TECHNOLOGICAL AIDS FOR THE TREATMENT OF THE TREMOR

C. A. Avizzano, M. Bergamasco
PERCRO
Simultaneous Presence, Telepresence and Virtual Presence
Scuola Superiore S. Anna,
Via Carducci 40, I-56127 PISA, Italy

Abstract

In this paper we present a cluster of Technological Aids for the analysis and the treatment of a particular kind of tremor caused by the multiple sclerosis. The developed technological aids are:

- *a system, provided with sensors, capable of monitoring all the movements of the upper trunk and of the right arm of a patient;*
- *a Joystick System capable of interfacing the users with a common Operating System by filtering the information caused by tremor;*
- *an Haptic Interface capable of mechanically damping the effects caused by tremor.*

Innovative approaches have been followed for the monitoring the upper limb and head movements, the filtering interface and the design of the haptic interface.

Keywords: Technological Aids, Advanced & Intelligent interfaces, Haptic interfaces

1. Introduction

"Tremor is a rhythmic uncontrollable oscillation that appears superimposed to voluntary movements. Approximately 0.4% of the population in U. S. is affected by some kind of pathological tremor"[1].

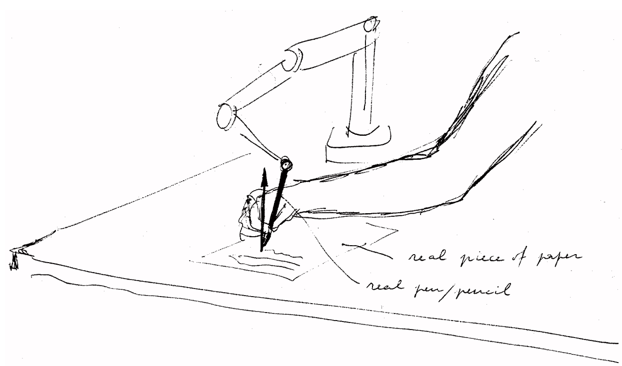

Figure 1: An Haptic Device for writing

This article deals with the tremor induced by Multiple Sclerosis (MS). This particular kind of Intention tremor presents frequencies which belongs to 2-6Hz range and amplitudes that vary from few to several centimetres depending on the limb as well as on the Disability Status Scale (DS)[2].

Intention tremor contaminates the voluntary activity in a simple additive way[3]. Even if tremor is quite regular and constant, it is very compromising in everyday-life activities.

The need for Technological Aids (TA), i.e. systems which are capable to help persons in the accomplishment of particular tasks, is largely felt among patients which suffer by tremor.

Hsu, in [4], addressed the problem of creating an assistive mechanical interface (a special pen) for handwriting and a particular mouse interface for working with computers. Some filtering systems for the Parkinsonian tremor have been developed by Riviere[5]. Riviere addressed the possibility of generating an auto-adaptive system for the tremor identification and suppression. In [1] Kenneth presented a FIR system which worked with MS-DOS systems.

Haptic technologies have also been proposed as a possible aid in the treatment of some motor and cognitive disabilities. A comprehensive research on this topic has been carried out by Avizzano and Bergamasco in [15].

Moreover similar technologies have been proposed for aiding disables patients to perform everyday-life actions such as Whittaker and Tejima did for helping disabled persons in eating [11] [12] without the assistance of an external person.

Several authors [6,7,8,9] presented some orthoses-like interfaces for the reduction of the tremor. Among the presented systems we have passive orthoses as well as dynamic controlled dissipative mechanical systems which generated dissipating signals that are proportional to the tremor intensity.

At present very few Technological Aids have been purposely developed for MS-induced tremor. This was essentially due to the behaviours of such a kind of tremor. The low band frequencies, typical of this type of tremor, joined with their large amplitudes, make it hard the realization of TAs for these patients. In this case, in fact, the data characteristics of the tremor are very similar to the data generated by normal movements.

In this paper we discuss the premises and the design of a cluster of Technological Aids for the analysis and the treatment of the MS induced tremor. These systems will take into account the doctors' need of accessing complete and accurate data on the tremor as well as the users' need for an interface capable of letting them to correct operate the instruments of the common life.

