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Physiological Tremor Estimation Methods : An Overview

Neha S Naik[1], Prof. R.R.Dube[2]

[1] Department of M.E Electronics, Walchand Institute of Technology,
Solapur University, Solapur, Maharashtra, India
(nehanaik.dh@gmail.com)

[2] Department of Electronics &Telecommunication, Walchand Institute of Technology,
Solapur University, Solapur, Maharashtra, India
(rajendradube67@rediffmail.com)

Abstract

In robotic assisted surgery accurate cancelation of physiological tremor plays vital role. Tremor is the core cause for human imprecision during microsurgery. Physiological tremor makes some procedures notably difficult to perform and this involuntary motion affects the performance of robotic based hand held instruments. The presence of phase delay due to sensing or filtering procedures degrades the performance of human-machine intervention. To conquer the phase delay, multistep prediction can be employed. The paper is overview of methods used for physiological tremor estimation. The existing method based on single frequency, Weighted Fourier Linear Combiner (WFLC) and the method which relies on multiple frequency known as Bandlimited Multiple Fourier Linear Combiner (BMFLC) are reviewed. The comparative study of these methods will be helpful in developing the algorithm for prediction of tremor and will be used to minimize its effect in critical microsurgeries.

Keywords: *Physiological tremor, Weighted Fourier Linear Combiner (WFLC), Bandlimited Fourier Linear Combiner (BMFLC).*

1. Introduction

Physiological tremor is natural in all human beings. Physiological tremor exists in all human with amplitude lying in the frequency range of 8–12 Hz. Robotics-assisted surgical instruments and procedures are increasingly playing a vital role for biological motion compensation due to their robustness, high precision, and estimation accuracy. Robotic technologies provide new ways to compensate quasi-periodic biological motion, enabling higher surgical accuracy without persistent measures such as cardiopulmonary bypass.

This tremor leads to an intolerable ambiguity of the surgical procedure(e.g., vitroretinal surgery) which requires a positioning accuracy of about 10 μm.

During surgeries, accuracy of the hand held instrument also varies due to surgeons hand tremor and it reduces surgeons ability to accurately manipulate instrument. This may cause irreparable damages to the small and delicate organs. Thus active cancellation of this tremor will improve manipulation accuracy in surgeries. Many involuntary components are present in normal human hand movement. These include physiological tremor, jerk and low frequency drift. These undesirable components have limited manipulation accuracy of surgeons in microsurgery, and cause certain types of procedures to be generally infeasible, such as arterio and retinal vein cannulation venous sheathotomy . Several types of engineered accuracy enhancement devices have been or are being developed in order to improve manipulation accuracy of microsurgeons, and fully hand-held active tremor cancelling instruments . To better engineer and evaluate performance of such systems, thorough knowledge of these components present in microsurgeons during microsurgical operations is required. Although adaptive tremor estimation introduces no additional phase delay, real-time tremor compensation accuracy depends on several factors such as prefiltering, numerical integration, noise, jerk, and drift. Multistep prediction is popular where time delay is inevitable or posteriori information is required.The different methods can be used for the proposed system. The suitable method can be used for multistep prediction.

2. Related Work

Due to the sturdiness, high precision, estimation accuracy robotic assisted surgical instruments and procedures need to concentrate on biological motion compensation [2],[3]. With the aid of this robotic technology, significant research was focused on compensation of various biological motions like heart beat in intracardiac surgery, respiratory motion in treatment of lung tumor , pathological tremor [6], and physiological tremor [3],[5].

To retain the advantages possessed by the human surgeons and to augment tip positioning accuracy, hand-held robotic instruments were developed for compensation of physiological tremor in real time [4]. In these instruments, filtering plays a vital role in attaining high accuracy. The filtered tremor signal from the sensed motion is used to generate an opposing motion to compensate for the tremor motion in real time. For effective tremor compensation, zero-phase lag is required in the filtering process.

To overcome the inherent disadvantages of linear filters, several adaptive algorithms are developed. In [5], [6] Fourier-series-based adaptive algorithms named as weighted frequency Fourier linear combiner (WFLC) and band limited multiple linear Fourier combiner (BMFLC) are proposed.

