerometer sensor as displacements of the robe relative to the neck.



a) b)

Fig. 6 – Sensors signals for hands movements.

The movement of the left hand in the frontal plan (down to top displacement of the hand) determines variations of all capacitive values (Fig. 6a–b). Unfortunately, the movements of the limbs, if not detected with sensors on the limbs, as in [13], become perturbations for the signals generated by the neck and head displacements. This drawback must be eliminated in the future by a combination of sensors on the neck (shirt /cloth collar as described here) and the limbs and the correlative processing of the respective signals.

3.3. FFT ANALYSIS OF NOISE SIGNALS

The system may be vulnerable to perturbations picked up by the relatively large capacitive sensors. We checked if such perturbations and system's noise are hampering the system operation under laboratory conditions. Figures 7 (a–d) presents for comparison the FFTs of the noise signals when the robe is worn by a subject in the standing position, respectively with the robe not warn put on a laboratory table. Notice in Figs. 7b and 7d the presence of the perturbations picked from the mains through the capacitive coupling via the subject.

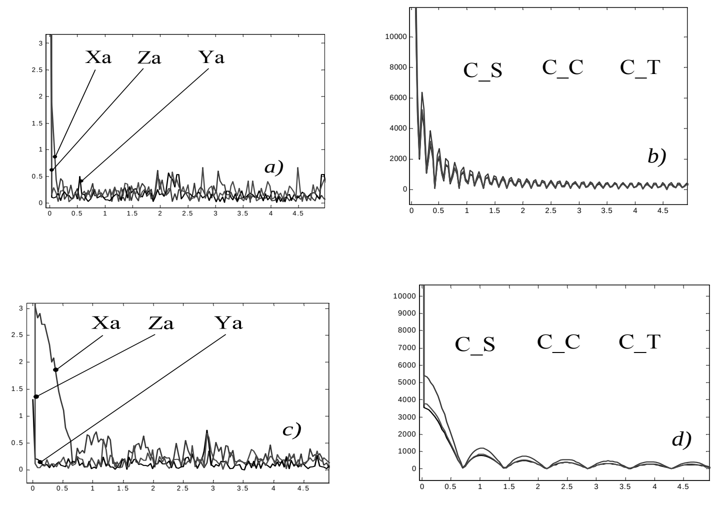


Fig. 7 – FFT of the noise signals in two cases: with the robe standing on the table (left, a and b) and with the robe worn by a human subject, in a stand position (right, c and d).

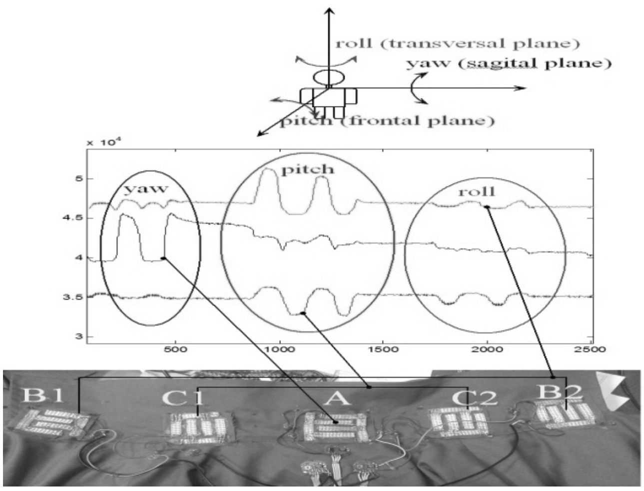


Fig. 8 – Sensors responses to roll, pitch yaw particular movements of the head.

3.4. PARTICULAR MOVEMENT OF THE NECK AND HEAD

The rotational movement in the sagittal plane (yaw movements) is detected by the sensor A in Fig. 8. The generated signal increases when the head moves backwards (the neck is approaching by the A sensor) and is decreasing for head movement in front (the neck is moving away from the sensor). The rotation movement in the transversal plane (roll movement, respectively turning the head from left to right and vice versa) is detected by the B1 and B2 sensors, which constitute together a differential capacitance; thus, when the head is turning to the left side the value of B1 capacitance is increasing (the chin is approaching the sensor B1) and the value of B2 capacitance is decreasing (the chin is moving away from the sensor B2); consequently, the value of the differential capacitance B2-B1 is decreasing.

The rotation of the head in the frontal plane (pitch movement) is detected by the B2-B1 and C2-C1 differential sensors in the differential mode; both B and C differential capacitance are influenced by the distance between the neck and the sensors.

