ACQUISITION AND ANALYSIS OF TREMOR SIGNALS USING FORCE AND ACCELEROMETER SENSORS

Marius Hagan
Technical University “Gheorghe Asachi”, Iaşi, Romania
marius.hagan@ramira.ro

ABSTRACT

The aim of this paper is to achieve an analysis of the postural tremor hands function by the palmar gripping forces, using a novel device based on three capacitive force sensors and a 3D accelerometer, for healthy persons. Two categories of persons took part in the test: people who use their hands intense in daily activities (workers) – the first category, and people who perform daily activities that not require hard physical activity. The force and the acceleration data were sampled for each person and FFT transform was applied to analyze the frequency spectra of the tremor when increasing the palmar gripping force.

Index Terms— hand tremor, acceleration sensor, gripping force, FFT transform, capacitive force sensors

1. INTRODUCTION

The human hand is a very complex anatomical structure indispensable for handling objects. More zones define the palm surface on which act forces during handling activities [1, 2]. The fingers develop the gripping forces, and the maximum pressure (reaction forces) acts in the so-called thenar zone (F_{tz}, Figure 1).

The correlation between the tremor and its origin has been studied since 1900s, when Gordon Holmes sensed that the frequency of the tremor is specific to its pathophysiological origin [17] cited by [3].

The parameters extracted from spectral estimations refer to the peak frequency, median frequency, frequency dispersion and power spectral density [5]. The wearable devices having the local processing capabilities will make possible a correlation between more physiological signals (EEG, EMG, EKG, tremor parameters, postural signals), the resulted data being useful in finding solution to improve the life quality.

More investigation techniques of the tremor are known [7, 8, 9, 10, 11 and 12]. We adopted to use a 3D acceleration sensor, considered as a sensitive, noninvasive, low power sensor, proper for neurological investigations [5]. We will follow the frequency spectra evolution as a function of the gripping force for the postural isometric tremor [4] in order to assess the isometric tremor for the healthy people.

2. MATERIALS AND METHODS

2.1. Testing Device

The System Dedicated to Assess some Neurological Disorders (SDAND) is a device conceived and developed by the author. This device uses three capacitive force sensors and an ADXL345 accelerometric sensor (Analog Device Co). The SDAND weight, including the batteries, is 180 grams.

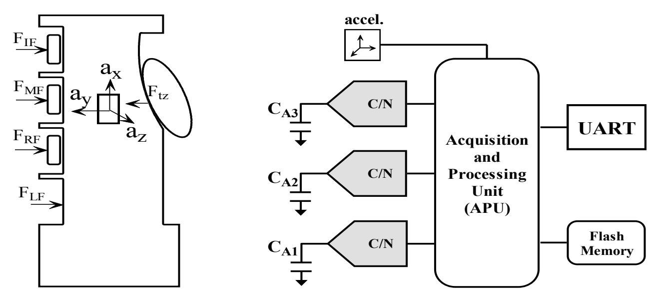

Figure 1 – SDAND device

2.2. Data Format

The ADXL345 is a 3-axis accelerometer that transfers the output data through I2C or SPI protocol [14]. It incorporates several registers to set the sensor measurement parameters as the resolution, measurement range, data rate etc. The acceleration data are grouped in three 16-bit words twos complement, DATA_X, DATA_Y and DATA_Z, the resolution being set to 13 bits, the measurement range is +/- 2g and the measurement resolution is 3.9 mg/LSB. The force data are grouped in three 16-bit words, DATA_FA, DATA_FB and DATA_FC each force datum being generated by a force sensor which is based on the AD7746 capacitive to number convertor [16]. The force data are transferred in the SDAND memory by I2C protocol. We used a polynomial equation to linearize the characteristics of the force sensors:

$$F = a + b \cdot x + c \cdot x^2 \quad (1)$$

The force sensors were handmade, so their characteristics are heterogeneous but respect the same law presented in the formula (1). We determined the linearization coefficients for each sensor (Table 1).

Table 1 – The linearization coefficients for the force sensors

	a	b	c
s_{FIF}	-0.3748	0.01380	$1.237*10^{-6}$
s_{FMF}	0.18135	0.01618	$5.7119*10^{-6}$
s_{FRF}	0.01155	0.003991	$5.5155*10^{-6}$

The linearization equations were implemented in Matlab™ before the data processing, the measurement range is 0-300N, with 0.3N/LSB resolution (in 10 bits data representation).

