33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Repeatability Analysis of Rollover Recognition in Changing Myoelectric Electrode Condition

Takeshi Ando, *Member*, *IEEE* and Masakatsu G. Fujie, *Senior Member, IEEE*

***Abstract*— Bone cancer metastasis patients feel severe pain while performing rollover movement. We have been developing a robotic trunk orthosis to support the rollover movement in bed for bone cancer metastasis patients. In this support system, the myoelectric signal is used to recognize the start timing of the rollover movement. However, the characteristics of the myoelectric signal can change easily from long-term use and due to electrode misalignment. In this paper, the effects of long-term use and electrode misalignment in rollover movement were analyzed. It was found that continuous usage of less than 18 hours was suitable. In addition, the electrode was needed to be attached around the ASIS from 0 to 23 (deg) to obtain a large potential and quick response signal.**

I. Introduction

WEARABLE robots to support many kinds of movements have been developed for elderly and disabled people all over the world [1–3], because we are facing a society that is increasingly dominated by the elderly. A surface myoelectric signal, which is measured a little before the start of body movement, is expected to act as the trigger signal for supporting the body movement.

We have also developed a myoelectric signal-controlled trunk orthosis, shown in Fig. 1, to support rollover movement, since rolling over in the bed is one of the most important activities of daily living (ADL). In particular, the rollover movement is focused on as the target movement of bone cancer metastasis patients. Bone cancer metastasis patients feel severe pain while performing rollover movement. The core of the rollover support trunk orthosis system is a pneumatic rubber muscle that is controlled by the myoelectric signals from the trunk muscle. As shown in Fig. 1, in our system, based on the analysis of trunk muscle activities, the surface myoelectric signal of the internal oblique (IO) muscle was selected as the input signal for the intelligent orthosis to recognize rollover movement, because myoelectric signal is detected before the rollover starts under isometric movement

Manuscript received March 15, 2011. This work was supported in part by: the MEXT global Center of Excellence Program “Global Robot Academia”, Waseda University, Tokyo, Japan; the MEXT Grant-in-Aid for Scientific Research (A) (20240058) and Grant-in-Aid for Scientific Research (20700415), The Okawa Fundation (09-08) and Rivernest.

T. Ando is with Dept. of Robotics & Design for Innovative Healthcare (Panasonic), Graduate School of Medicine, Osaka University, Osaka, Japan and Faculty of Science and Engineering, Waseda University, Tokyo, Japan. (Corresponding author to provide phone: +81-3-5286-3412; e-mail: takecando@gmail.com).

M. G. Fujie is with Faculty of Science and Engineering, Waseda University, 59-309, Okubo, Shinjyu-ku, Tokyo, 169-8555, Japan.

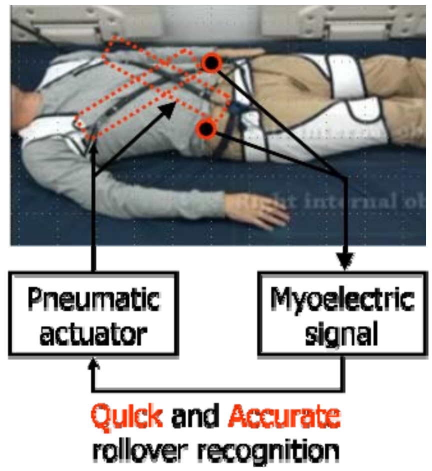


Fig. 1 Concept of rollover support trunk orthosis using myoelectric signal and pneumatic rubber actuator.

[4]. In addition, based on the recognition of rollover, the pneumatic rubber actuators were arranged on the chest side of the trunk to assist rollover movement [5]. Therefore, the most important technology is to recognize rollover movement quickly and with high accuracy using an original neural network called Micro Macro Neural Network (MMNN) [6]. The MMNN discriminated the rollover from the other movement on the bed such as standing up movement [9].

The myoelectric signal is easily affected by change in electrode position and orientation even when the electrode is placed on the target muscle (IO muscle). When the operation of robotic rollover support system is managed in real environments such as hospitals, it is very difficult for the medical staff to place the electrode at the exact same position and orientation. In addition, the signal characteristic varies over time due to fatigue and sweat even if the electrode is placed on the same position and orientation [7]. Tsuji et al [8] proposed an on-line entropy-based learning algorithm to solve this problem for the artificial upper limb which is normally moved frequently and then gets sweaty easily. However, the rollover movement, which is the target movement of this study, is normally performed less frequently, such as once in 15 minutes, and sweat is not produced easily.

