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SYSTEM FOR MEASUREMENT AND ANALYSIS OF TREMOR USING FORCE AND ACCELEROMETRIC SENSORS

BY

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Abstract. The aim of this paper is to present a new low-cost, easy to use, noninvasive System Dedicated to Assess some Neurological Disorders (SDAND). This system through simultaneous sampling of the palmar pressures and hand tremor as well as to process the pressure and accelerometric signals. SDAND consists of a rigid body, on its external surface being mounted some force sensors, CA1, CA2 and CA3, which have as position correspondence some acting palmar zones. The reaction zone, RZ, respectively thenar zone, is the reference area to which relate the acting zones, AZ1 – the acting zone of the thumb, AZ2 – the acting zone of the index and middle fingers and AZ3 – the acting zone of ring finger and little finger.

Key words: palmar pressure; force sensor; tremor sensor; isometric tremor.

1. Introduction

Several investigation techniques for the tremor are known (Dobrea & Teodorescu, 2002; Geman, 2011; Teodorescu *et al*., 2001; www.analog.com, 2012). We adopted a 3-D acceleration sensor, considered as a sensitive, noninvasive, low power sensor, proper for neurological investigations (Geman,

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2011). We will follow the frequency spectra evolution as a function of the gripping force for the postural isometric tremor (Dobrea & Teodorescu, 2002) in order to assess the isometric tremor for the healthy people.

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 (Chuckpaiwong & Harnroongroj, 2009). The fingers develop the gripping forces, and the maximum pressure (reaction forces) acts in the so-called *thenar zone* (Hăgan, 2012).

Two time series were analysed, the first set represents the hand tremor as accelerometric signal and the second set represents the isometric tremor (as force signal) during a rigid object is gripped in the hand. This analysis falls in category of tools that are dedicated to observe "if two measured chaotic dynamics are (probably) the same" (Teodorescu, 2012).

2. SDAND Architecture

System Dedicated to Assess some Neurological Disorders (SDAND) is a device conceived and developed by the author. This device is based on three capacitive pressure sensors, also originally, and ADXL345 accelerometric sensor (ADXL345, 2012) developed by Analog Device Co. The SDAND weight, having the batteries inside, is 180 g (Fig. 1).

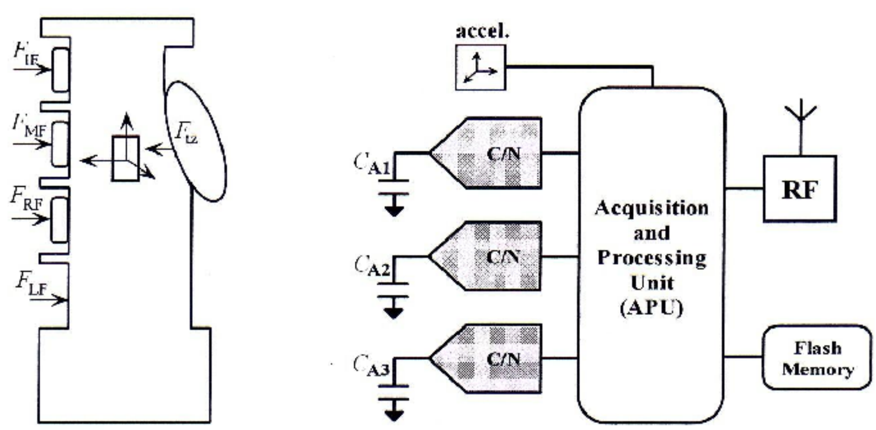

Fig. 1 – SDAND Architecture (Hăgan, 2012).

3. Acceleration and Force Data Acquisition

The acceleration and force data are acquired by an ADuC7026 microcontroller through I2C buses and are temporally stored in a 252 bytes table after that are transferred in a 1 Mbytes flash memory (Fig. 2). The AduC7026 has incorporated an ARM7 core (AduC7026, 2012). In order to