2.3. Data Acquisition

The acceleration and force data are sampled both with the same data rate, 80 SPS. We chosen the sampling frequency based on two criteria: we consider the maximum tremor frequency being 15 Hz, and in this case, the Nyquist frequency condition will be satisfied, and must consider that the capacitive to number data rate conversion is maximum 90 SPS. The stream data are successive acquired by the Acquisition and Processing Unit (APU), as six 16-bits words and then they are stored during the test in a flash memory having 1Mbytes capacity. APU is implemented in the ADuC7026 microcontroller being responsible with the management acquisition for the present application; although it has a strong power-processing core (ARM7) [15] the time resources are taken by the data transfers.

2.4. Test Method

Two groups of healthy human subjects were chosen to participate in the test. The first group, named "group R" is represented by 15 persons (all males) who perform daily and job activities that require a great physical effort. The second 15 persons group (10 males and 5 females), named "group S", is composed of people who perform easy physical activities. The persons from "group R" work in a company where they assemble iron pieces, so they have a good skill to handle heavy objects.

The test resources are generated by the SDAND device, a progressive intensity sound generator (PISG), a laptop, and a serial data transfer cable. The PISG was implemented using "Audacity" audio editor software. More sounds sequences were generated, in five time sequences for five different acoustic intensity levels : I- silence (14 sec), II – the second intensity level (5 sec), III – the third level (5 sec.), IV – the fourth level (5 sec.), V – the fifth level (maximum – 3 sec). After these increasing intensity levels follow decreasing intensity levels, until the silence level (14 sec.), whole series of the sequences having about 60 seconds (Figure 2).

Each subject was asked to take a vertical position keeping the SDAND device in the left hand (for the first time) and listens the progressive sounds. For the silence level (level I) the gripping force is minimal, the SDAND records the postural physiologic tremor only. When the sound begins, the subject gripped the device, acting on the force sensors; as the sounds intensity increases the gripping force increases as the subject perceive the sounds intensity (levels II, III and IV). When the sound intensity is maximum, the gripping force became maximum possible developed by the subject (level V). After the increasing levels follows the regressive levels and the gripping force had gradually released (levels IV-III-II). The hand remained in the horizontal posture during level I, and the SDAND device recorded the postural physiologic tremor after an effort task period. The subject removed the SDAND from the left hand in the right hand and a new listening-gripping cycle had followed. The test had finished after about 65 seconds, after the data (in hexadecimal format) were transferred in the PC through the serial RS232 port and saved as txt extension files, getting a unique name for each subject; so, 30 data files have resulted. We adopted this method following two targets: the first one refers to the method itself, each subject respects the same test cycle, and the second target is to analyze the palmar force response function by the progressive – regressive intensity acoustic levels.

2.4. Data Analyzing Method

The data are stored in text files structured in six columns, the first three are destined for the acceleration data and the last three for the force data. The columns sizes are the same for all data, so all files will have the same dimensions. Matlab™ software was used to analyze the data. To assess the tremor frequency the acceleration columns are divided in 50% overlapped windows, each window having 512 bytes. A 3-order median filter was applied for the acceleration data and for the forces was applied a 5-order filter using medfilt1 Matlab™ function. Each window was multiplied by a Hamming window and a FFT transform was applied. We are interested for the x and z (Figure 1) tremor directions, so a_x and a_z was considered for the tremor analyzing. The environmental noise effect is minimal (the output sensors signals are digital values). The maximum order of the median filter, for acceleration data, was chosen considering the maximum tremor frequency that is interesting for us, this one being 12 Hz, a higher order filter could cut spectral components that is important for the signals analyzing. The force signals were filtered using an order 5 median filter, the force frequency domain isn't interesting for this study.

3. RESULTS

The force data and the acceleration data are simultaneously represented for the whole test period (Figure 3) which is about 65 seconds; the forces evolution respect the progressive-regressive intensity sounds levels (Figure 3). The sFMF sensor that is dedicated to the middle finger registers the maximum force value. The acceleration values (a_x, a_y and a_z) reflect the subject hand posture, the a_x axis has a vertical direction and indicates 1000 mg (static gravitational acceleration) value for a correct hand posture, also a_y and a_z that are horizontal axes, indicate zero output values for correct rest position. We multiplied by 10 the force value to obtain approximately the same range for the acceleration data and force data.