3. Proposed System

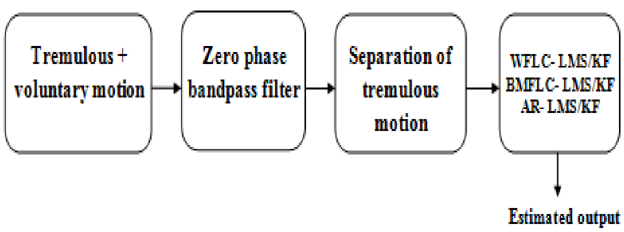

Fig: 1: Block Diagram of Proposed Scheme

According to the literature view it is observed that the voluntary motion of the surgeon's hand lies between 0-2 Hz, and the tremulous motion lies between 8-12 Hz.The output from the accelerometer is fed to the bandpass filter to separate the tremulous motion from the voluntary motion. The input for the proposed system will be the simulated sensed tremulous motion. To remove the unwanted integration drift and noise, a fifth-order Butterworth filter with passband 2–20 Hz can be employed . The filter order and cutoff frequency need to be chosen so that the filter removes unwanted low-frequency drift significantly.

In the adaptive modelling the prediction methods with kalman filter can be used to get the minimum prediction errors. Adaptive algorithms like least mean square **(LMS)** and Kalman filter**(KF)** can be employed for adaptive estimation of state. To overcome the phase delay, multistep prediction based on BMFLC and AR methods can be used. The difference between actual tremor and predicted tremor i.e. estimated output signal is calculated as prediction error.

3.1. Tremor estimation using adaptive filter:

Employing LMS or KF, the estimated output *yk* and prediction error ∈*k* can be obtained asThe equation for the single step prediction can be given as:

$$y_k = \widehat{W}_k^T X_k$$
$$\in_k = S_k - y_k \qquad (1)$$

where the S_k represents the amplitude of the signal at the *k*th sample.

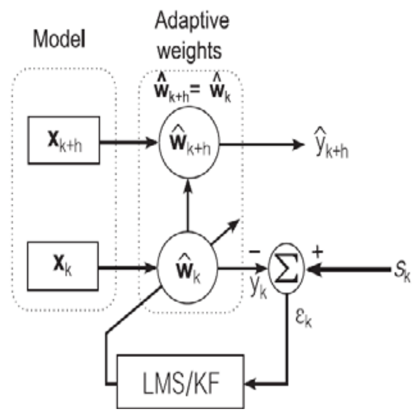

Fig: 2: Block diagram for multistep prediction.

The model X_k together with the adaptive weights W_k represents the time-varying model for the signal S_k in the state-space form as above. [equation (2)]

$$S_k = W_k^T X_k + e_k \qquad (2)$$
$$W_{k+1} = W_k + \eta_k \qquad (3)$$

With the reference vector (X_{k+h}) accurately known at the time instant $k + h$, the estimated parameters (weights) at the current sample $(\hat{w}_k)$ can be employed to obtain multistep prediction for output as

$$\hat{y}_{k+h} = \widehat{W}_k^T X_{k+h} \qquad (4)$$

3.2. Methods:

Existing methods for tremor can be considered as single frequency based tremor estimation methods and multiple-frequency based tremor estimation methods.

The method rely on single frequency estimation is Weighted Fourier Linear Combiner (WFLC), and the method rely on multiple frequency components estimation is Bandlimited Multiple-Fourier Linear Combiner (BMFLC).

3.2.1.Weighted Fourier Linear Combiner (WFLC):

Weighted Fourier Linear Combiner (WFLC) is suitable for estimation of periodic or quasi-periodic motion with single dominant frequency. The WFLC algorithm extends the well-known Fourier Linear Combiner (FLC) algorithm to also adapt to the time-varying reference signal frequency, using a modification of the least-mean-square (LMS) algorithm. As FLC only operates at a fixed frequency, the goal of the WFLC algorithm is to adapt to a periodic signal of unknown frequency, phase and amplitude. The reference input vector to WFLC, $\vec{x}_k = [x_{1k} \dots \dots x_{2Mk}]^T$,

$$x_{rk} = \begin{cases} \sin(rT \sum_{t=0}^{k} w_{0t}), & r = 1,2,\dots,M \\ \cos[(r-M)T \sum_{t=0}^{k} w_{0t}], & r = M+1, M+2, \dots, 2M \end{cases} \quad (5)$$

where M is the number of harmonics used, k = 1, 2,… represents time-index, T is a sampling period. As in FLC, the weight vector is updated using the LMS algorithm:

