Dominant Component in Muscle Fatigue Induced Hand Tremor during Laparoscopic Surgical Manipulation

Sourav Chandra, Mitsuhiro Hayashibe, and Asokan Thondiyath

***Abstract*—Accuracy of laparoscopic surgery gets affected by the hand tremor of the surgeons. Though cognitive load is inevitable in such activity which promotes tremor, muscle fatigue induced tremor is significant among the most important sources of tremor. Characteristic of fatigue induced hand tremor and its dominant directional properties are reported in this work. For a fixed laparoscopic tool grip with temporally synchronized predefined task protocols, characteristics of fatigue induced tremors have been studied. Dominant component of tremor was found to be in the sagittal plane in case of both static and dynamic tasks. In order to relate it with the muscle fatigue level, spectral properties of surface electromyography (SEMG) were also investigated simultaneously. A study of transient effect on tool positioning was also included, which conjointly advocates the other experimental results on fatigue induced hand tremor as well.**

Index Terms- Minimal Invasive surgery (MIS), tremor compensation, muscle fatigue, Electromyography (EMG), dominant tremor axis.

I. Introduction

Studies on surgical skills and related hand tremor in MIS, have focused on perception, dexterity, and the optimal positioning of instrument[1]. The measured hand tremor RMS amplitude were found to be 2mm to 6mm within 3 to 25 Hz frequency band[2]. For surgeons under fatigued condition, tremors are substantially higher [3]. In order to increase the surgical accuracy, analysis of hand tremor in such application is crucial. In robot assisted surgery, tremor compensation strategy can be used for smarter supervisory control and in manual laparoscopic surgery this can be adopted as training metric.

SEMG reflects the internal electrical activity of a muscle pair, which makes SEMG an unique choice for study[4]. The frequency content of SEMG shows the amount of consecutive muscle fatigue as well[5]. Temporal and spectral studies of hand tremor was also been a topic of prior research[6]. A detailed analytical study was conducted to establish the relation in between joint torque variation and muscle fatigue [7]. Though studies have been reported by several groups on several aspects of hand tremor, correlating the spectral and the temporal characteristics with the dominant direction of fatigue induced hand tremor is not so well documented to the best of our knowledge. This work is primarily directed towards analyzing fatigue induced hand tremor component in different orthogonal plane and finding the principle direction of the tremor in case of laparoscopic tool manipulation.

Sourav Chandra (phone: +918015844089. e-mail: ed11d004@smail.iitm.ac.in) and Asokan Thondiyath (e-mail: asok@iitm.ac.in) are with Indian Institute of Technology Madras, Chennai-600036, India.

Mitsuhiro Hayashibe (e-mail: Mitsuhiro.Hayashibe@inria.fr), is with INRIA Demar team and LIRMM, CNRS/University of Montpellier, Montpellier-34095, cedex 5, France

II. Experimental Setup

In order to perform the tremor studies for laparoscopic surgical activities, a virtual laparoscopic simulator was designed. The system had provision to track the tool tip position while recording SEMG and acceleration data from the sensor placed on surgeon's hand. Fig. 1 shows the schematic of the setup and Fig. 2 shows the actual system developed. Two cameras (Microsoft LifeCam Studio™) were used for tracking the tool tip, as shown in the Fig.2. They were calibrated using NI Vision ™ camera calibration package. The laparoscopic tool tip was tracked in three dimensional manipulation space using color segmentation algorithm of NI Vision Tracking™ package; a marker was placed at the laparoscopic tool tip. Positioning of laparoscopic tools (a *tenaculam forceps* and a *grasper*) as well as video monitor was based on accepted standards and common laparoscopic surgical scenarios[1]. An arm rest was also provided with the set up[8].

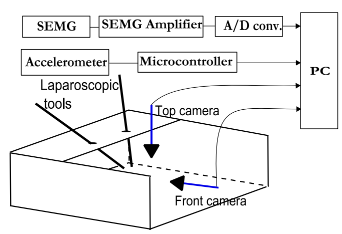

Figure 1.Schematic of the set up.

Figure 2.The experimental setup.

