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2.7.1: Interfaces for Control

On-line Canceling of Pathological Tremor for Computer Interface

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ABSTRACT

An adaptive filter designed to cancel pathological tremor in computer pen input is tested on-line. The adaptive filter, called the WFLC (Weighted-frequency Fourier Linear Combiner) filter, estimates tremor frequency as well as amplitude and then cancels the tremor. The WFLC algorithm was implemented into pen driver software and tested with subjects with pathological tremor. A standard low-pass filter which is commonly used to attenuate tremor was also tested and compared with the WFLC filter. Tests were conducted through a series of quantitative target objectives. Best results were obtained when the WFLC filter was used.

I. INTRODUCTION

Persons afflicted with pathological tremor are hindered from performing everyday tasks that many of us take for granted. Some of those tasks involve human-machine control of devices such as computers. Tremor patients have difficulty using simple computer interfaces such as a mouse, which necessitates the need for an assistive interface that suppresses tremor. This objective is accomplished by a filtering algorithm implemented in computer software to cancel tremor movements.

Voluntary motion is often at a lower frequency than tremor, which is typically in the range of 3 to 12 Hz [1]. Hence, low-pass filtering has often been used to suppress tremor in mechanical devices [2]. But there are disadvantages associated with low-pass filters such as the lag they produce in faster voluntary motions. More suitable is an adaptive filter [3]. Such a filter cancels by subtraction and therefore preserves phase. The Weighted-frequency Fourier Linear Combiner (WFLC [3], an adaptive notch filter, has been designed for this purpose. Since both the amplitude and frequency of tremor are time-varying, the WFLC is capable of adapting to changes in both quantities to maintain tremor cancellation.

The WFLC algorithm has demonstrated its effectiveness off-line in a series of qualitative tests such as improvements seen in a tremor subject's handwriting [4]. The current goal is to perform on-line quantitative experiments so as to assess the degree of improvement the filter can accomplish.

II. METHODS

A. Design

The fundamental component of the adaptive tremor canceling system is the WFLC [3]. The WFLC algorithm is used to model the pathological tremor as a modulated sine wave with a time-varying frequency and amplitude. At every time step, error is measured between the tremor signal and the reference sine wave; depending on the error, frequency and amplitude of the reference sinewave are adjusted. The WFLC algorithm is as follows:

$$x_{r_k} = \begin{cases} \sin\left(r \sum_{t=0}^{k} w_{0_t} \right), 1 \le r \le \mathrm{M} \\ \cos\left((r-\mathrm{M}) \sum_{t=0}^{k} w_{0_t} \right), \mathrm{M}+1 \le r \le 2\mathrm{M} \end{cases}$$

$$\varepsilon_k = s'_k - \mathbf{w}_k^{\mathrm{T}} \mathbf{x}_k$$

$$w_{0_{k+1}} = w_{0_k} + 2\mu_0 \varepsilon_k \sum_{i=1}^{\mathrm{M}} \left(w_i x_{\mathrm{M}+i} - w_{\mathrm{M}+i} x_i \right)$$

$$\mathbf{w}_{k+1} = \mathbf{w}_k + 2\mu_1 \mathbf{x}_k \varepsilon_k,$$

$$\text{where } \mathbf{w}_k = [w_{1_k} \dots w_{2\mathrm{M}_k}]^{\mathrm{T}}, \ \mathbf{x}_k = [x_{1_k} \dots x_{2\mathrm{M}_k}]^{\mathrm{T}}$$

M is the number of harmonics used. When M=1, the WFLC acts as a notch filter. s_k becomes s'_k when it is high passed at a 1.5 Hz cutoff (WFLC estimates frequency best on a high passed input signal so that the mean of the input becomes zero). μ_o and μ_1 are adaptive gain parameters. The filter weight w_{0k} is the adjustable frequency of the reference sinusoid that models the tremor. The running sum of w_{0k} values used to define $\mathbf{x}_k$ is necessary so that crucial phase information is not lost. Two channels of filtering are used for the two orientations (x and y) of input.