The presented cluster is made up of three different systems:

- a Sensitive Corset capable of monitoring all the movements of the upper trunk and of the right arm of a patient. This device can be used by therapists for precisely monitoring the tremor activities of patients;
- a Joystick Unit: capable of interfacing the users with a common OS and, at the same time, of filtering the information caused by tremor on the effective position of the cursor on the screen. It is a 2 DOF input interface. It is capable of damping the vibrations induced by tremor and of extracting the voluntary movement characteristics. This device can be used by both children and adults as an interface allowing them to successfully interact with the most common computer applications;
- an Haptic Interface (HI) capable of generating feedback force information

to patients and of mechanically damping the effects caused by the tremor.

2. Addresses of the systems

Tremor has never been considered as a disease. It is rather considered as a diagnostic sign of various diseases such as Multiple Sclerosis, Ataxic tremor, Parkinsonian tremor.

TREMOR is an European Community project for the development of these Technological Aids. It aims to focus the interest of scientific community on this impairment and to realise valid instruments for the analysis of the tremor characteristics and the treatment of this impairment. At the same time his scope is to give to the disable people the possibility of operating systems and tools in the presence of tremor.

TREMOR has been conceived for the development and the validation of technological aids for patients affected by cerebellar tremor. This kind of tremor, characteristic of patients affected by Multiple Sclerosis (MS), generates severe disabilities in the patient's everyday life activities.

Even if the results of TREMOR could be used also in other pathologies, the system components have explicitly developed for Multiple Sclerosis.

The project aims at developing the three technological aids presented in this article.

3. The Sensorized System

The Sensorized System (SS) is a device developed for medical analysis of the tremor characteristics. It should be used by patients assisted by doctors for the monitoring and the analysis of the tremor influence over the user movements.

The primary application for the SS will be the analysis of the results given by different therapies and the production of virtual therapy based methods.

The SS presents itself as an exoskeleton-like passive structure which can be worn by the patient and be adapted to his proper size.

Doctors can access to the system potentialities by recording data collected by the system while the user is performing one from a set of predefined tests.

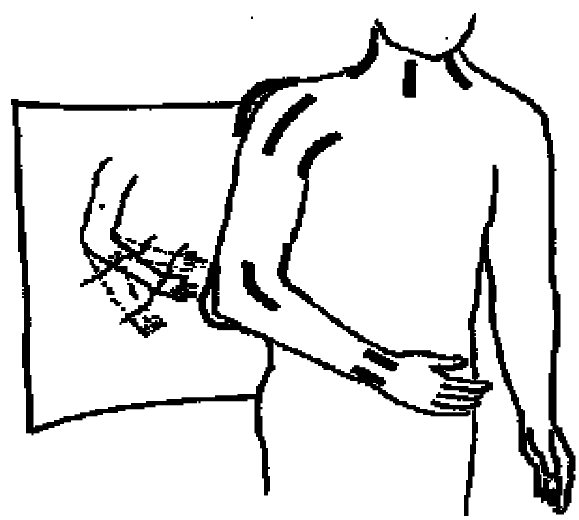

Figure 2: The SS Concept.

Using the SS doctors can monitor the patients' tremor by means of a set of numerical data. In this way then can monitor the results of precise drugs treatments as well as the reactions of the patient's bodies during the day or when performing particular activities.

The system consists of the following components:

- a passive structure, equipped with sensors, capable of measuring 10 degrees of freedom (DOF) of the human body and possessing a workspace large enough for letting to users a great mobility. These DOFs are distributed on the user's body in this way: shoulder 3DOFs; elbow 2DOFs; wrist 2 DOFs; head 3 DOFs. Standing to this structure the system can monitor the neck and the right arm movements.
Even if the system is a mono-lateral asymmetric device, its structure is good enough to perform a complete medical analysis of the tremor impairment;
- a computer interface for the jacket. It is an electronic unit which interfaces the jacket sensors with the host computer system;
- a data-collection unit which is connected to the computer system interface and provides to the rest of the system features for storing the real data;
- a video display for replicating the test paths. This system integrates a table with a large flat color LCD screen and an adequate software for drawing on the video the executed test path;
- a data-analysis software program which allow the therapist to extract meaningful indexes from the recorded trajectories;
- a virtual-therapist program. It is an animated 3D software which interacts with the patient and shows him the exercises to be done.

The data-analysis software program and the Virtual Therapist Program are the two main keys of access for the Sensorized system. An analysis of the achieved data can be done each time an user executes one from a set of given test exercises [16]. The results of the data analysis will strike out an evaluation of the performances of the subject.