The originality of this paper is, firstly, to measure and analyze the myoelectric signal generated in rollover during long-term evaluation to discuss the need for an algorithm to solve the sweat effect. The second point is to measure the myoelectric signal to analyze the effect of electrode position and orientation in rollover to determine the permissible area for getting a reproducible signal.

II. SIGNAL CHARACTERISTIC CHANGE IN LONG-TERM MEASUREMENT

A. *Objective*

The characteristic change in the myoelectric signal in long term use is evaluated, because it has been treated as a problem in the myoelectric signal controlled artificial hand. The objective is to investigate time-dependable change in the myoelectric signal in myoelectric controlled rollover support systems. In addition, the need to cope with time-dependable change is discussed.

B. *Methodology*

A healthy young subject was made to perform rollover movements thirty times, at timings of 0, 3, 6, 12, 18 and 24 hours after starting the measurement. At each rollover movement, the myoelectric signal was measured. The electrode was not replaced during this period of 24 hours. The EMG electrodes (Biometrics inc.; active electrode made of AgCl; electrode spacing: 20 (mm); sampling frequency: 1(kHz)) were placed on the lower part of the right and left IO muscles. In addition, the experimental conditions were: maximum temperature 27.1 Celsius; minimum temperature 19.7 Celsius; and humidity 53%. During this experiment, the subject did not move outdoors or perform strong movements.

The maximum (*Max.*) and average reflected value (*ARV*) voltages during rollover movement and average (*noise*) voltage in relax phase were calculated as evaluation indexes.

Before starting the experiments, we gave the subject a detailed account of our experimental objectives, explained that they were entitled to stop the experiment whenever they desired, and obtained their consent.

C. *Result*

Figure 2 shows *Max.*, *ARV* and *noise*. There was no decrease in these three values for 18 hours after starting measurement. However, after 24 hours, *Max.* decreased but remained sufficiently larger than *noise*. Therefore, it was possible to measure the myoelectric signal accurately even 24 hours after the electrode was changed, without it being affected by sweat or other factors.

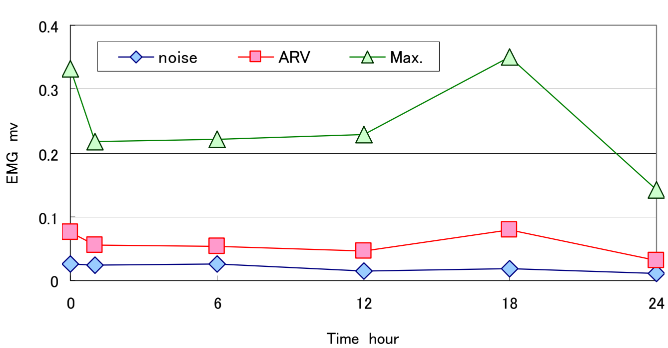


Fig. 2 Effect of continuous use on myoelectric signal

D. *Discussion*

The reasons why it was difficult for the measured myoelectric signal to be affected so as not to be measured or recognized in long-term evaluation were: firstly, the subject did not move strongly and did not sweat. Secondly, the electrode is placed not on the dorsal side where the electrode will be wedged between back and bed but on the ventral side which is drafty.

According to this result, the nurse who works at the terminal care ward is required to change the electrode once or twice in a day. This work is of low burden for the busy nurse.

III. SIGNAL CHARACTERISTIC CHANGE IN CHANGING THE ELECTRODE POSITION AND ORIENTATION

A. *Objective*

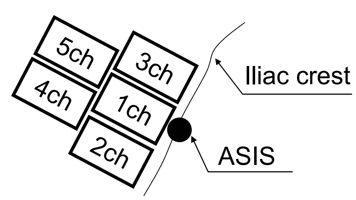
The objective is to analyze the effect of electrode mis-arrangement, position and orientation on the myoelectric potential of the IO muscle in rollover movement.

B. *Methodology*

Firstly, the effect of electrode position on the measured myoelectric potential was analyzed. The myoelectric signals of the IO muscle in rollover movements were measured at five electrodes around the ASIS (Anterior Superior Iliac Spine). The positions of the electrodes are shown in Fig. 3. The reference electrode was attached on the head of the talus.