Actual signal canceling is executed by a second set of amplitude weights, w'_k, which operate on the raw signal s_k. The second set of amplitude weights operates essentially as a Fourier Linear Combiner (FLC). Finally, a bias weight μb limits the amount of distortion the FLC can impose upon the voluntary component of motion [5].

B. Testing

A Summagraphics SummaSketch digitizing tablet with a pen-shaped stylus was used as the data input device. Movements of the computer pen were taken in by the digitizing tablet, attenuated by the filtering algorithms, and the filtered motion was exhibited on the computer screen by a cursor. Subjects were asked to look at the computer screen as they were tested so an element of visual feedback came into play. Five tremor subjects, ages ranging from 63 to 86, provided written consent before proceeding with the testing.

Two filters were tested: the WFLC filter and a standard low-pass filter. Unfiltered trials were used as well. The tremor subjects performed a series of target objectives on-line to measure the performance of the filters (and no filter). There were two main tests:

1) Target Circle: Subjects traced a circle and did their best to follow a pacer cursor which revolved at one of two frequencies: 0.5 or 1 Hz. The displayed circle was 2.9 cm in diameter which translated to a 1.5 cm circle on the digitizing tablet (the tablet has an adjustable gain). See Figure 1.

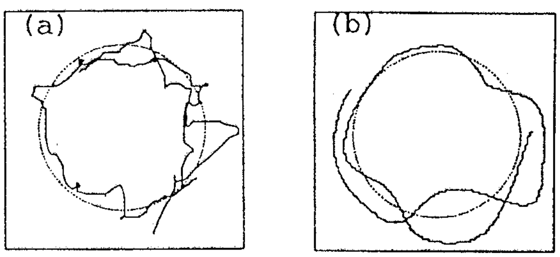
2) Random Point: Subjects moved towards a stationary point target on the screen. One random target appeared after another after a fixed time interval. The random points appeared in 1 of 9 places on the computer screen. Time intervals were set at either 2 or 4 seconds.

Subjects were given several practice runs before each trial. Different types of trials were sufficiently randomized to ensure unbiased results.

III. RESULTS

Target Circle: Values indicate the RMS distance between the subject and the pacer cursor. See Table 1.

Random Point: Distance values indicate the RMS distance between the subjects and the random point in the last second before the random point is replaced by another. Acquisition time refers to the time it took to come within 1.5 cm's of the target point. Settling time refers to the time it takes before the subject is able to stay within 1.5 cm's of the target point [6]. See Table 2 and 3.



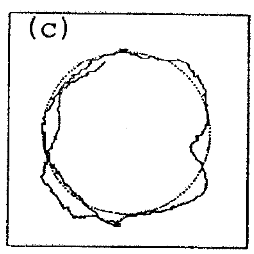


Figure 1. Samples of on-line testing for target circle.
(a) Tracing motion without filtering
(b) Tracing motion with a low-pass filter
(c) Tracing motion with a WFLC filter

Table 1. Target Circle: RMS values

	Unfiltered	Low-Pass	WFLC
Circle(.5 Hz)	0.655 cm	0.634 cm	0.579 cm
Circle(1 Hz)	1.055 cm	1.641 cm	0.936 cm

Table 2. Random Point, 2 second time interval: RMS values

	Unfiltered	Low-Pass	WFLC
Distance (1s)	1.06 cm	1.64 cm	0.93 cm
Acquisition	1.49 sec	1.99 sec	1.40 sec
Settling	1.58 sec	2.24 sec	1.50 sec

Table 3. Random Point, 4 second time interval: RMS values

	Unfiltered	Low-Pass	WFLC
Distance (1s)	0.21 cm	3.97 cm	0.23 cm
Acquisition	1.53 sec	1.63 sec	1.43 sec
Settling	1.58 sec	1.86 sec	1.60 sec

IV. DISCUSSION

The target circle experiments test the ability of a person to generate a desired curve, which is relevant to evaluating the filtering algorithm's usefulness in handwriting, drawing, and other types of freehand curve generation. The target point experiments test target acquisition, which is relevant to point and click tasks such as selecting an icon or button in a windows environment.

V. CONCLUSION

The proper use of human-machine interface is often a problem for those afflicted with pathological tremor. The WFLC, which cancels tremor, has the potential to provide effective assistance for the aforementioned problem.

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