All the tests are controlled by the "Virtual Therapist" application (VT). The VT defines 9 different tests which can be executed and evaluated separately: place finger on nose, move a cup, trace a square on the display system, trace a circle and so on. During the execution of the tests the VT will record and analyse a set of data in order to figure out an estimation of the quality of the movements. Possible recordings are the whole trajectory made by users, the amount of time for the test execution, the average frequency of hand tremor, the average frequency for the wrist and the elbow tremor, the neck movements

4. The Joystick System

The Joystick System (JS) is essentially an input device for computer systems having the following scopes:

- to replace the mouse as a screen pointer device for the computer;
- to support operation made by users affected by tremor;
- to be completely transparent to the host system and the user.

The JS has been conceived to be used without the continuous assistance of a therapist, which could help the patient to manoeuvre the interface.

Figure 3: The JS Concept

It is simple to be used, non-dangerous for the patient and capable of filtering the tremor's component of the movement caused on the interface by the patient disease.

Accessing the JS, the user will be able of using most of the programs available on interface computer such as: Internet browser, interfaces controlling applications, modem programs and so on. The potentialities offered by such a type of interface are enormous. With the help of the JS, patients can access the computer world which allows them not only to access and communicate with "Internet-People" but also to use the available software in order to recover lost capabilities. For sake of clarity let us present an example: a simple modem program allows, among the other things, an ordinary user to access the modem just like it was a telephone, by making automatically the desired phone number and by reproducing the audio via the plugged in audio-board or the modem speaker. This simple utility, which has just a marginal value for a common user, shows itself very useful for TREMOR patients. In fact the use of a telephone, which is *de facto* very difficult for a lot of them, is automatically given by the Joystick capabilities.

Different prototypes of joystick systems have been developed. Each of them is based on different data-acquisition technology. This choice has been suggested from the nature of the tremor. In fact, tremor can act differently on distinct patients: some patients cannot use their hand but not the foot or the head, other have not the possibility of using the foots owing to the tremor induced weakness and so on.

We have joystick interfaces that can be driven by foot (pedals), by the hand position on a plane (joysticks and mice), by the hand force (force sticks), by the hand position in the space (glove interfaces) and also by the head (Helmets).

The user program and drivers for accessing the whole interfaces set is unique. The program controls the filtering process and forwards the result signal in the adequate way to the Operating System (OS). This program is the core work of the system. It includes a support for different interfaces, a rough real-time kernel, a filtering module and a user interface for controlling the pointer actions. The whole programs works on-line in a completely transparent manner.

The filtering module of the Joystick system has been entirely realised without the help of device dependent hardware.

As far as the filtering process is concerned, an appropriate joystick driver reads the interface output and separates the tremor component from voluntary movements. This is done by means of a filtering unit built into the joystick device driver. Most of the driver filtering-parameters are configurable in order to allow the best adaptation is possible to the particular kind of user.

The device driver incorporates configurable options (movement strategies) to modify the movement policy for the pointer and to support the parallel use of different interfaces and.

Finally the device driver incorporates a set of strategies (button strategies) for the interpretation of the button pressure (click and double click control).

5. The Haptic Interface

Haptic interfaces are mechanical systems that operate in direct contact with humans. Haptic interfaces have been developed for Virtual Reality and Teleoperated systems [14] as natural and complete interface for reaching an immersive feedback.

In TREMOR the Haptic Interfaces will be employed in a contest of movement recovery. The main goal of the Tremor HI is to recover the user dexterity by mechanically damping the tremor behaviors.

Like the joystick interface this is an instrument developed for the patients.

The Haptic Interface is a mechanical system capable of working in a cubic volume of 0.3m wide. It has been conceived for small force magnitudes but with high force and position resolution values. The force bandwidth of the system is more than 20 times the tremor frequency i.e. about 100Hz.

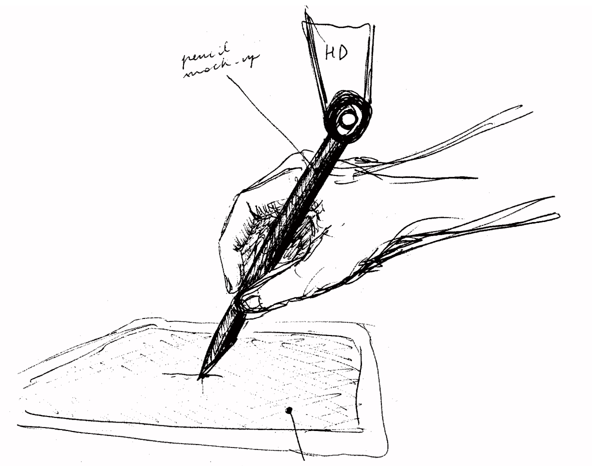

Figure 5: The HI Concept

The main user of the Haptic Interface is the patient. Anyway in the development phase doctors have been considered as complementary users of the system. This fact is motivated by the observation that at the start up and during all the setup times, the main user will need the help of the doctor for tuning the interface.