For measuring hand tremor, two digital accelerometers (Freescale™ MMA8452) were used with a sampling frequency of 400 Hz and a resolution of 12 bit. The digital SEMG amplifier unit was designed with Common Mode Rejection Ratio (CMRR) 90 and with a gain of 250. SEMG signal was digitized with a sampling frequency of 4 kHz with NI-USB 6210 after low pass filtering (1 kHz). Commercially available disposable surface (Ag/AgCl) electrodes were used for acquiring SEMG signals. For the experiments, given tasks were:

- static tool holding (without any movement);
- point tracking;
- line following.

While the first task is implemented by isometric contraction of muscle, the other two task results from isokinetic activities of the concerned muscle.

A mixed group of male and female (total 8) subjects had volunteered for the experiment. All of the subjects had a priory familiarization with laparoscopic manipulation.

978-1-4244-7929-0/14/$26.00 ©2014 IEEE

They were instructed to firmly hold the tool with a pre instructed grip to reduce variability in the grip. A firm grip with non slip condition between palm and tool was considered as a rigid system in the analysis.

III. ANALYSIS OF DEPENDENT FATIGUE INDUCED HAND TREMOR IN LAPAROSCOPIC TOOL MANIPULATION

A. Study of dominant tremor axis

A static tool holding task with a typical laparoscopic pinch grip is produced by isometric contraction of respective muscles. This study is important to understand the dominant direction of the fatigue induced hand tremors while holding the tool, without any movements. For each session, the data was acquired for 5 minutes. In this experiment, one tri axial accelerometer was placed on the palm and another one was placed on the middle of the forearm as shown in Fig.3. Palm and Fore arm accelerometer gives tremor generated due upper arm and fore arm muscles. Subjects were also trained to get familiarized with the type of tool manipulation activity before the experiment. Data processing was done in two steps, first the offset nullification, followed by a band pass (2nd order Butterworth band pass with cut off at 0.1 Hz) filter for extracting the tremor data[9]. A typical result from one of the subjects is shown in Fig.4.

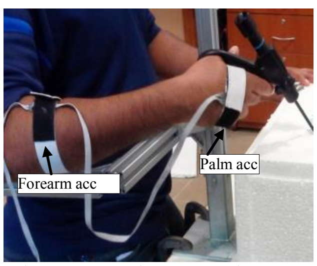

Figure 3. Accelerometer placement. on palm and forearm

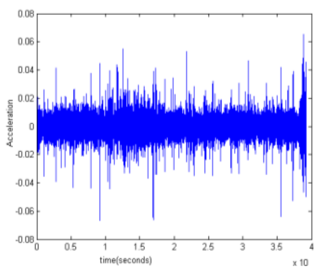

Figure 4. Accelerometer output in dominant axis.

Root Mean Square Error (RMSE) of the tremor was calculated for each axis of the accelerometer recording for all subjects, the mean for all the subjects was also calculated along with its standard deviation. Average tremor RMSE in different axis for all subjects is shown in Fig.5.

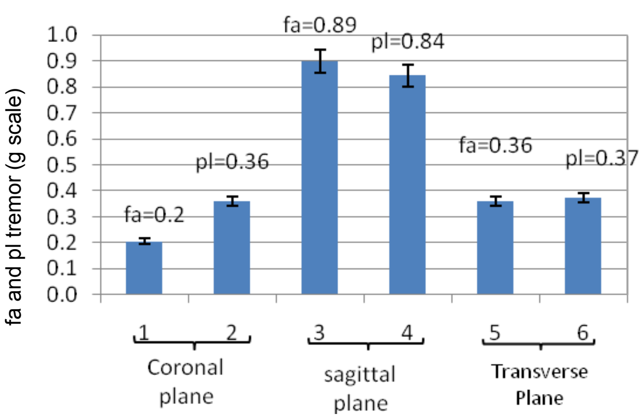

Figure 5. Tremor component in all three axis.

Forearm accelerometer output (1, 3, and 5) is denoted as 'fa' and 'pl' represents the accelerometer (2, 4, and 6) output placed on the palm. Result shows that the variation in the sagittal plane is considerably higher than the other two planes.

