Application of Filtering Strategies to Multiple Sclerosis Tremor: Analysis of Results

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Abstract

Intention tremor severely compromises everyday life tasks in patients suffering by Multiple Sclerosis or Parkinson 's disease.

In this paper we report the result of our investigation on the properties of Multiple Sclerosis tremor. We analysed the case of handwriting and the effects of filtering tremor with proper numerical systems.

An index for the evaluation of movements has been proposed, its properties have been verified with healthy users and used for evaluating efficiency of filtering on Multiple Sclerosis patients.

The achieved results have been applied in the development of some technological aids for assisting therapist and patients in their work/life.

Keyword: Tremor, Motion analysis, Filtering, Performance Indexes

Introduction

Tremor is a largely spread disease among people, almost 0.4% of the population of U.S. is affected of Multiple Sclerosis (MS) tremor [9].

Patients affected by Multiple Sclerosis are generally young people possessing full mental capabilities whose normal activities are strongly reduced by tremor.

The analysis of intention tremor, such as that produced by MS, is an important theme of research in order to develop technological aids that can be useful in assisting disables. Multiple Sclerosis, in fact, is a progressive pathology that can not be reversed nor stopped. In order to make patients' quality of life better, the best solution seems to be of providing this type of assisting devices to them.

The first attempts to characterize tremor's properties can be found in the latest sixties [11]. Stiles [12] analysed the hand tremor properties by means of EMG sensors.

In the last decade, more and deeper contributions on tremor analysis were achieved. The technology progress allowed the researches to measure tremor with more accuracy, and to develop on-line filtering systems for damping tremor effects [10, 13, 15]. For example the tremor frequency range has been studied with commercial digitising tablets, optical and magnetic sensors, in order to realize electrical and software filtering, and to reduce the noise in drawing and handwriting operations [4][8].

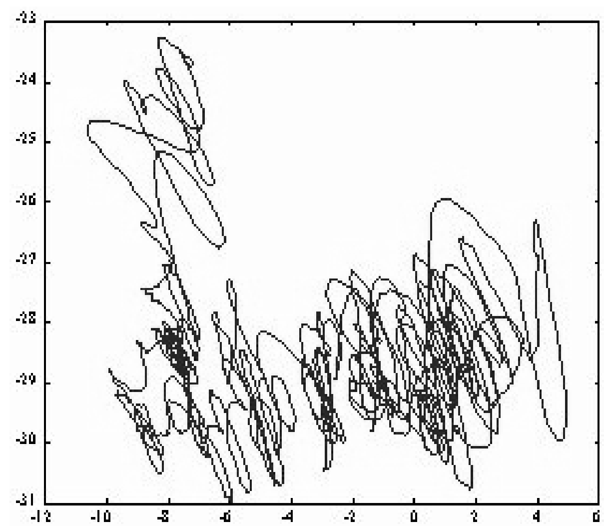

Figure 1: Example of test compromised by intention tremor: the Handwriting.

Actually the main focus of the research activities in concentrated on developing mechanical interfaces (intelligent or not) capable of damping the hand tremor [7] [3] [16]. Several devices have been developed to help such individuals to operate in normal activities such as writing, using a computer or taking an object.

Riley and Rosen [5] evidenced that, when evaluating filtering performance of patients using manual control devices, it is very important to have the possibility of customising the settings of the filter for each individual disable person. Filter properties should be shaped very differently from one person to another and for different kinds of tremor.

MS Tremor

Tremor appears as an oscillatory involuntary motion over-imposed to voluntary movements. The tremor-genesis mechanisms are yet controversial point of discussion. Several hypothesis have been formulated and tested for the mechanism of normal tremor. Riley reported three mechanisms at the basis of tremor-genesis [11]:

- an instability generated in the force closed-loop on the muscle limb which is like an under-damped spring mass system;
- an unstable oscillation generated by closed neuro-muscular loops;
- an oscillator present in central nervous system that drive the neuromuscolar loops at the tremor frequencies.

For what is concerning the first hypotheses several possible reasons have been identified:

- damaged neural control loop;
- a delayed control of the ballistic movement;
- problems with the neuro-transmission mechanism.

Riley also observed that intention tremor contaminates the voluntary activity in a simple addictive way, so that voluntary tracking of a periodic tracking can be extracted from the movement recording by means of an average of the effective movements.