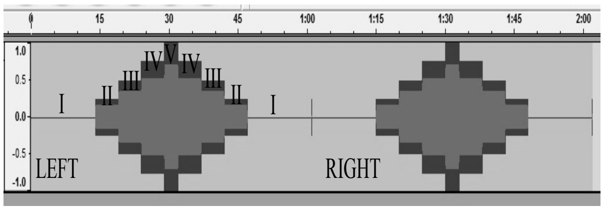

Figure 2 – progressive intensity sounds generator

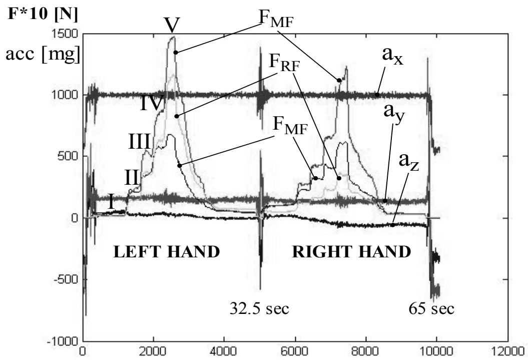

Figure 3 – Force data and acceleration data for 65 seconds of acquisition

The Figure 4 shows the dependence between hand gripping force and tremor acceleration in the time domain. The tremor acceleration amplitude increase by increasing the gripping force.

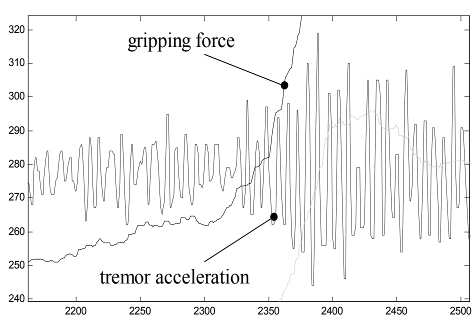

Figure 4 – Griping force and tremor acceleration in time domain

The FFT results were represented in four plot windows (Figure 5): on the left side are shown the frequency spectra for the left hand, f_{axs} is frequency for the *x-axis* and f_{azs} for the *z-axis*. On the right side are shown the frequency spectra for the right hand, f_{axd} is frequency for the x-axis and f_{azd} for the *z-axis*. The next two windows represented the gripping force levels, for the left hand on the left side and the force of the right hand on the right side.

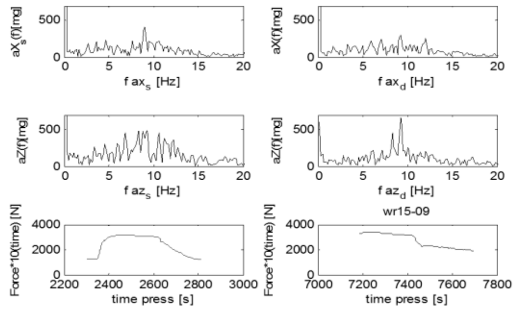

Figure 5 – FFT results according to the hands gripping force

The tremor-force ratio (TFR_w) was calculated for each data window as ratio between the maximum value of the acceleration spectral component and the maximum force value of the window, the force value is the sum of the action forces of the fingers on the sensors surfaces. The acceleration spectral component is selected for physiological tremor domain, 5-12 Hz.

$$TFR_w = \frac{\max\left(F(w[n])\right)_{[5-12Hz]}}{10 * \max\left(F_t\right)}; \qquad (2)$$

The standard deviation of the TFR is given by the formula:

$$\sigma_{TFR} = \sqrt{\frac{1}{12}\sum_{w=3}^{14}(TFR_w - \mu_{TFR})^2}; \qquad (3)$$

Where:

$$\mu_{TFR} = \frac{1}{12}\sum_{w=3}^{14} TFR(w); \qquad (4)$$

where μ_{TFR} is the mean of the tremor-force ratio.