This experiment helps us to find out the dominant axis of tremor. One of the principal muscles which are responsible for this axis motion was found to be *Flexor Carpi Ulnaris* (FCU) as shown in Fig. 9. This superficial muscle with comparatively flat belly was preferred for SEMG recording in case of radial deviation of wrist.

B. Study of tremor during hand motion

As the tremor studies in static condition shows that tremor in sagittal plane is significantly higher than the other two, this study was extended to find out the dominant tremor direction in case of hand in motion under laparoscopic pivotal constraint. These types of task dependent motions are produced by isokinetic muscle contraction. Subjects were instructed to move the tool along a pre-determined trajectory (as shown in Fig.6) for 8 minutes. This trajectory was chosen based on standard laparoscopic training protocol and with the help of senior laparoscopic surgeons. Time synchronization was provided to the subjects visually, to minimize the subjective variation of hand movement among the subjects, as much as possible[10]. Laparoscopic tool tip was optically tracked (shown in Fig.7) together with the accelerometer recording. Tooltip movement in each separate axis was analyzed individually as shown in Fig. 8.

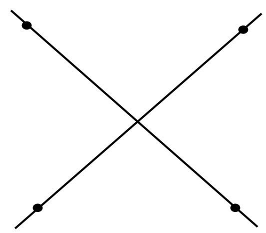

Figure **6**. Defined trajectory.

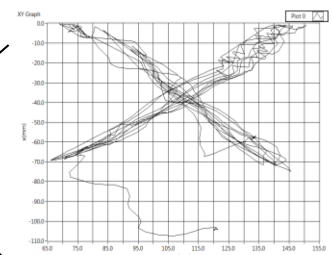

Figure **7**. Tracked tooltip position

Positional variations of the tooltip in all three planes are individually plotted in Fig.8 with respect to time base for one subject.

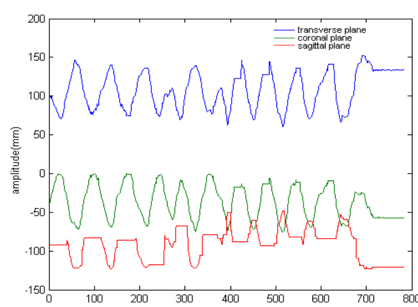

Figure 8. Tooltip position variation.

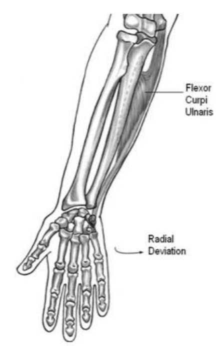

Figure 9. FCU muscle.

The tracked positions in each direction were high pass filtered with cut off of 3 Hz retaining the higher frequency of the movement. This experiment shows that even when the given task is on another plane, average hand tremor is more prominent in the sagittal plane as shown in Fig. 10.

Along with the optical tracking, an accelerometer was also placed on the subject's palm.

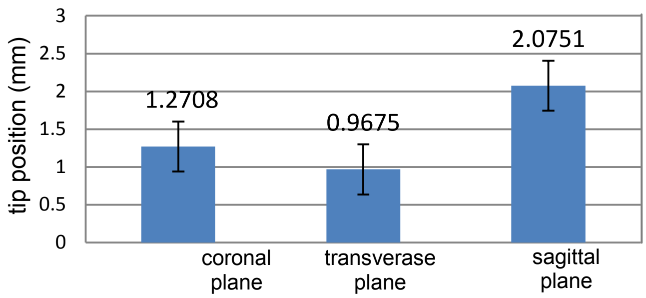

Figure 10. Mean RMSE of the tracked tool tip.

All the three axis data were high pass filtered; average variations for all 8 subjects were calculated along with its deviation as shown in Fig. 11. This result also advocates the idea about the dominant plane of tremor, which were evident from the previous experiments.