The strict mechanical relations between tremor intensity and oscillation frequencies have been outlined by Stiles [12]. The oscillation amplitude diminishes as the mean tremor frequency increases. For the same reason, large amplitude tremors are related to low frequencies characteristics.

Parkinson tremor presents frequencies which ranged from 6 to 12 Hz depending from patient, posture and patient's condition. MS tremor is generally larger than Parkinson's tremor and is bound to lower frequencies. Typical frequencies of MS tremor are within the 2-6Hz range.

Producing assistive devices for MS patients is much more difficult due to tremor properties. Since voluntary movements can present spectral components which lie in the same frequency range of the intention movements. In this case there is no way to produce a frequency filter which can cancel the tremor effects without affecting also the voluntary movements.

The Experimental Set-up

A common task has been chosen for verifying our experiments: the handwriting.

As shown in figure 2 the handwriting presents three specific characteristics, which make it suitable for such the analysis of tremor:

- the handwriting allows us to clearly express and evaluate the intentional user movements; even if the shape of the handwriting may largely vary from one person to another, it is almost easy for the reader to produce a subjective evaluation of the handwriting quality;
- the handwriting seems to be one of the most compromising task for most users. The amplitude of the tremor is generally as large as the writing size is and this can cause large distortion on the writing shape, which can produce unreadable text;
- finally we are interested in handwriting in order to identify the characteristic required from an haptic interface capable of actively damping user tremor while writing [18].

The Recordings of MS Patients' movements during handwriting have been obtained by equipping a Pencil with a 6 DOF Position Sensor. The Position (X,Y) of Pen Tip on the writing plane has been computed for each sampling interval and used for analysis; We have chosen to use a positional sensor attached to a real pencil rather than a digitizing tablet, as Elble did in [8], in order to set the user in a normal operation condition. The user is consequently capable of seeing his real handwriting on the paper and a processed analysis of the writing on the video screen.

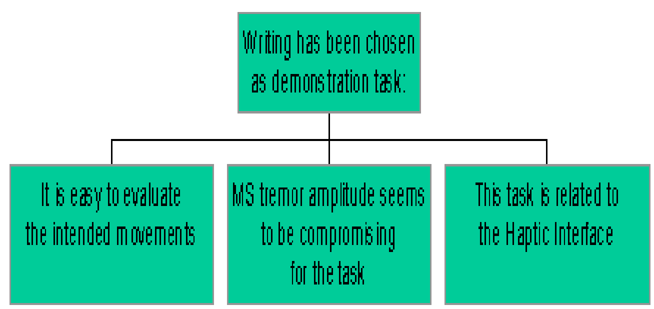

Figure 2: Handwriting and Tremor.

Three types of writing test have been reproduced from patients:

- tracking: the user follows the word "demo", which has been previously drawn on the paper he is writing on;
- signing: the user is asked to write his/her name;
- writing: the user is asked to write a word on the white paper.

Since we did not stopped analysis when the user raised the pen from the paper, we gave just one only particular instruction to patients of keeping the pencil tip always in contact with the paper and we avoided too complex words to be written.

All the experiments have been recorded foe a second step analysis. An off-line analysis has been performed on each collected experiment. The scheme of the interaction loop is presented in figure 3.

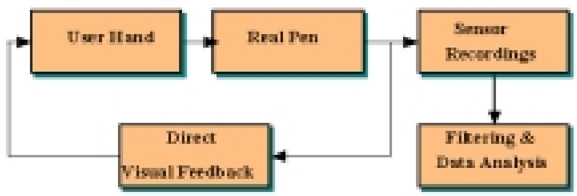

Figure 3: The block scheme used during the experimental-data collecting session.

The 6 DOF Position Sensor we used is a magnetic sensor Fastrack Polhemus, with latency time less of 4 msec, and in a 120 Hz reading frequency has accuracy RMS 0.025^o, $6 \cdot 10^{-6}$ m and accuracy Abs. 0.25^o, $1 \cdot 10^{-3}$ m; the resolution at the velocity induced of 6 cm/sec was $0.5 \cdot 10^{-3}$ m.

The tests have been organized in two phases :

- the laboratory tests: an appliance and algorithm test/verification which has been accomplished with healthy users;
- the clinical tests described below.

In the laboratory tests we have chosen 13 patients, two of StelMar (Stella Maris Foundation in Pisa, Italy) and eleven of NCMS (National Centre of Multiple Sclerosis in Mellsbroek, Belgium).