Table 2 – The average standard deviation of the tremor-force ratio and the average of the maximum forces and accelerations values

	ax_s	*az_s*	*ax_d*	*az_d*	F_{max}*[N]*	a_{max}*[mg]*
gr. S	2,819	3,012	2,600	2,351	117	1623
gr. R	1,406	1,920	0,927	0,885	229	1544

In the table 2 are represented the average values of the *TFRs* standard deviation for the acceleration spectral components in 5-12 Hz domain, this frequency range being specifically for the physiologic tremor, and the average of maximum forces and acceleration spectral components values. The average value of the *TFRs* for the acceleration on *x-axis* of the left hand is named *ax_s*, for de right hand *ax_d* and for the *z-axis* are named *az_s* (left hand) and *az_d* (right hand).

4. DISCUSSION

The sounds level listened by the subjects are found as clearly force level for the most of "group R" subjects, specially for experienced workers who are able to control accurately the gripping force (Figure 3).

In the Figures 6-8 is represented the spectral frequency evolution for the same subject during the test. When the force level is low (Figure 6), the frequency spectral components for the physiological tremor (around 10 Hz value) are also low. Increasing the gripping force levels, the spectral components increase and become maximum when the gripping force is the maximum one developed by the subject (Figure 7). The force values are approximately equal for left hand and right hand, and the spectra evolution is the same for both hands. All the subjects reported that they use mainly the right hand in the daily activities.

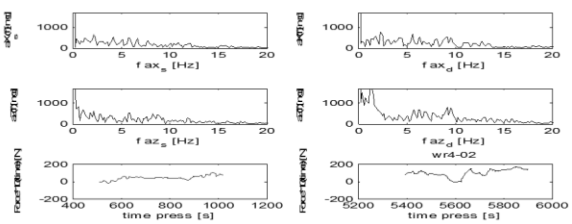

Figure 6 – FFT results for the no gripping forces at the begin of the test

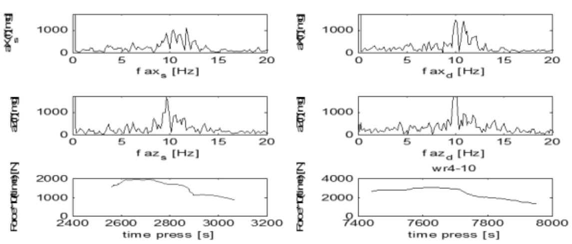

Figure 7 – FFT results for the high gripping forces (window 10)

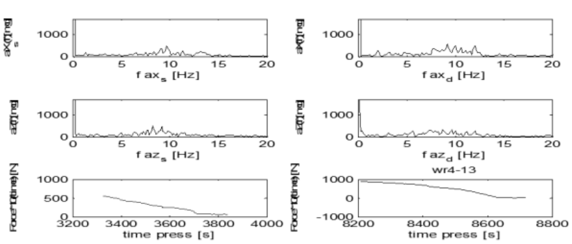

Figure 8 – FFT results for the medium gripping forces (window 13)

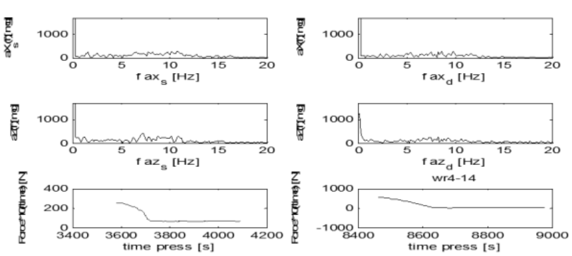

Figure 8 – FFT results for the no gripping forces at end of the test

Comparing Figure 6 and Figure 8 that represent the postural physiological tremor for no gripping forces we observe that the power spectral density is larger for the begin of the test (Figure 6) than the similar case (no gripping force) from the end of the test (Figure 8). In other words the tremor-force ratio is larger at the begin of the test than at end of the test.

In the Figure 9 is represented the tremor-force ratio (TFR) defined by the (2) formula for the same subject whose frequency spectra evolution was shown above.