$$\varepsilon_k = y_k - \vec{w}_k^T . \vec{x}_k \quad (6)$$

$$\vec{w}_{k+1} = \vec{w}_k + 2\mu \vec{x}_k \varepsilon_k \quad (7)$$

where $\vec{w}_k = [w_{1k} \dots \dots w_{2Mk}]^T$ is the coefficient or weight vector of the reference input, the input to the algorithm y_k contains the desired periodic or quasi-periodic signal which is to be modelled or estimated, S_k and other undesired components such as noise and low-frequency signals. μ is the adaptive gain parameter. The frequency, $W0_k$, which is required in the reference input vector, is estimated by modified LMS as follows:

$$w_{0\,k+1} = w_{0k} + 2\,\mu_0 \varepsilon_k \sum_{i=1}^{M} i(w_{ik} x_{M+ik} - w_{M+ik} x_{ik})$$

3.2.1.Bandlimited Multiple Fourier Linear Combiner (BMFLC):

Presence of multiple peaks in the FFT spectrum is the result of modulation of multiple frequency components in tremor. The range of frequencies and the bandwidth for subjects are analyzed in the previous section. Existing methods FLC, WFLC algorithms in general adapts to a single frequency present in the incoming signal. For the case of tremor signal modulated by multiple frequencies close in spectral domain, the performance of WFLC will be degraded . Even the presence of two or three frequencies closely spaced in spectral domain can adversely affect the performance of WFLC. One limitation of WFLC is its inability to extract a periodic signal containing more than one dominant frequency. To overcome the problems associated with WFLC, a new algorithm bandlimited multiple Fourier linear combiner (BMFLC) which comprises of several Fourier Linear Combiner's was developed. Bandlimited Multiple-Fourier Linear Combiner (BMFLC) is suitable for estimation of band limited signals consisting of multiple frequency components.

For the estimation of the unknown tremor signal, a series comprising of sine and cosine components to form bandlimited multiple Fourier linear combiner at time instant 'k' is given by equation (8).

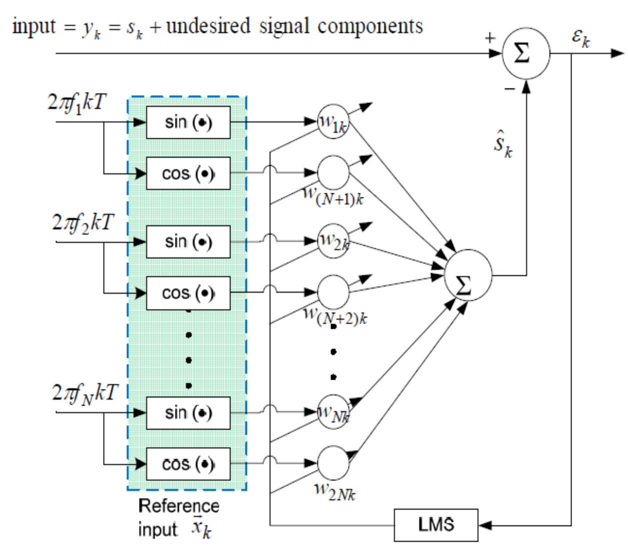

Fig: 3: BMFLC algorithm

$$x_{rk} = \begin{cases} \sin(2\pi f_r kT) & r = 1,2,\dots,M \\ \cos(2\pi f_{r-N} kT) & r = 1,2,\dots,M \end{cases} \quad (8)$$

where fr are the frequencies within a given band of interest and N represents the number of frequencies used. The frequencies can be an integer as well as a rational number. Here LMS algorithm is used to update the weight vector. The weights of BMFLC can be updated via equations (6) and (7) as:

$$\varepsilon_k = y_k - \vec{w}_k^T . \vec{x}_k$$
$$\vec{w}_{k+1} = \vec{w}_k + 2\mu \vec{x}_k \varepsilon_k$$

An estimate of the desired signal can be given by:

$$\hat{s}_k = \vec{w}_k^T . \vec{x}_k \quad (9)$$

4. Conclusions

In this paper the methods useful for the tremor estimations are given. Existing method Weighted Fourier Linear Combiner (WFLC) and the effective method Bandlimited Multiple Fourier Linear Combiner (BMFLC) are studied to develop the new algorithm for the multistep prediction of physiological tremor with Least Mean Square (LMS) or Kalman Filter (KF).

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