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Tremor Detection for Accuracy Enhancement in Microsurgeries Using Inertial Sensor

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Abstract

Physiological tremor is inherent in all humans. During surgeries accuracy of the hand held instrument also varies due to surgeons hand tremor and it and reduces surgeons capability to accurately manipulate instrument. This may cause irreversible damages to the small and delicate organs. Thus active cancellation of this tremor will improve manipulation accuracy in surgeries. In this paper we propose a simple algorithm for tremor measurement using low cost inertial sensor. Tool displacement due to tremor motion is estimated which further can be used for active cancellation of tremor.

Keywords: Tremor mensurent, Inertial sensor, Mechatronics, BMFLC.

Introduction

Tremor is termed as involuntary human muscle motion. Tremor are quasi sinusoidal in characteristic and can be approximate as a sinusoidal wave for simulation purpose [1]. Physiological hand tremor lies in the frequency range of 8-12 Hz and has amplitude of 100µm approximately along each axis. When precise position of the tool is required during surgeries tremor results in the inaccuracy. With recent advancement in medical robotics active methods of tremor cancellation methods has been developed which mainly includes master slave control for tremor suppression and accuracy enhancement.

This paper purpose a tremor measurement technique with a low cost inertial sensor. System mainly includes two subsystems, first is measurement system which comprise of orientation estimation using complementary filter and gravity compensation to obtain acceleration due to surgeons hand alone.

Second is tremor estimation it includes BMFLC [2] algorithm which provides tremor estimation in sensor body frame and tool tip kinematics for measurement of acceleration at tool tip of the device which can be used for the active cancellation of tremor by providing equal and opposite acceleration to the tool tip.

Fig. 1. show the flow chart of the system. Algorithm of systems are implemented and tested in the MATLAB/Simulink environment.