Even if the Haptic Interface has been designed as a general purpose oriented tool, some reference tasks have been kept into account during the interface design:

- to write by hand;
- to work with a screwdriver or other types of tools;
- to use spoons, knives or forks for eating purposes.

These tasks have been considered as case studies in the design of the HI. Their properties have been taken under consideration for the determination of the system specifications.

The Haptic Interface consists of different components: an electromechanical system, an electronic unit and a software module.

From a technical point of view the HI must be able to perform the following operations:

- interacting with the user allowing him the most possible comfortable and stable precision grasping;
- leaving to the user the capability of generating both confirming actions and three dimensional moving actions;
- correctly reading the user movements;
- analyse and divide the user movements into voluntary and involuntary actions;
- to apply the correct force patterns in order to compensate vibrations and stabilise the movement.

6. Preliminary Results

At present two different types of validation procedures have been performed for the systems:

- an evaluation phase of the filtering algorithms on MS patients;
- a test of the technical results achieved with the joystick system.

The characteristics of the tremor and the capabilities of the filtering algorithms have been tested with some writing experiments. These experiments have been conducted with real patients. Particular equipment has been realised for recording the user-pen movements during writing. The set of experiments has been recorded at clinical centres, while the data analysis has been performed off-line. The data have been collected and filtered by means of software developed at PERCRO. The recorded data have been processed in order to recover clean writing.

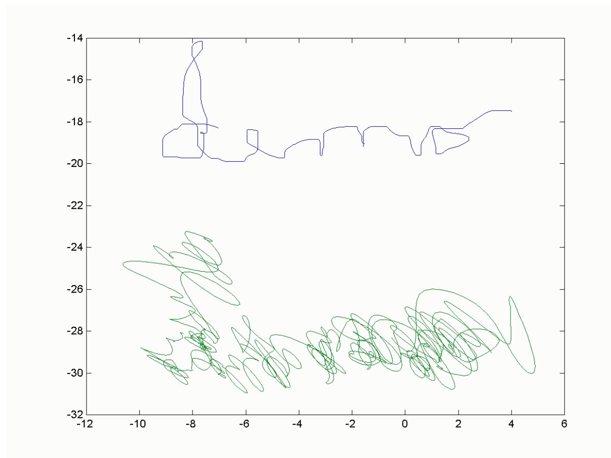

Figure 5: Filtering result for a case of severe tremor.

A sample graphical result of this test has been reported in figure 5. In its lower part, the figure 5 shows the typical shape of the acquired data in the case of a severe tremor. In the upper part, the figure outlines the typical result which can be achieved applying the filtering algorithms on the data achieved with the interface.

In all cases of filtering we verified improvements in the readability of the outputs. Once more, we verified that the properties of the tremor estimated by the filter, in terms of spectral diagram, stationarity and mean amplitude are similar to those identified in the

scientific literature. The results of this comparison outlined a close confidence between the estimated tremor and the real one and revealed the capability of satisfactory filtering tremor for MS patients.
During the test made on the Joystick System, we have analysed the properties of non-linear filters designed for acquiring bidimensional data. These data have been used for controlling the pointer on a computer screen.
A special version of the joystick system allows to the user to record the data read from the different interfaces as well as the filtered data produced by the joystick filter.

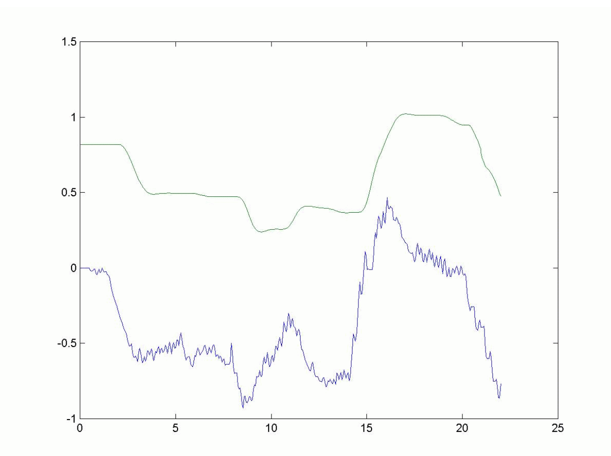

Figure 6: One-dimensional filtering of Joystick data.