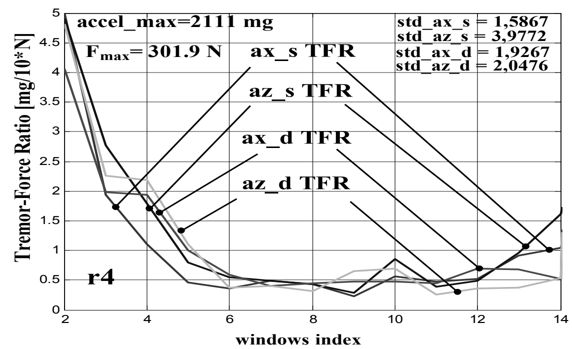

Figure 9 – Tremor-Force Ratio (I)

The tremor-force ratio is larger for the case when the gripping force is smaller (windows 2-4, Figure 9), becoming the lowest for larger forces (windows 6-10, Figure 9).

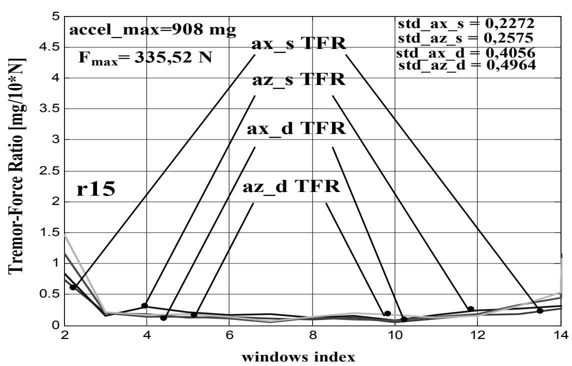

Figure 10 – Tremor-Force Ratio (II)

The tremor-force ratio does not depend on the force size; it is specific for every subject capability to control the tremor during gripping force development. The Figure 10 shows a case where the gripping force is very large (334.52 N) but the tremor-force ratio remains approximately at a constant value. Not all subjects respect this rule. In the Figure 11 is represented a case where for the maximum force level the tremor force ratio is large. The tremor spectrum has one or two peaks (Figure 7), which means that two mechanisms generate the tremor since that simple variations in amplitude or frequency produce the multiple peaks [3]. If we consider the hand tremor as an approximately sinusoidal oscillation [3], we conclude that both the amplitude and the frequency fluctuate when increasing the gripping force.

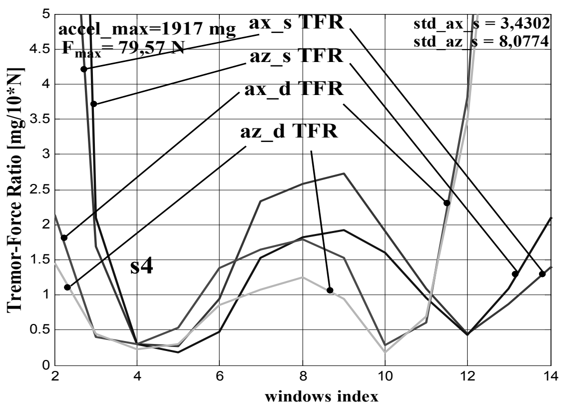

Figure 11– Tremor-Force Ratio (III)

The tremor-force ratio (TFR) varies from person to person, a subject from "group R" developed 335 N (The maximum gripping force that can be generated by the hand in males is 400 N and in females 228 N [13]; the maximum spectral component value (at 10 Hz) is 998 mg.

5. CONCLUSIONS AND FUTURE RESEARCH

The SDAND device proves to be suitable to assess the hands tremor offering the possibility to investigate the tremor evolution reported to the hands gripping forces. The tremor FFT analyzes correlated with the forces shows that the power spectral density increase, depending on the forces size, for the healthy people. We defined the tremor-force ratio parameter (TFR), this indicates the person behavior during gripping force developing. The TFR is low for the people who have a good experience in the objects handling. The gripping force and the tremor force ratio could be considered as input parameters for prediction and rehabilitation methods [12] in order to implement such algorithms in real time tremor screening and rehabilitation devices.

We propose to implement a real time algorithm for the tremor and palmar gripping force assessment, using a microcontroller or DSP as wearable processing unit. In the next step of the research, we intend to analyze the influence of the gripping force on the Parkinson's disabilities persons. We expect to identify a decrease of the tremor magnitude increasing the gripping force value. We find it interesting to do a correlation between hands tremor and postural stability using the SDAND together with a pedometric platform [6].