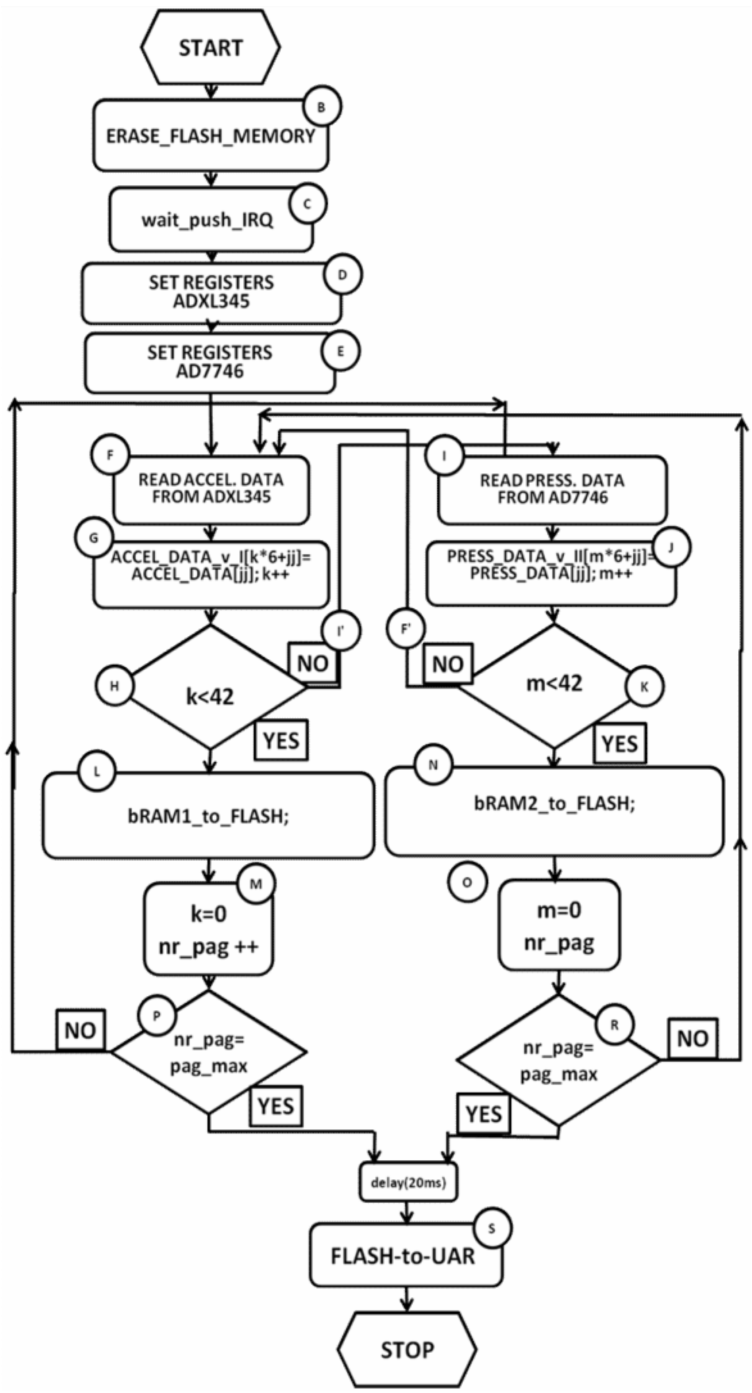

Fig. 2 – SDAND flow chart algorithm.

assess the program steps three LEDs are used as indicators. After powering the electronic module the flash memory is initialized (*B* label, Fig. 2), the initialization end is indicated by the LED_1 lighting following the data gathering. The ADXL345 accelerometer and AD7747 capacitive to number convertor registers are set up (*D* and *E* labels). The tremor acceleration data are transferred *via* I2C bus from de acceleration sensor and are stored in the ACCEL_DATA_v table that has 252 bytes (*G* label). The force data are transferred from the sensors *via* three I2C buses (*I* label) and are stored in PRESS_DATA_v table (*J* label). The acceleration and force data are interlaced written in order to respect the acquisition simultaneity. After writing three words of acceleration data, according with the *Ox*, *Oy* and *Oz* directions, follows writing of the force data table PRESS_DATA_v and the cycle are repeated until ACCEL_DATA_v and PRESS_DATA_v are completely filled. The ACCEL_DATA_v is the first filled (*H* label) and its contents will be transferred in the RAM_1 memory of the AT45DB081 memory and after that in the one flash page memory (*L* label). To avoid the data loss, one of the acquisition cycle period is shorter than the transfer time from RAM in a flash page. The acquisition – tabled writing – flash writing are repeated for a preset number of flash pages (*P* and *R* labels) and the acceleration and force data acquisition is finished, the data are transferred in a computer.