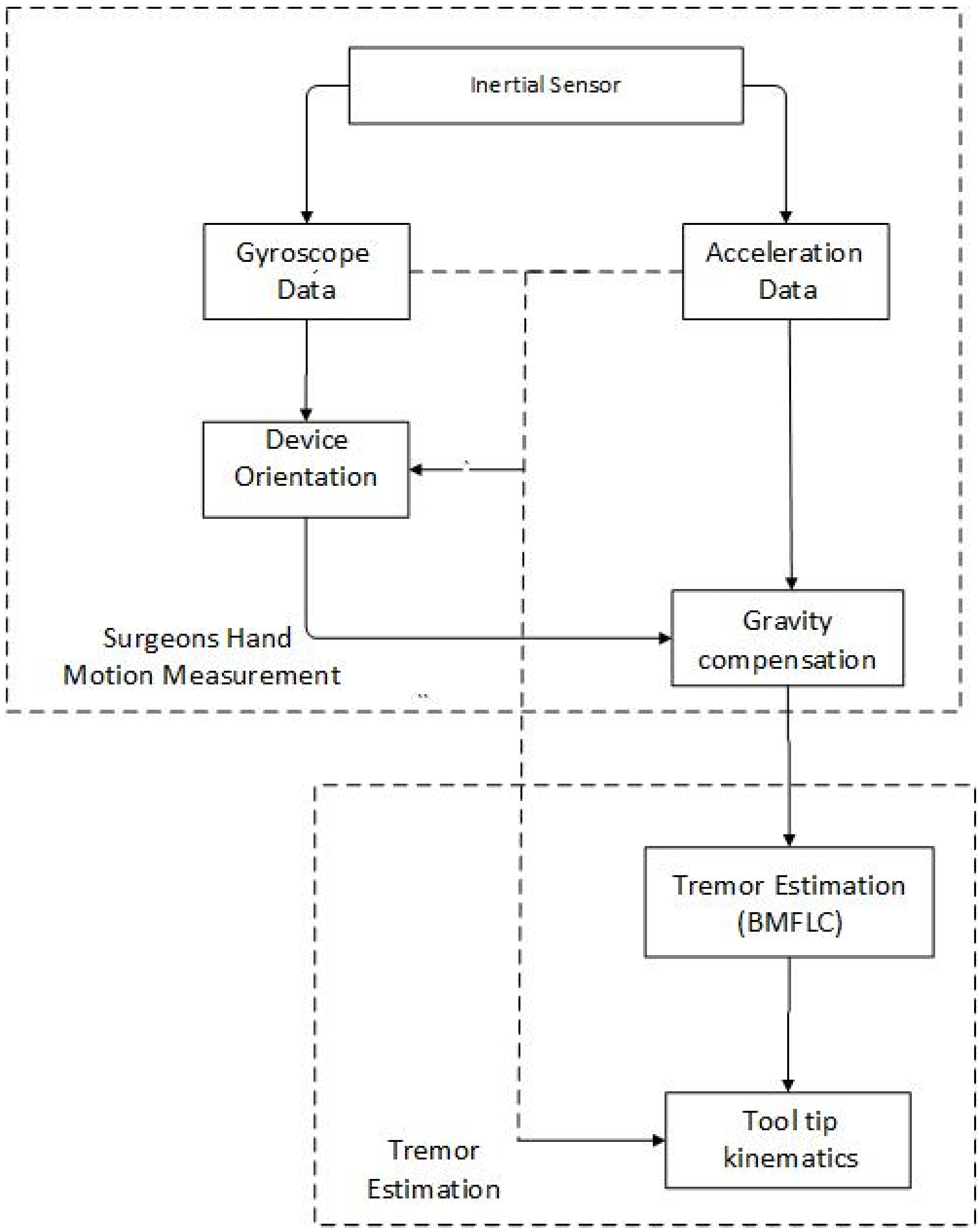

Fig. 1. System Algorithm

MEASURMENT SYSTEM

When accelerometer is static it gives a constant force of +1g due to gravity. When accelerometer tilts the projection of gravity vector along the accelerometer axis determines the acceleration of the axis which includes the gravity component as shown in Fig. 2. Thus in order to obtain acceleration measurement data due to surgeon hand motion alone gravity component has to be eliminated from the accelerometer measurement hence accurate orientation estimation of the tool is very important which further can be used for tremor estimation.

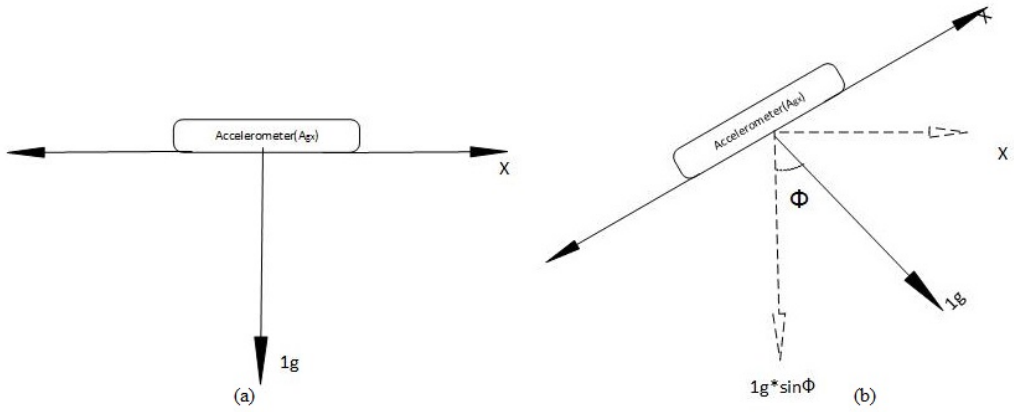

Fig. 2. (a)Static accelerometer with constant 1g gravity component (b)Tilted accelerometer with gravity component along X axis

Orientation Estimation and Gravity compensation

The inertial sensor suffers from error like noise, gyro bias etc. [3]. Hence data fusion is necessary in order to obtain accurate measurement.