All the patients of NCMS were in the range between 35 and 50 years old, and with different levels of tremor, from mild to very high; they were 6 males and 7 females.

The StelMar patients were two child's, a boys and a girl, with a medium level of tremor.

Name	Tr. Right	Tr. Left	Sex	Age
Andre	severe	severe	M	50
Ingrid	severe	severe	F	35
Jan	severe	severe	M	50
Eric	mild	mild	M	50
Ingrid(2)	mild	none	F	40
Fernanda	mild	mild	F	45
Luc	severe	none	M	42
Nancy	mild	mild	F	37
Bernadette	mild	mild	F	35
Nadine	severe	severe	F	33
Rony	mild	non	M	39

Table 1: Patient examined at NCMS (Belgium) - Courtesy of Prof. P. Kaeteler.

We did over 50 different test recording about 3000 seconds of data, on which we applied our research filter.

Analysis of Results

The main problem, when we analyzing the experimental data, is to evaluate the quality of the signal and the tremor influence. Tremor is an additive signal on the voluntary movement [5, 6, 9] and not correlated to it.

It is difficult to analyse tremor and hand movements by using the typical analysis tools, because they are non-stationary signals: for example, the spectrum characteristics of the hand movements strongly depend on the kind of action and does not present regular properties over the time.

The most typical analysis of tremor is made using the Short Period Fourier Transform, a sequence of transform on contiguous pieces of signal. This analysis considers the movements to be almost stationary [18]. However the numerical correct result of the SPFT is not sufficient to have a clear data, useful to evaluate the data goodness.

The spectrum information of the signals are used to determine the frequency range of the movements, but there are poor of information about the real distortion and the correct movement.

Later on we will describe some indexes, which we have used to evaluate the results obtained by filtering the tracked movements. The indexes we propose are specified after some different considerations about tremor and movements.

The index is a numerical value which is computed on the whole trajectory. It has been conceived in order to show larger values when tremor is present on the user movements.

The index we chose is not related particularly to the handwriting task. It takes into account only general properties of the movement and can be applied to other exercises.

We applied the index to the analysis of the results achieved on movements by means of digital filtering. We would like to evidence that the numerical values presented in the index are not strictly related to the handwriting readability, but their differences can mark up in most cases clear reading from tremor affected writing.

The Index

When user moves data collected by sensors report information on the position and the orientation of the grasped pencil. During handwriting experiments the whole set of recorded data have been translated into a two components vector $(x(t), y(t))$ which represents in the sheet planar coordinate the position of the pen tip.

Such movement description is not well suited for abstracting those general information on the movement that our index uses for the evaluation of the user handwriting.

A different representation $(v(t), \phi(t))$ of the moving trajectory has been used for the determination of the given index. This representation could be achieved s-tarting from the previous one by means of the following transformations:

$$v(t) = \sqrt{\dot{x}^2(t) + \dot{y}^2(t)}$$

$$\phi(t) = atan2(\dot{x}(t)/v(t), \dot{y}(t)/v(t))$$

This coordinate transformation associates to each point of the trajectory the relative velocity and orientation measured along the shape.

If we indicate with $\bar{v}(\alpha)$ the mean linear velocity of the pen tip when moved along the α trajectory and with $\sigma_v(\alpha)$ the variance of the signal with respect to $\bar{v}(\alpha)$, we have:

$$I_v(\alpha) = \frac{\sigma_v^2(\alpha)}{\bar{v}^2(\alpha)}$$

It is easy to verify that $I_v(\alpha)$ is a purely a-dimensional index which does not depends on the mean velocity of α. In fact if we define β such that

$$(x_\beta(t), y_\beta(t)) = (x_\alpha(t/a), y_\alpha(t/a))$$

it is:

$$v_\beta(t) = \frac{1}{a} v_\alpha(t/a)$$

$$\bar{v}_\beta(t) = \frac{1}{a} \bar{v}_\beta(t)$$

and consequently:

$$\sigma_v^2(\beta) = E[(v_\beta(t) - \bar{v}_\beta(t))^2] =$$

$$= \frac{1}{a^2} E[(v_\alpha(t/a) - \bar{v}_\alpha(t/a))^2] =$$

$$= \frac{1}{a} \sigma_v^2(\alpha)$$

$$I_v(\alpha) = I_v(\beta)$$

hence for the quality index I_v is such that it does not depend on the real velocity the user makes the movement but it is related to the smoothness of the movement. Handwritings, which are subjected to tremor, clearly present larger values of the I_v index.