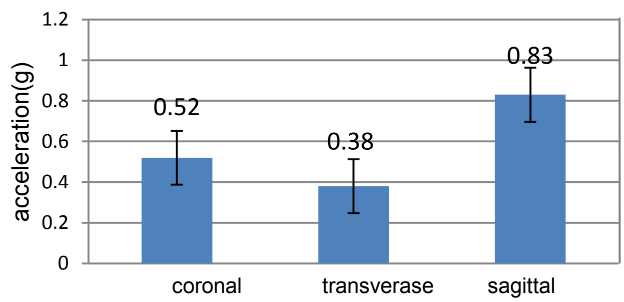

Figure 11. Mean RMSE of the tri-axis accelerometer.

C. Temporal studies of the tremor

Based on the previous data analysis with the above mentioned laparoscopic task, a temporal study of the tremor was also conducted on all 8 subjects. The tremor (sensed in the palm accelerometer) in the sagittal plane was sampled with a window size of 5 seconds and the amplitude variation was calculated with (RMSE). The process was continued with a gap of 50 seconds (total 55 second time cycle is termed an epoch). Nine of such epochs were studied. The mean RMSE for all the subjects were calculated along with its deviation.

The result is plotted in Fig. 12. The increasing trend of the graph shows clear indication of positional inaccuracy increases with the time due to muscle fatigue.

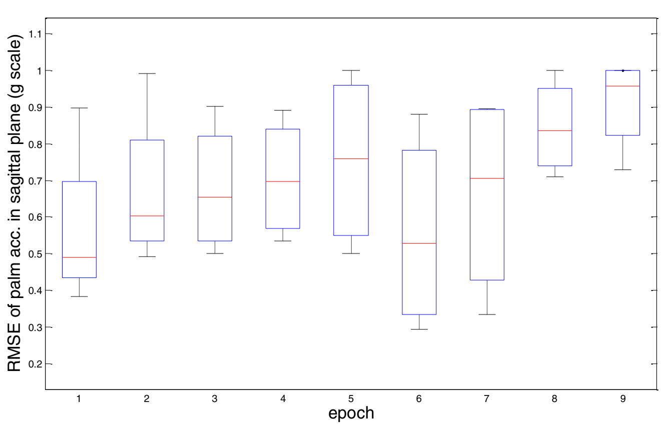

Figure 12. Temporal characteristics of hand tremor for all the subjects.

D. Study of SEMG and its relation with tremor

To understand the temporal characteristic of along with muscle fatigue, change of SEMG median frequency was studied simultaneously from FCU muscle (shown in fig.9). Previous studies showed that tremor increases with time. As SEMG is a qualifier of muscle activities, an experiment was done to find out the SEMG behavior with time for the aforementioned activity. Electrode pair was placed on the belly of FCU muscle with an inter electrode distance of 4cm (as shown in Fig. 9). The protocol was designed using the S.E.N.I.A.M standards. As a part of post processing, the signal was band limited with a 3rd order Butterworth filter having lower and upper cut off as 3Hz and 1kHz.

Muscle fatigue is well reported to be reflected in the frequency domain parameters of the surface myoelectric signal[11].Time domain representation of SEMG signal looks like a random noise sequence, and in frequency domain it shows a peak around frequency of 100 Hz (Fig.13).

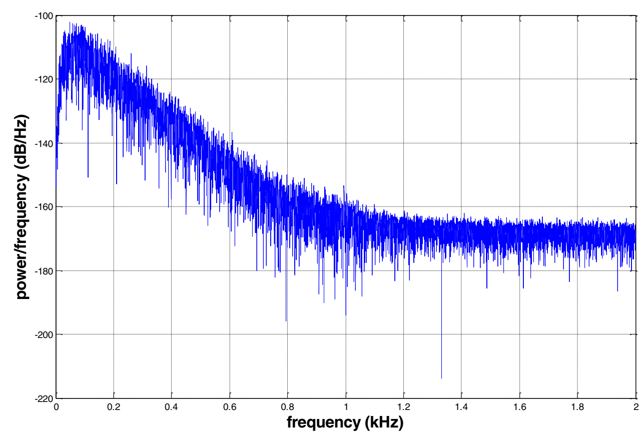

Figure 13. Power spectrum of FCU SEMG without fatigue.