Figure 6 reports a one-axis comparison between filtered and unfiltered signals. The input data for the system have not been collected into clinical centres but produced with a simulated tremor in the development centre. The filtered signal and the original one have been produced on-line by the joystick system. In the figure the upper trajectory represents the outputs of the filter.
Different offsets have been added to the data represented in the figure in order to improve the shape readability. The scale on the X-axis is in seconds and Y-axis represents the mouse positions with reference to a frame placed in the middle of the screen and having {-1,1} values close to the borders.
The input oscillations, which are present in the input signals, are cancelled from the joystick algorithms.
A more detailed numerical analysis of the collected data is being now performed. The tremor technological aids are now in a validation phase at four European MS clinical centres. The results of the validation phase in terms of usability, efficacy and comfortability of the systems are expected by June 1999.

7. Conclusions

A new non-invasive system has been conceived for the treatment of several motor disabilities caused by tremor. It is capable of tracking up to 10 different DOF of the human upper trunk and is well suited for the medical research and the development of new medical rehabilitation therapies.
A new system extending the classical joystick capabilities has been set up in order to let a wide number of disables to access to computer system and interact with the most common application.
A new haptic tool for controlling the execution of the patient movements

during particular task based on high performances and force feedback interaction has been designed.

In the 1998 after the completion of the system and a test phase with healthy subjects, a period of clinical experimentation in the clinical centres for the first and the second system has been planned.

The present work contributes to update the current State of the Art in the medical technologies for the treatment for tremor diseases by the realization of a set of system which are still under research in the robotic field.

8. Acknowledgements

This research was supported by the European commission under the project DE n.3216 TREMOR. The cooperation of the TREMOR consortium partners is gratefully acknowledged.

The authors wish to thank all the PERCRO team which have been collaborating in the development of the presented interfaces.

References

[1] Kenneth EB et al., *Control and Signal Processing Strategies for Tremor Suppression*, Independent Living Aids 1996;

[2] Kurtze JF, *Rating Neurologic Impairment in Multiple Sclerosis; An Expanded Disability Status Scale (EDSS),* Ann. Neurol 1983;

[3] Riviere CN, Thakor NV, *Adaptive Human Machine Interface for Persons with Tremor,* Eng. Medicine Biology Conference, 1995;

[4] Hsu DS et al., *Assistive Control in Using Computer Devices for Those with Patological Tremor*, Rehab R&D Progress Report, 1996;

[5] Riviere CN, Thakor NV, *Suppressing Pathological Tremor during Dextrous Teleoperation*, Eng. Medicine Biology Conference, 1995;

[6] Rosen MJ et al. *Design of a Controlled energy-dissipation orthosis (CEDO) for functional Suppression of Intention Tremors*, Jour. Rehabil Res. Dev 1995;

[7] Elble RJ, Randall JE, *Mechanistic Components of Normal Hand Tremor*, Electroencephalography and Clinical Neurophysiology 1978;

[8] Stiles RN, *Ligthly Damped Hand Oscillations: Acceleration-Related Feedback and System Damping*, Jour. Neurophysiology 50, 1983;

[9] Aisen ML et al., *The Effects of Mechanical Damping Loads on Disabling Action Tremor*, Neurology 43, 1993;

[10] Satava R, *VR Surgical Simulator, The First Steps*, Proc. VR Systems 1993 NY;

[11] Whittaker M, *Handy1 Robotic Aid to Eating: A Study in Social Impact*, Proc. RESNA Int. 1992;

[12] Tejima N, *Evaluation of Rehabilitation Robots for Eating*, Roman 1996, Tsukuba;

[13] Buche M et al., *Analysis of Tremor Methodology and Clinical Perspectives. Preliminary Results*, Schweiz Medical Wochenschr 1984;

[14] Burdea GC, ‘‘Force and Touch Feedback for Virtual Reality”, Wiley-Interscience Publication 1996.

[15] Bergamasco M, Avizzano CA, *Virtual Environment Technologis in Rehabilitation*, Proceedings of Roman 1997;

[16] Ketelaer, P. Feys, ‘‘Report of the Questionnaire Health Care Professionals”, Newcastle Upon Tyne, 5th june 1997.