3.5. SPECTRAL ANALYSIS OF SIGNALS GENERATED DURING VARIOUS MOVEMENTS

The spectral analysis was performed to determine if the sensors achieve wide enough bandwidth when sensing the tremor. We were interested to check that the higher harmonics of the tremors and the various frequencies of the tremor movement are revealed by the sensor network. A Matlab™ FFT function was used for sliding windows of the signals, before a median filter having a window with 5 samples was applied for all signal length. The windows overlapped two by two with 50% overlapping factor. This method was also applied for postural data analysis, in [13].

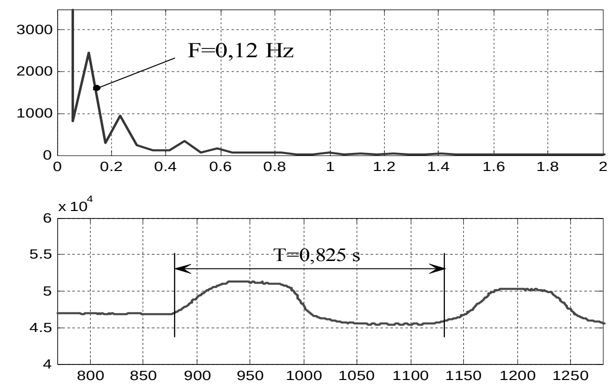


Fig. 9 – FFT of the pitch movement signal captured by the differential *B* capacitive sensor.

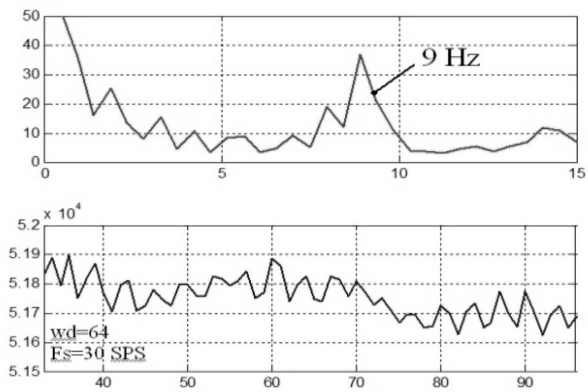


Fig. 10 – FFT of the tremor signal in the sagittal plane.

Figure 9 (bottom panel) presents a signal window of 512 samples, which covers the sequence corresponding to a pitch movement. The upper panel of Fig. 10 shows the spectrum of the same signal with several harmonics.

During a tilt movement of the head, the differential *B* capacitance generates a variable signal that increases when the head is tilting to the right side, the chin is approaching the capacitive sensor 5 (Fig. 10) and it is moving away from the capacitive sensor 1; the signal decreases for an inverse head movement (when the head is tilting to the left side). The tilt moving period is about 0,825 seconds, corresponding to 250 samples with 30 SPS sampling frequency. The FFT analysis of the signal reveals a 0.12 Hz fundamental spectral component (Fig. 8, upper panel), which is accompanied by some higher spectral components (harmonics) at 0.25 Hz, 0.5 Hz and 1 Hz. The signal acquisition was also performed for the rest (non-tremor) position of the neck. A FFT analysis of the signal related to the sagittal plane reveals a spectral component of 9 Hz that is specific to the essential tremor. This spectral component also appears in the case of the neck movement and for intentional tremor (when the subject deliberately produces a tremor of a body's part).

An example of intentional tremor is presented in Fig. 11. The tremor of the head in the sagittal plane was emulated by the subject wearing the robe endowed with the capacitive and accelerometric sensors placed inside the collar. In this case, the FFT analysis of the signals highlights two spectral components at 2 Hz and 3 Hz, specifically for the intentional movement of the head.

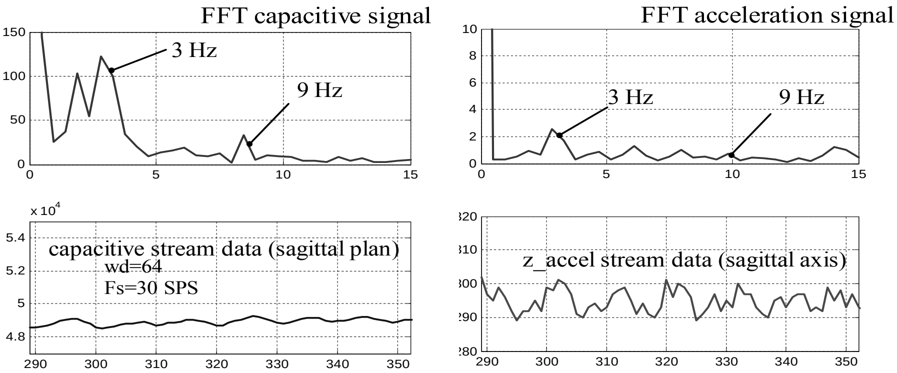


Fig. 11 – Intentional tremor detected by the capacitive sensor versus acceleration sensor.