Note that this index, standing to its formulation, is not strictly related to the handwriting context and can easily be adopted for different applications.

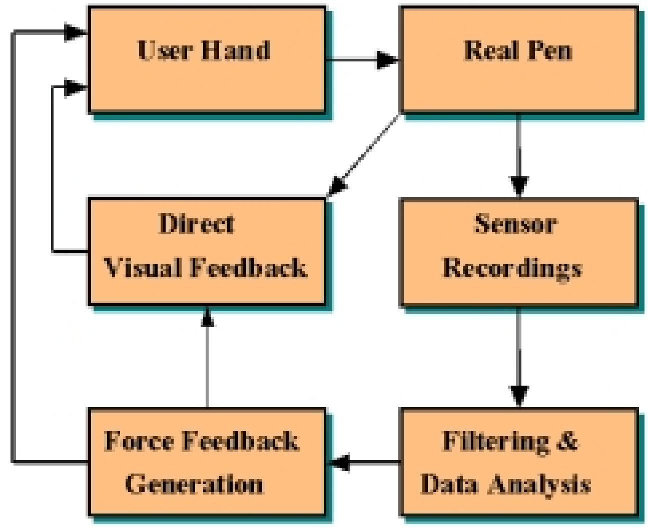

Figure 4: Software and mechanical system for mechanical damping.

Verifying Index Properties

In order to verify the numerical properties of a simple filter we computed $I_v(\alpha)$ on some movements (α) produced by healthy user. If we model tremor as an oscillatory signal added to the voluntary movement, it is easy to verify that the index value increases:

$$v_t(t) = v_M(t) + Asin(\omega t)$$

$$\bar{v}_t(t) = \bar{v}_M(t)$$

$$\sigma_{vt} = E[(v_t - v_m + Asin(\omega t))^2] =$$

$$= E[(v - v_m)^2 + 2(v_t - v_m)Asin(\omega t) + A^2 sin^2(\omega t)] =$$

in case of uncorrelated tremor to movement

$$= \sigma_v + 0 + \frac{A^2}{2} E[1 - cos(2\omega t)] =$$

$$= \sigma_v + \frac{A^2}{2} \qquad (1)$$

$$I_t = I + \frac{A^2}{2\bar{v}_M^2} > I$$

Differences in index values may be due to text written to handwriting style or to tremor. The kind of test chosen for evaluation eliminates most difference sources, all users have tracked the same word, eliminating in such a way differences on handwriting style and test written. In order to consider significative the results evidenced from the index, it is important to verify that the index changes due to tremor are larger than changes due to normal handwriting.

The following table report some results achieved for different users and different tracking speed.

Analysis of Clinical Tests

We investigated filtering capabilities on MS tremor for two different kind of application: Software damping and Mechanical damping. As shown in [16] and in figure 4 the two cases present themselves differently. Software damping produces no direct force feedback on user hand but performs filtering just for on-line visual feedback or off-line processing. Mechanical damping on the other hand is exerted by means of Haptic interfaces. In this case the user takes part of a closed control loop by exchanging a direct force-position interaction with the mechanical interface.

Table 2 help us to explain how comparison and analysis of data produced by patients affected by tremor can be done.

The table collects the indexes of different users which are tracking at different speeds. The index is expressed as as percentage. On both right and down sides of the table the total variations index values is expressed. Right side reports index changes which are due to different testers. Bottom side represents index changes for an user when tracking at different speeds.

Figures 5 shows the effects of filtering on handwriting produced by a MS patient, which is trying to track the word “demo”. The plot sequence can be easily visually inspected by humans for determining the best results. Unfortunately such a procedure can not be automated nor quantified in result by means of an absolute value. In this case the use of the previously indicated index help us to find this means of automation.

When index is applied to the data from a patient affected by tremor, index values are different. Since equation the results we get when computing index performances resulted higher (as shown in table 3).

We used the performance index for evaluating for the filtering is acting on the user handwriting and to identify best filtering parameters for achieving optimal index values.

Figures 5 reports the results achieved by filtering movements with different cut-off frequencies. The cut-off frequency used is reported as a title for each subplot.