Secondly, the effect of electrode orientation on the measured myoelectric potential was analyzed. At a position around the ASIS which was selected as the optimal position, as shown in

(a) Attached position



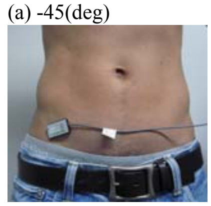
(b) Position model

Fig. 3 Electrode position

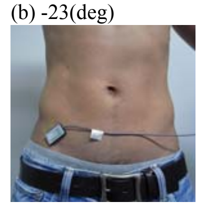
(a) -45(deg)

(b) -23(deg)

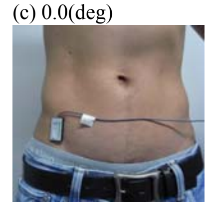
(c) 0.0(deg)



(d) 23(deg)



(e) 45(deg)



(f) 90(deg)

Fig. 4 Electrode orientation

Fig. 4, the myoelectric signal of the IO muscle was measured at orientations of six angles (-45, -23, 0, 23, 45 and 90 (deg) to the line which connected the right and left ASIS) during rollover movement. The reference electrode was attached on the head of the talus.

In both experiments, two subjects each performed rollover movements thirty times. The subjects were thin body shape, because bone cancer patients are often thin. The Average Reflected Value (ARV) was calculated; this is the average value during the rollover movement. The time to conduct rollover movement was calculated using an ON/OFF switch that was grasped by the subject. The same electrodes used in Section 2 were used.

We gave the subjects a detailed account of our experimental objectives, explained that they were entitled to stop the experiment whenever they desired, and obtained their consent.

C. Result

Figure 5 shows an example of raw myoelectric signals measured at five different positions. TABLE 1 shows the ARV calculated using the data of thirty rollover movements. The signals measured at 1ch, 2ch and 3ch were found to be more active than those at 4ch and 5ch.

Fig. 6 and TABLE 2 show examples of raw myoelectric signals and extracted value measured for six different electrode orientations from -45 (deg) to 90 (deg). The strong activity of the IO muscle was confirmed at 0, 23 and 45 (deg), which angles almost corresponded with the muscle fiber direction of the IO muscle.

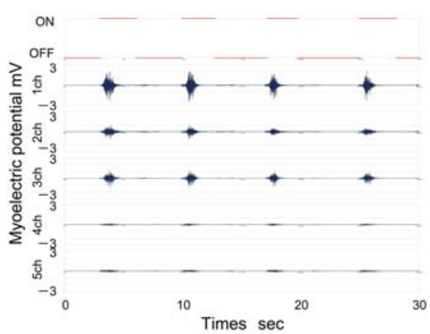


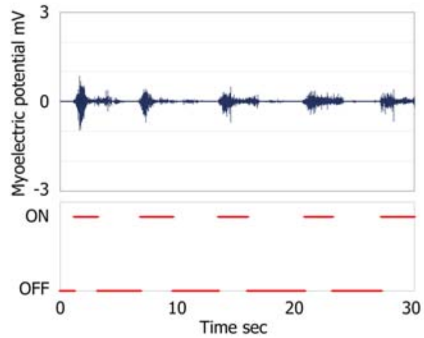
Fig. 5 Measured myoelectric signal at different positions

Table 1 Effect of electrode position

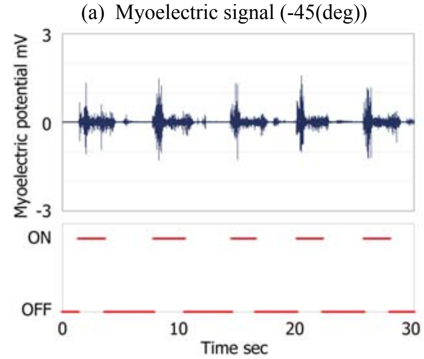
Channel #.	1	2	3	4	5
Myoelectric potential mV/sec	0.077	0.035	0.054	0.012	0.014
S.D. mV/sec	0.027	0.011	0.018	0.004	0.003