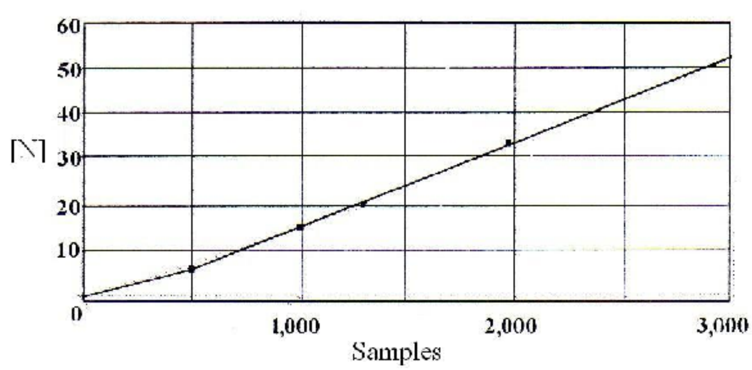

Fig. 3 – Force sensor characteristic for [0,…,50 N] range.

4. Data Format

The accelerometric data are generated by the ADXL345 circuit which is a 3-axis accelerometer that transfers the output data through I2C or SPI protocol (ADXL345, 2012). It incorporates more 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 ±2 g and the measurement resolution is of 3.9 mg/LSB (Hăgan, 2012).

Acceleration data are represented in 2's complement format and we used the code sequence to convert it in decimal format. A 3-order median filter was applied for each accelerometric signal using MATLAB medfilt-1. The acceleration values are obtained by multiplying the signals with 3.63 constant that represent the ADXL345 sensor resolution.

The force sensors were handmade, so their characteristics are heterogeneous but respect the same law presented in the relation (Hăgan, 2012)

$$F = a + bx + cx^2, \tag{3}$$

where: F_{IF}=(–0.3748+0.01380C_{A1}+(1.237(C_{A1}.C_{A1})10^(–6)))10, F_{IM}=(0.18135+ + 0.01618C_{A2} + (5.7119(C_{A2}.C_{A2})10^(-6)))10, F_{IR} = (0.01155 + 0.003991C_{A3} + + (5.5155(C_{A3}.C_{A3})10^(–6)))10.

We determined the linearization coefficients for each sensor (Table 1).

Table 1
The Linearization Coefficients for the Force Sensors (Hăgan, 2012)

	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 eqs. were implemented in MATLAB™ before the data processing, the measurement range is [0, 300] N, with 0.3 N/LSB resolution (in 10 bits data representation).

The force data are grouped in three 16-bit words, DATA_FA, DATA_FB and DATA_FC, each force date being generated by a force sensor which is based on the AD7746 capacitive to number convertor (AD7746, 2012). The force data is transferred in the SDAND memory by I2C protocol.

5. Test Method

The palmar pressure is assessed during closing the hand; the PD subject will keep his hand in a horizontal posture and will perform multiple closings–openings of the hands. These approaches were tested experimentally and the system using pressure an accelerometer sensors was shown to be capable of analysing frequency, amplitude of tremor and pressure (Hăgan, 2012).

Two groups of human subjects were chosen to participate in the test. The first group is represented by 15 persons who perform daily and job activities that require a great physical effort and the second 15 persons group who perform easy physical activities. The test resources are made by SDAND device, a Progressive Sounds Generator (PSG), a laptop and a serial data transfer cable. PSG was implemented using "Audacity" audio editor software;

more sounds sequences were generated, in five time sequences for five different acoustic intensity levels : I – silence (10 s), II – the second intensity level (5 s), III – the third level (5 s), IV – the fourth level (5 s), V – the fifth level (maximum – 3 s), after these increasing intensity levels follow decreasing intensity levels, until the silence level (10 s), all. Each subject was asked to take a vertical position whole series of the sequences having about 60 s. 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 analyse the palmar force response function by the progressive – regressive intensity acoustic levels (Hăgan, 2012).

6. Data Processing

The coherence is a assessment method for two signals analysing and defines the relationship between two signals in phase and frequency (Cieslak-Blinowska *et al*., 2011)

$$Y_{xy}(f)=\frac{S_{xy}(f)}{\sqrt{S_x(f)S_y(f)}}, \tag{2}$$

where

$$S_{xy}(f)=\int_{-\infty}^{\infty}R_{xy}(\tau)\mathrm{e}^{\mathrm{i}2\pi f\tau}\mathrm{d}\tau \tag{3}$$

represents the cross-spectrum between x and y signals,

$$R_{xy}(\tau)=\int_{-\infty}^{\infty}x(t)y(t+\tau)\mathrm{d}t \tag{4}$$

is the correlation function between x and y signals.