Median frequency of SEMG is a convenient measure of muscle fatigue[5], considering the signal to be quasi stationary with a small window. The median frequency is found to be decreasing gradually (Fig.14) throughout the course of the laparoscopic activity. A plot of median frequency for all 8 subjects shows a decreasing trend clearly. The median frequency change was having a span of more than 20 Hz throughout the laparoscopic task given to the subjects.

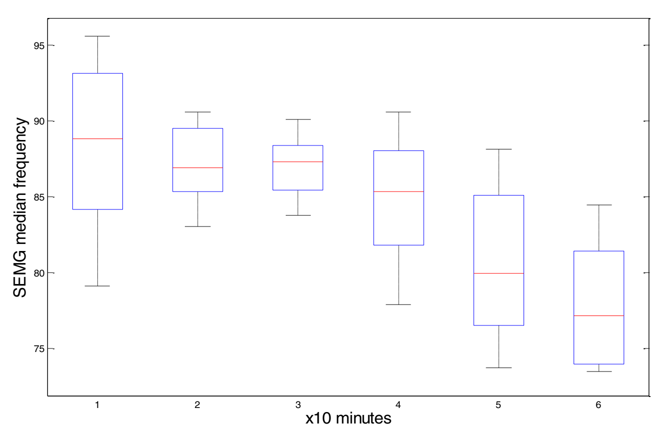

Figure 14. FCU SEMG median frequency change with time.

E. Transient studies of the tremor at tool tip

Recent literatures show that inaccuracies in laparoscopic tool positioning does not only change in overall response but it also has transient characteristics[9]. Transient effect of tool positioning inaccuracy is one of the qualifiers that found to increase with time. A laparoscopic grasper tool tip was tracked for restricted (1cm up/down) movements in sagittal plane. All 8 subjects were instructed to hold a laparoscopic grasper and perform a push and hold task to perform a 1 cm depth movement and to hold for 10 seconds. The task was repeated every 5 seconds. The data was acquired during a 5 minute long experiment. A metronome was provided to synchronize the activity.

Along with tool tip position, SEMG and accelerometer data were recorded for further analysis. The position plot for the tracked tool tip in sagittal plane is shown in Fig. 15.

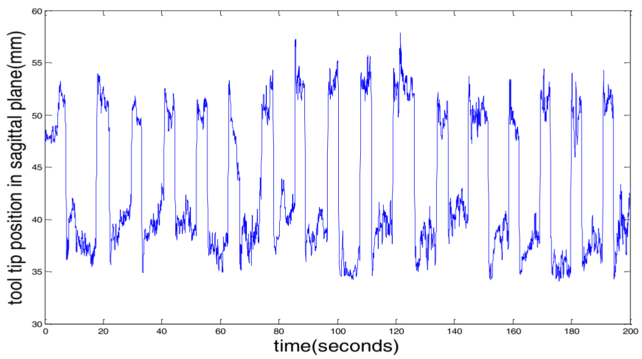

Figure 15. Position of tool tip.

The standard deviation of the positional variation at holding condition was calculated. Positional RMSE of all subjects for each alternative cycle of such movement (epoch) is shown in Fig. 16. An increasing linear trend was found in the RMSE variation with time

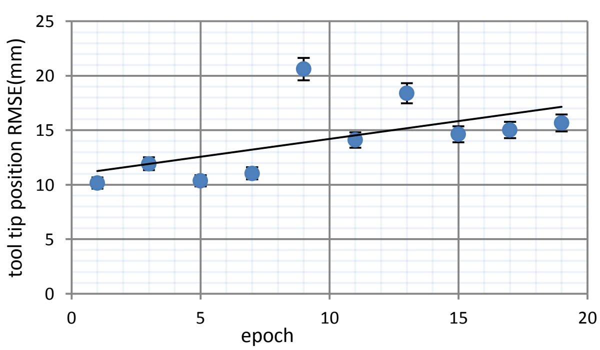

Figure 16. Increment of position inaccuracy in depth movement.

The trend of the plot shows that inaccuracy increase due to muscle fatigue. The results emphasize the necessity of introducing time dependant response property analysis to accurately model myoelectric response with the manifested mechanical hand tremor signal.