Accelerometers give reliable estimate of orientation at low frequency, whereas orientation estimates using gyroscopes are reliable at high frequency. Hence their output can be combined using complementary filters for accurate estimation of orientation. By using a set of complementary filters $F_1(s)$ and $F_2(s)$, such that $F_1(s) + F_2(s) = 1$ where $F_1(s)$ and $F_2(s)$ are low pass and high pass filters respectively, it is possible to obtain an accurate filtered estimate x'(t) of the original signal x(t)[4].

$$F_1(s) = \frac{C(s)}{s + C(s)} \text{ And } F_2(s) = \frac{s}{s + C(s)} \quad (1)$$

Where

$$C(s) = K_p + \frac{k_i}{s}$$

Once we know the orientation of the device as shown in Fig. 2. we can easily obtain the acceleration caused due to surgeons hand by removing sine component from the accelerometer data along each axis.

$$[A_i] = [A_{i_m}] - [A_{i_m} * \sin\theta_i] \quad (2)$$

Where i is x y and z Axis, A_m is measured acceleration θ is orientation and angle and A is acceleration due to surgeons hand alone.

TREMOR ESTIMATION

BMFLC Algorithm

Approximate sinusoidal periodic nature of the tremor signals can be used to model it using a dynamic truncated Fourier series [5]. Thus BMFLC is used for the tremor estimation; it differentiates between voluntary and involuntary and accurately estimate tremor signal over the frequency range of 8-14Hz. The equations for the BMFLC shown [2]are implemented in MATLAB/simulink environment.

$$y_k = \sum_{r=0}^{L} \begin{pmatrix} a_r \sin(2\pi(f_0 + \frac{r}{G})k) \\ + b_{rn} \cos(2\pi(f_0 + \frac{r}{G})k) \end{pmatrix} \quad (3)$$

Where

$$L = (f - f_0)*G.$$

$$x_{r_k} = \begin{cases} \sin(2\pi(f_0 + \frac{r}{G})k), 1 \le r \le L \\ \cos(2\pi(f_0 + \frac{r}{G})k), L + 1 \le r \le 2L \end{cases} \quad (4)$$

$$\varepsilon_k = S_k - W_k^T X_k \quad (5)$$

$$W_{k+1} = W_k + 2\mu \varepsilon_k X_k \quad (6)$$

Tremor estimation at Tool tip.

Once the tremor is estimated in sensor body frame using BMFLC further to obtain cancellation signal we need to estimate effect of tremor acceleration at the tool tip and obtained displacements δ_X, δ_Y and δ_Z along X, Y and Z axis. As the acceleration at a point 'p' fixed on rigid body, A_p can be obtained if acceleration at location 'i' which is at known distance form 'p' is known. Also for calculation angular velocity and angular acceleration of the body are required.

As the in our case we will be having a motion in the micron range w can ignore centripetal acceleration and only tangential acceleration can be taken under consideration. Thus we can obtain Ap as[6].

$$A_p = A_i + \alpha * P_{ip} \quad (7)$$

Where Ai = An acceleration vector at location 'i', αi = An angular acceleration vector. and Pip = displacement vector from location 'i' to 'p'.

Further double integration of the acceleration will provide tool tip displacement due to tremor motion along X, Y and Z axis

RESULTS:

The algorithm is implemented and tested in MATLAB/Simulink Fig. 3 shows the result for algorithm with a simulated tremor as a 5 Hz sine wave. Testing is carried out over the tremor frequency range. For the testing purposes sensor to tool tip distance is taken as 8. 6 mm, 10. 4 mm and 192 mm along X, Y and Z axis. Form simulated results it can be concluded that error in the tremor estimation increase with increase in amplitude and frequency of the tremor signal. But as tremor signal lies in the low frequency range (8-14 Hz) with amplitude range in micron (100 µm)[1]. Thus developed algorithm is suitable and can be used for the tremor detection.. Further it can be used to provide equal and opposite cancellation signal for accuracy enhancement in microsurgeries.