If we drown the index value versus the cut-off frequency used we obtain a simple graph which helps us to analyse filter effects. For lower cut-off frequencies filter eliminates everything producing unreadable results since tremor has been cut together with handwriting shapes. When cut-off frequencies become higher handwriting is recovered when tremor still remains filtered. In this frequencies range the filter produces the best results.

We have examined the index vs frequency plot (figure 6) by analysing the frequency range for which the recovered handwriting is readable. This analysis evidenced that the selected ranges for disabled people corresponds to index values which are close to those produced in the handwriting by healthy users in the same time.

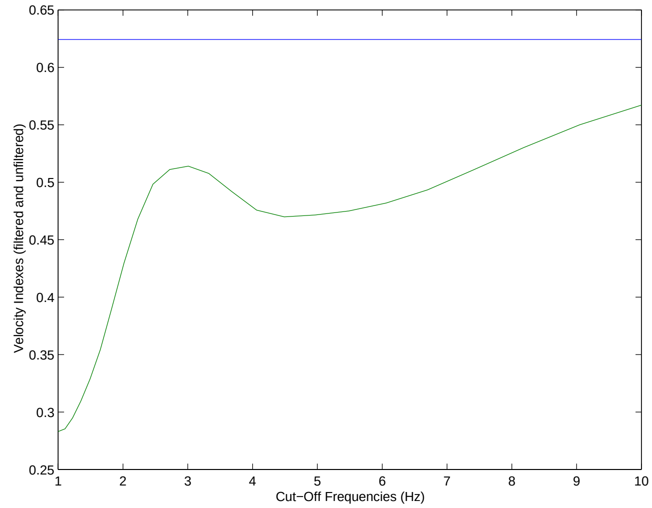

Figure 6: The index vs frequency graph for a tremor affected patient.

Application of Results

At PERCRO, in the last two years we are setting up some technological aids for MS patients and therapists. Among these devices we have a Joystick System and an Haptic Interface.

Both systems implements a filter structure which damps the user oscillations. The Joystick System provides only a visual feedback and can be used for recovering user capabilities when using the graphical user interface of a PC.

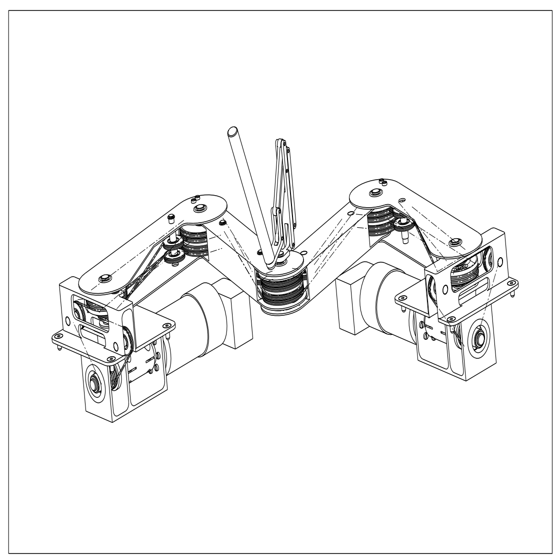

Figure 7: Haptic Interface designed at PERCRO.

The Haptic Interface is a two-degrees of freedom device which produces a force feedback adapted to user movement on tremor. Details on these systems can be found in [3].

	Andrea	Carlo	Chiara	Giusy	Δ%
6 sec	0,3007	0,4127	0,4400	0,4326	0,13
10 sec	0,2705	0,3509	0,2047	0,3186	0,14
15 sec	0,3399	0,2836	0,2711	0,2310	0,11
20 sec	0,2839	0,2708	0,2397	0,2826	0,04
30 sec	0,3151	0,2031	0,3657	0,2164	0,16
Δ%	0,07	0,20	0,23	0,21	

Table 2: Indexes of different users at different speeds.