For the same movement of the head, both sensors (accelerometric and capacitive) are able to detect neck position variations. The capacitive sensor is more sensitive, the magnitudes of its spectral components are more ample in comparison with the accelerometric results. In fact, the acceleration sensor reflects the trunk movement caused by the head tremor.

4. DISCUSSION AND CONCLUSIONS

The use of interdigital capacitive sensors embedded in clothes, as proposed in [13] and further refined in [24, 25, 26], proved a viable manner for monitoring the tremor of various parts of the body, including neck and head. Determining the position and movement of the neck using capacitive sensors inserted in the clothes is a reliable method in order to analyze neck tremor. Neck movement and tremor are detected by a network of capacitive sensors; the accelerometric was also acquired, but accelerometric signals are largely redundant, having lower amplitude than the capacitive values for the same movement parameters. The new implementation of the capacitive wearable sensors has a reliable operation. While the accuracy of movement detection is not very good, this method of sensing, of using capacitive sensors inserted in the clothes is proper for the analysis of the user's daily activity and for determining the evolution and the early detection of the tremor produced by neurological disorders. In this study we were not preoccupied to ensure low power consumption; future work should supplement the system with wearable photovoltaic modules, or other solutions such as the one suggested in [25] to guarantee energetic independence of the system. Concluding, a robust monitoring system embedded in a robe was demonstrated with good results, suitable as a screening device for tremor detection and monitoring. The system, which is based on a new type of capacitive wearable sensor for displacement, removes some disadvantages of the other solutions, but has its own limitations. Therefore, we see this approach complementing rather than replacing other solutions in tremor monitoring.