6. ACKNOWLEDGMENTS

The author would like to thank Mrs. Oana Geman from "Stefan cel Mare University" of Suceava, for her initiative to develop a force-tremor assessment device, and to Mrs. Adina Badarau from SC Silicon Service SRL from Iasi for her suggestions regarding some test methods.

7. REFERENCES

[1] Chuckpaiwong B, Harnroongroj T, *Palmar pressure distribution during push-up exercise*, Singapore Medical Journal, Vol. 50, Issue 7, pp. 702-704, July 2009.

[2] Aldien, Y. D. Welcome, S. Rakheja, R. Dong, P.-E. Boileau, *Contact pressure distribution at hand–handle interface: role of hand forces and handle size*, International Journal of Industrial Ergonomics, Volume 35, Issue 3, pp. 267-286, March 2005.

[3] Gresty, M., Buckwell, D., Spectral analysis of tremor: understanding the results, Journal of Neurology, Neurosurgery, and Psychiatry, Volume 53, pp. 976-981, 1990.

[4] Geman, O., *Data Processing for Parkinson's Disease Tremor, Speech and Gait Signal Analysis*, IEEE International Conference - 2011 E-Health and Bioengineering Conference, EHB, ISBN 978-606-544-078-4, Iasi, Romania, 24-26 November, (2011).

[5] Grimaldi, G., Manto, M., *Neurological Tremor: Sensors, Signal Processing and Emerging Applications*, Sensors, Volume 10, Issue 2, pp. 1399-1422, February 2010.

[6] SMAGA, S., *Tremor*, American Family Physician, Volume 68, No. 8, pp. 1545-1552, October 2003.

[7] N. Mamorita, T. Iizuka, A. Takeuchi, M. Shirataka, N. Ikeda, Development of a System for Measurement and Analysis of Tremor Using a Three-axis Accelerometer, Methods Inf Med. Volume 48 Issue 6, pp. 589-594, November 2009.

[8] Latt, W.T., Tan, U-X, Veluvolu, K.C., SHee, C. Y., Ang, W.T., Physiological Tremor Sensing using only Accelerometers for Real time Compensation, Proceeding of the 2009 IEEE International Conference on Robotics and Biomimetics, Bangkok, pp. 474-479, February 2009.

[9] R-S. Chang, J-H. Chiu, F-P. Chen, J-C Chen, J-L. Yang, *A Parkinson's Disease Measurement System Using Laser Lines and a CMOS Image Sensor*, Sensors, Volume 11, pp. 1461-1475, November 2011.

[10] Veluvolu, K-C., Ang, T., *Estimation of Physiological Tremor from Accelerometers for Real-Time Applications, Sensors*, Volume 11, pp. 3020-3036, November 2011.

[11] Dobrea, D-M., Teodorescu, H-N., *A New Type of Non-Contact 2D Multimodal Interface to Track and Acquire Hand Position and Tremor Signal*, Proceedings of the 8th Biennial Baltic Electronics Conference 2002, pp. 359-362, Tallinn, Estonia, October 2002.

[12] Teodorescua, H-N., Chelaru, M., Kandela, A., Tofan, I., Irimia, M., *Fuzzy methods in tremor assessment, prediction, and rehabilitation,* Artificial Intelligence in Medicine (Elsevier), Vol. 21, Nr. 1-3, pp. 107-130, January-March 2001.

[13] Burdea, G, *Force and Touch Feedback for Virtual Reality*, John Wiley and Sons, New York, 1996.

[14] ADXL345: 3-Axis, ±2 *g*/±4 *g*/±8 *g*/±16 *g* Digital Accelerometer, datasheet, http://www.analog.com/en/mems-sensors/mems-inertial-sensors/adxl345/products/product.html, accessed on 12/10/2011.

[15] ADUC7026: Precision Analog Microcontroller, 12-Bit Analog I/O, ARM7TDMI® MCU, datasheet, http://www.analog.com/en/processors-dsp/analog-microcontrollers/aduc7026/processors/product.html, accessed on 12/10/2011.

[16] AD7746: 24-bit, 2 Channel Capacitance to Digital Converter, datasheet, http://www.analog.com/en/analog-to-digital-converters/ad-converters/ad7746/products/product.html, accessed on 12/10/2011.

[17] Holmes, G., *On certain tremors in organic cerebral lesions*, Brain, Volume 27, pp. 360-75, 1904.