IV. DISCUSSION AND CONCLUSION

Moving the laparoscopic surgical tool is considered to be voluntary manipulating task which exerts artifact on the accuracy of the positioning accuracy. Most importantly, this inaccuracy was found to be increasing with time in this experiment. Though the increment was not linear, an increment of this inaccuracy was mainly due to the muscle fatigue during laparoscopic task since we observed the decrease of mean frequency of SEMG along with proportional increase of hand tremor. Both for the cases of isometric and isotonic muscle contraction in laparoscopic environment, sagittal plane movements were worse being affected by the fatigue induced tremor. While designing the protocol, minimum cognitive load is considered. In both static and dynamic laparoscopic task, the dominant component was found in sagittal plane with both temporal and spectral studies. As the laparoscopic task requires a subject to hold the arm posture against gravity, the sagittal component tends to have a significant hand tremor.

Frequency domain change of SEMG is a metric of muscle fatigue state but it was found to be varying significantly due to fatigue and being highly correlated to the amount of the tremor level. However, a task dependent study of muscle fatigue cannot be standardized as contraction dynamics and underlying biochemical process is highly subjective.

Currently a better metric for muscle fatigue is being analyzed and studied with a purview of relation in between SEMG and hand tremor.

V. ACKNOWLEDGMENT

Funding for this work was provided by Indian Institute of Technology Madras, and Erasmus Mundus Action 2 program.

REFERENCES

[1] A. N. Supe, G. V Kulkarni, and P. A. Supe, “Ergonomics in laparoscopic surgery,” *J. Minim. Access Surg.*, vol. 6, no. 2, pp. 31–36, 2010.

[2] P. S. Slack and X. Ma, “Tremor amplitude determination for use in clinical applications,” *Meas. Sci. Technol.*, vol. 18, no. 11, pp. 3471–3478, Nov. 2007.

[3] R. Sandoval, R. A. Maclachlan, M. Y. Oh, and C. N. Riviere, “Positioning Accuracy of Neurosurgeons,” in *29th Annual International Conference of the IEEE EMBS*, 2007, pp. 206–209.

[4] D. J. Bennett, “Stretch reflex responses in the human elbow joint during a voluntary movement.,” *J. Physiol.*, vol. 474, no. 2, pp. 339–51, Jan. 1994.

[5] J. F. Sarmiento, A. B. Benevides, M. H. Moreira, A. Elias, T. F. Bastos, I. V Silva, and C. C. Pelegrina, “Comparative muscle study fatigue with sEMG signals during the isotonic and isometric tasks for diagnostics purposes.,” in *Annual International Conference of the IEEE EMBS*, 2011, vol. 2011, no. c, pp. 7163–6.

[6] P. S. Slack, C. J. Coulson, X. Ma, K. Webster, and D. W. Proops, “The effect of operating time on surgeons’ muscular fatigue.,” *Ann. R. Coll. Surg. Engl.*, vol. 90, no. 8, pp. 651–7, Nov. 2008.

[7] Q. Zhang, M. Hayashibe, P. Fraisse, and D. Guiraud, “FES-Induced Torque Prediction With Evoked EMG Sensing for Muscle Fatigue Tracking,” *IEEE-ASME Trans. mechatroics*, vol. 16, no. 5, pp. 816–826, 2011.

[8] R. Galleano, F. Carter, S. Brown, T. Frank, and A. Cuschieri, “Can Armrests Improve Comfort and Task Performance in Laparoscopic Surgery?,” *Ann. Surg.*, vol. 243, no. 3, pp. 329–333, 2006.

[9] W. T. Ang, “Active Tremor Compensation in Handheld Instrument for Microsurgery Wei Tech Ang,” Carnegie Mellon University, 2004.

[10] A. J. Hansen and R. T. Schlinkert, “Hand movements in laparoscopic suturing,” *Surginal Endosc.*, vol. 19, pp. 412–417, 2005.

[11] A. Phinyomark, S. Thongpanja, and H. Hu, “The Usefulness of Mean and Median Frequencies in Electromyography Analysis,” in *Computational Intelligence in Electromyography Analysis*, G. R. Naik, Ed. InTech, 2012, pp. 195–220.