REFERENCES

1. AMARANDEI L.A. AND HAGAN M.G., *Wearable, assistive system for monitoring people in critical environments* (Ch. 22), in *Improving Disaster Resilience and Mitigation – IT Means and Tools*, edited by H.-N. Teodorescu *et al*., Springer, 2014, pp. 335-344; DOI 10.1007/978-94-017-9136-6_1. (accessed March 3, 2015).
2. BAHL I.J., *Lumped elements for RF and microwave circuits* (Ch. 7: Interdigital Capacitors), Artech House, Boston, London, pp. 229, 2003.
3. CANCELA J., *et al*., *Wearability assessment of a wearable system for Parkinson's disease remote monitoring based on a body area network of sensors*, Sensors (Basel), **14**, *9*, pp. 17235-55, 2014.
4. CHARLON Y., FOURTY N., BOURENNANE W., CAMPO E., *Design and evaluation of a device worn for fall detection and localization: Application for the continuous monitoring of risks incurred by dependents in an Alzheimer's care unit*, Expert Systems with Applications, **40**, pp. 7316–7330, 2013.
5. CHARLON Y., W. BOURENNANE, F. BETTAHARA, E. CAMPO, *Activity monitoring system for elderly in a context of smart home*, IRBM **34**, *1*, pp. 60–63, 2013.
6. CHIUCHIȘAN I., COSTIN H.N., GEMAN O., *Adopting the Internet of Things Technologies in Health Care Systems*, Proc. 2014 Int. Conf. Electrical and Power Engineering (EPE 2014).
7. GEMAN O., *Nonlinear Dynamics, Artificial Neural Networks and Neuro-Fuzzy Classifier for Automatic Assessing Tremor Severity*, Proc. IEEE Int. Conf. E-Health and Bioengineering, EHB 2013, 2013.
8. GEMAN O., POHOAȚĂ S., GRAUR A., *Acquisition and Processing data for Early Stage of Parkinson's Disease*, Rev. Roum. Sci. Techn. – Electrotechn. et Energ., **58**, *3*, pp. 324-334, 2013.
9. GEMAN O. et al., *Towards an Inclusive Parkinson's Screening System*, Proc. 18th Int. Conf. System Theory, Control and Computing, Sinaia, Romania, October 17-19, 2014, IEEE, 2014, pp. 476-480.
10. GEMAN O., TEODORESCU H.N., ZAMFIR C., *Nonlinear analysis and selection of relevant parameters in assessing the treatment results of reducing tremor, using DBS procedure*, IEEE International Joint Conference Neural Networks, Vols. 1-4, Proc. IEEE Int. Joint Conference on Neural Networks (IJCNN), July 25-29, 2004, Budapest, Hungary, pp. 2461-2466.
11. GEMAN O., ZAMFIR C., *Using wavelet for early detection of pathological tremor*, Proc. 20th European Signal Processing Conf. (EUSIPCO), Bucharest, Romania, Aug. 27-31, 2012, pp. 1723-1727.
12. HAGAN M.G., *System for measurement and analysis of tremor using force and accelerometric sensors*, Bulletin of the Polytechnic Institute of Iasi, LVIII, 3, Electrical. Energy. Electronics, pp. 57-65, 2012.
13. HAGAN M.G., TEODORESCU H.-N., *Intelligent clothes with a network of painted sensors*, The 4th IEEE Int. Conf. E-Health and Bioengineering – EHB 2013 Proceedings, Iasi, Romania, Nov. 21-23, 2013.
14. LEE Y.D., CHUNG WY, *Wireless sensor network based wearable smart shirt for ubiquitous health and activity monitoring*. Sensors and Actuators B: Chemical, **140**, *2*, pp. 390–395, 2009.
15. LORINCZ K., B. CHEN, G. WERNER CHALLEN, A. ROY CHOWDHURY, S. PATEL, P. BONATO, and M. WELSH, *Mercury: a wearable sensor network platform for high-fidelity motion analysis*. SenSys, cs.swarthmore.edu, 2009.
16. NATIONAL INSTITUTE OF NEUROLOGICAL DISORDER AND STROKE (NINDS), http://www.ninds.nih.gov/research/parkinsonsweb/ (2015).
17. NATIONAL PARKINSON FOUNDATION (NPF), www.parkinson.org (2015).
18. MAETZLER, W., DOMINGOS, J., SRULIJES, K., FERREIRA, J. J. AND BLOEM, B. R., *Quantitative wearable sensors for objective assessment of Parkinson's disease*. Mov. Disord., **28**, pp. 1628-1637, 2013.
19. MCADAMS E., C. GEHIN, B. MASSOT, J. MCLAUGHLIN, *The challenges facing wearable sensor systems*. In: Studies in Health Technology and Informatics, **177**, Editors B. Blobel, P. Pharow, F. Sousa, Proc. e-Health Conf., 2012, pp. 196-202, 2012.
20. PANTELOPOULOS A., BOURBAKIS N.G., *A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis*. IEEE Trans. Systems, Man, Cybernetics–Part C, **40**, *1*, pp. 1-12, 2010.
21. PATEL S., K. LORINCZ, R. HUGHES, N HUGGINS, *Analysis of feature space for monitoring persons with Parkinson's disease with application to a wireless wearable sensor system*, Proc. Conf. IEEE Eng. Med. Biol. Soc., 2007, pp. 629.
22. PATEL S., H. PARK, P. BONATO, L. CHAN AND M. RODGERS, *A review of wearable sensors and systems with application in rehabilitation*. J. of NeuroEngineering and Rehabilitation, **9**, pp. 21-38, 2012, DOI 10.1186/1743-0003-9-21. (accessed March 3, 2015).
23. SHANY T., REDMOND S.J., NARAYANAN M.R., LOVELL H.N., *Sensors-based wearable systems for monitoring of human movement and falls*. Sensors J., IEEE, **12**, *3*, pp. 658-670, 2012.
24. TEODORESCU H.-N., *Textile-, conductive paint-based wearable devices for physical activity monitoring*, 4th IEEE Int. Conf. on E-Health and Bioengineering – EHB 2013, Proceedings, Iasi, Romania, Nov. 21-23, 2013.
25. TEODORESCU H.-N., *Model of an adaptive energy harvester with electro-rheological fluid*, Proceedings Romanian Academy, Series A, **16**, *1*, pp. 110–117, 2015.
26. TEODORESCU H.-N., HAGAN M., *High accuracy acceleration measuring modules with improved signal processing capabilities*, IEEE Int. Workshop IDAACS on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 6-8 Sept 2007, Dortmund, Germany, 29-34, 2007.

27. TEODORESCU H.N.L., KANDEL A., HALL L.O., *Report of research activities in fuzzy AI and medicine at USFCSE*. Artificial Intelligence in Medicine, **21**, *1-3*, pp. 177-183, 2001.
28. THAYNE I., ELGAID K., TERNENT G., *Devices and fabrication technology* (Ch. 2), in I.D. Robertson, S. Lucyszyn (Eds.), RFIC and MMIC Design and Technology, IET, London, 2001, pp. 40-41.
29. WORLD HEALTH ORGANIZATION (WHO), http://www.who.int/research/en/ (2015).

Received March 12, 2015