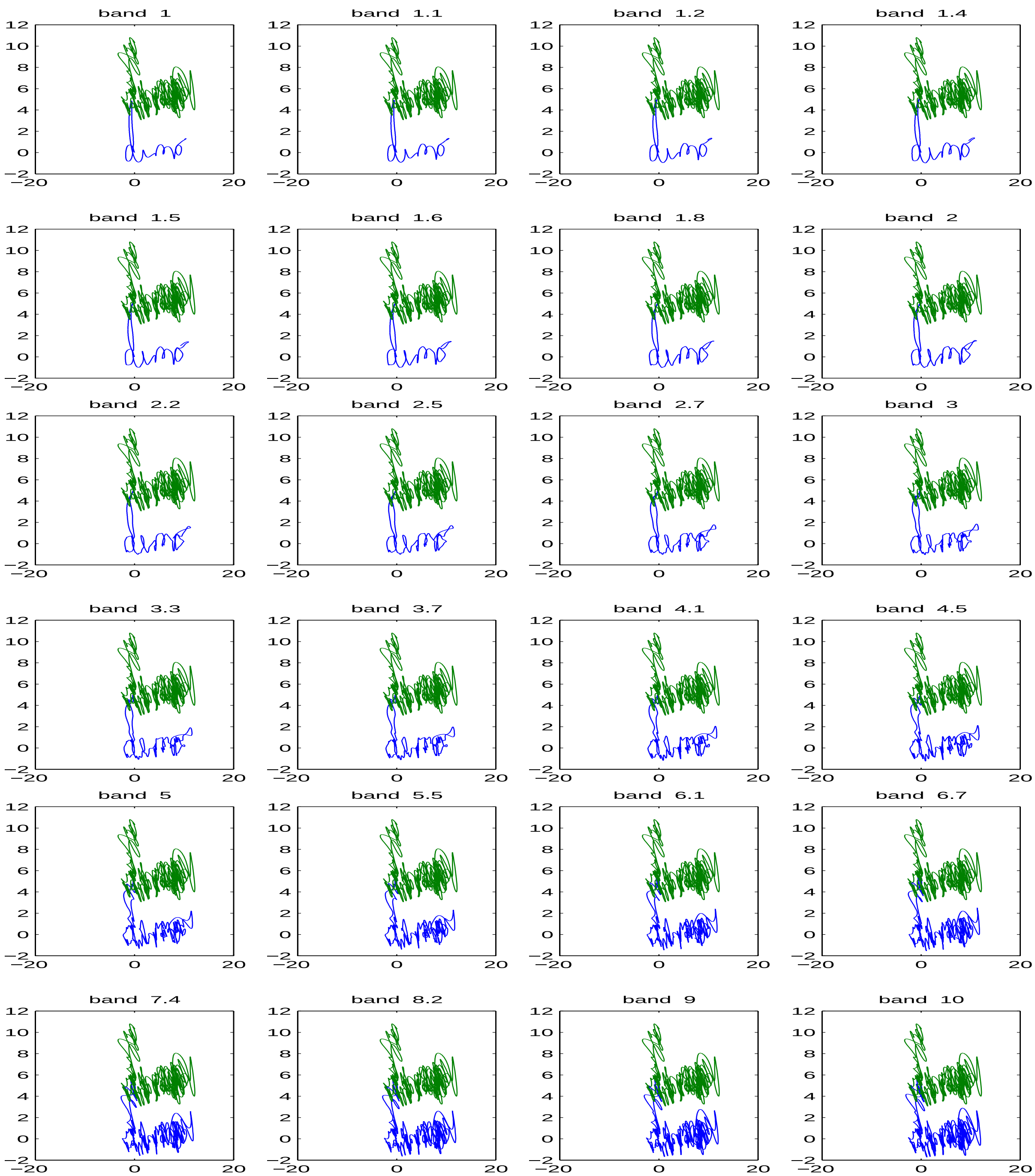

Figure 5: Effect of filtering on different frequencies.

	Nadine	Ingrid	Fernanda
band (Hz)	1.1 - 1.2	1 - 4	2.1 - 5.0
$index_{nf}$	0.6242	0.8972	0.4120
$index_f$	0.289 - 0.455	0.204 - 0.352	0.170 - 0.250
time (sec)	20	24	14

Table 3: Indexes filtered and unfiltered for some tremor affected patiens.

Filter parameters of these systems can be adopted both on the basis of the achieved result and consulting the index performances.

Figure 7 shows the design layout of the haptic interface we developed for handwriting. Interface indexes parameters have been optimized for maximum isotropy on the workspace given as shown in [2].

Conclusion

We have developed and tested a new index for evaluating tremor during handwriting and for setting up design parameters while developing systems for disables.

The index has been shown be stable for healthy users and to correctly identify tremor when applied to patients affected by Multiple Sclerosis.

Finally the index has been used for the control-tuning of two technological aids developed at PERCRO for MS tremor.

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