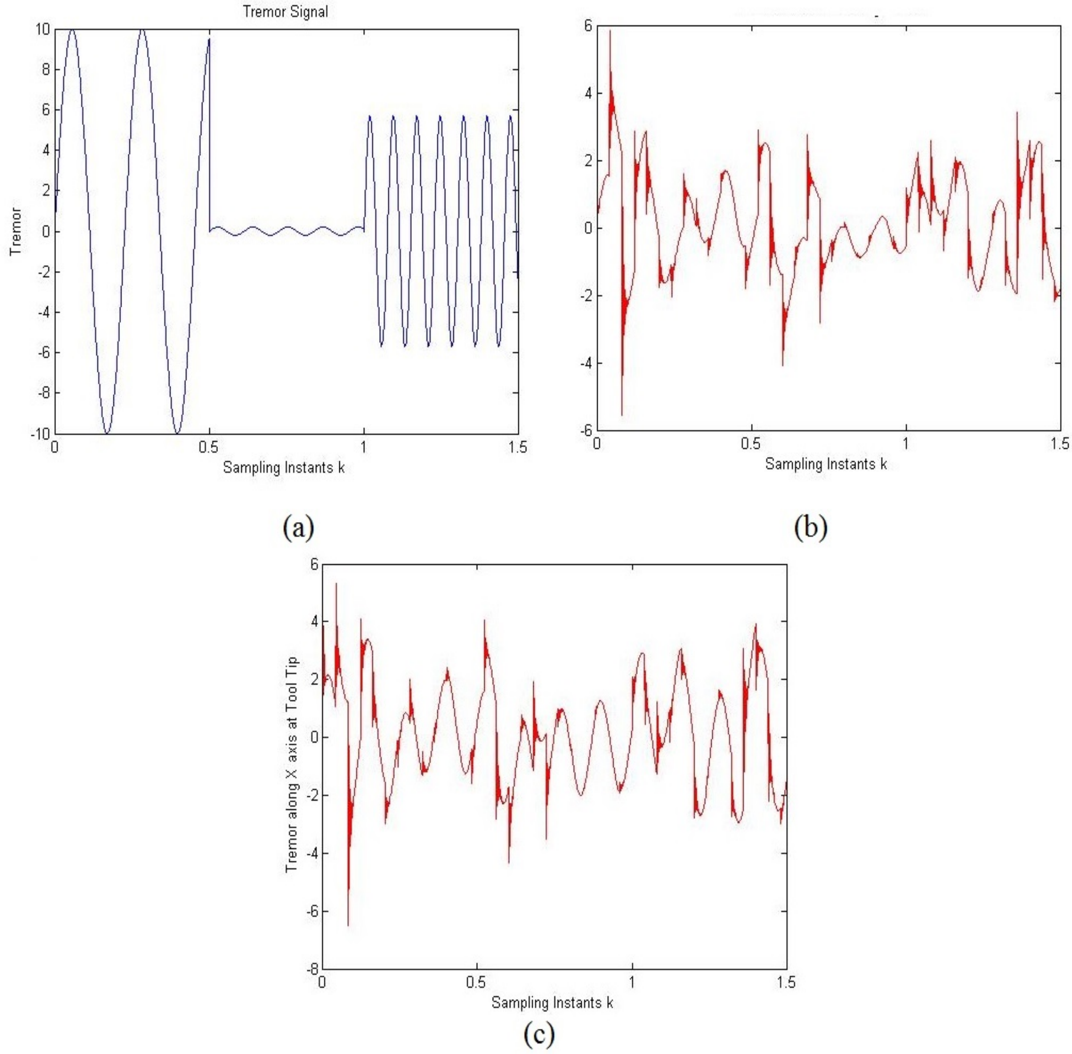

Fig. 3. (a)Simulated Tremor signal (b) Estimated Tremor Signal (c) Estimated Tremor Acceleration at Tool Tip

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