We are interested to analyse the spectrum assessment for gripping forces and tremor acceleration values during the test cycle. For this purpose we used “wcoher” MATLAB^{TM} function.

The bifurcations of the coherence trajectories occur in griping forces transient zones where the force levels are changed (Fig. 4). The corresponding pseudo-frequencies of the bifurcations points are calculated with the aid of MATLAB^{TM} function scal2frq(A,'wname',DELTA), where A is the scale, ‘wname’ is the wavelet function and DELTA is the sampling period (www.mathworks.com, 2012). “The wavelet coherence can be interpreted as the local squared correlation coefficient in the time-scale plane” (www.mathworks.com, 2012) The coherence between gripping forces signal and the acceleration of the isometric tremor signal (depending on the first) is pronounced for small force values and large frequencies (at begin of the test when gripping force is 10 N and pseudo-frequency is F_{I} = 14.5 Hz) and is also pronounced for large forces and small frequencies (when gripping force is 30 N and pseudo-frequency is F_{III} = 9.2 Hz.

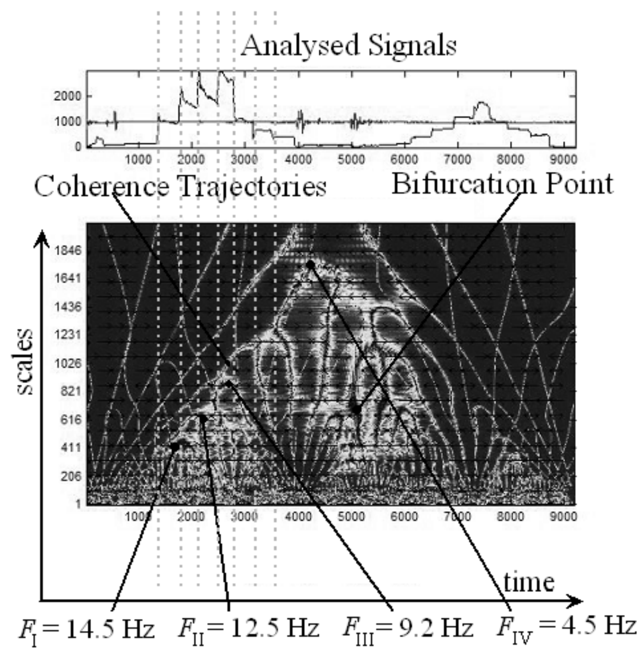

Fig. 4 – Gripping Force Signal and Accelerometric Signal Coherence.

We define the hetero-coherence of two dependent signals the case where the coherence is pronounced for opposite signals values (for example the first signal's value is small and the second signal's value is large). In our case the physiological tremor frequency increase function by gripping force increasing but the coherence of force signal and accelerometric signal is weak.

7. Conclusions

We conceived and developed a new device dedicated for assessment of hands isometric tremor that we named SDAND (System Dedicated to Assess some Neurological Disorders). The novel device is based on three new capacitive force sensors and a three-axial accelerometer. A new test method was conceived in order to obtain the identical test conditions for all subjects. The acquisition data algorithm was implemented in a microcontroller with ARM7 core and the data is stored in a computer as .txt files, in hexadecimal format, being processed using MATLAB functions. The coherence of accelerometric and force data was evaluated. We have introduced a new concept, namely *hetero-coherence of two signals*.

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SISTEM DE MĂSURARE ŞI ANALIZĂ A TREMORULUI UTILIZÂND SENZORI DE FORŢĂ ŞI ACCELERAŢIE

(Rezumat)

Evaluarea tremorului izometric este posibilă prin utilizarea unui nou sistem ce are la bază un grup de trei senzori capacitivi de forţă şi un senzor de acceleraţie pe trei axe. Noi am numit acest sistem SDAND (System Dedicated to Assess some Neurological Disorders – Sistem Dedicat pentru Evaluarea unor Afecţiuni Neurologice); menţionăm că nu am mai întâlnit în literatură un dispozitiv care să aibe funcţii similare. SDAND poate fi privit ca un “screening device” ce va putea fi utilizat în identificarea unor stări patologice. Datele de forţă şi cele accelerometrice sunt stocate într-o memorie locală de tip FLASH pe perioada de testare iar apoi sunt transferate în calculator printr-un cablu serial. SDAND este un dispozitiv multi-senzor ce generează date de natură diferită (forţă şi acceleraţie), prin integrarea cărora rezultă informaţii specifice sistemelor sinergetice.