Table 2 Effect of electrode orientation

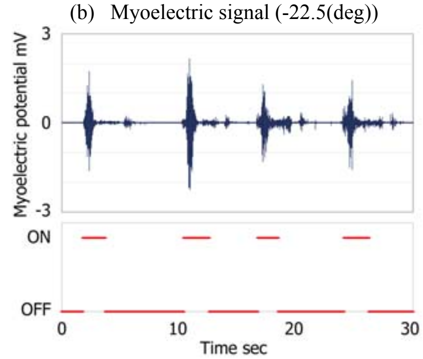
Electrode orientation deg	-45	-23	0.0	23	45	90
Myoelectric potential mV	0.040	0.096	0.075	0.086	0.105	0.047
S.D. mV	0.014	0.029	0.039	0.018	0.037	0.019



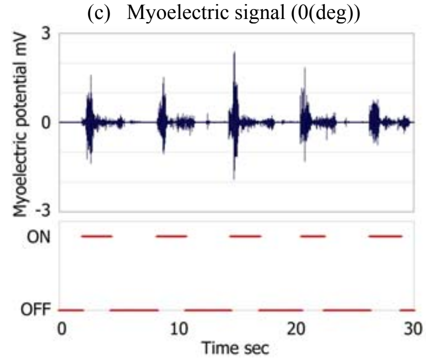
(a) Myoelectric signal (-45(deg))



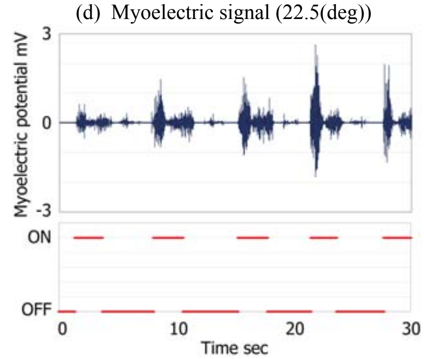
(b) Myoelectric signal (-22.5(deg))



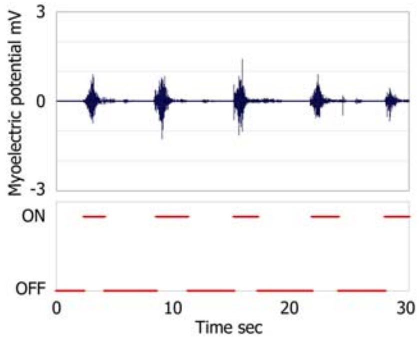
(c) Myoelectric signal (0(deg))



(d) Myoelectric signal (22.5(deg))



(e) Myoelectric signal (45(deg))



(f) Myoelectric signal (90(deg))

Fig. 6 Effect of electrode orientation on the myoelectric signal

D. Discussion

Regarding electrode position, the myoelectric potential of CH. #1 which is the closest to the ASIS was the largest. The strong muscle activities at the up (#3) and down (#2) positions of CH. #1 were confirmed. On the other hand, the activities of CH. #4 and #5, which were far from the the ASIS to the regio umbilicalis side, were weaker in rollover movement. This is because the innervation area of the IO muscle during rollover movement exists around CH. #4 and #5. Therefore, it is more suitable for the electrode position to be put along the iliac crest, especially around the ASIS.

On the other hand, on the electrode orientation, from the view point of anatomy, the IO muscle was affected by the rectus abdominis muscle at 90(deg) and the external oblique muscle at -45 and -23(deg). However, the myoelectric signal was measured at any orientation, because as mentioned in [4], the rollover is conducted not only by the IO muscle but also by other trunk muscles. However, the myoelectric potential at -45 and -90 (deg) became smaller than that at other orientations.

Therefore, the suitable position and orientation were respectively determined as the position around the ASIS and angle from 0 to 45 (deg) so as to run parallel with the IO muscle fiber orientation. Moreover, the effect of position on the myoelectric potential of the IO muscle in rollover movement is larger than that of electrode orientation.

IV. ROLLOVER RECOGNITION IN CHANGING ELECTRODE POSITION AND ORIENTATION

A. Objective

In Section III, it was found that misalignment of the electrode had little effect on the measured myoelectric signal of the IO muscle in rollover movement. The objective of this section is to analyze the effect of electrode position and orientation on the recognition performance from the view points of recognition rate and response performance.

B. Methodology

The data of the myoelectric signals was the same one which was measured at Section III at five different positions and six different orientations. An original neural network, known as MMNN [6] to accurately recognize slower movement such as rollover with quick response, was used to evaluate the difference in recognition performance. The MMNN is able to recognize the rollover more correctly and steadily using the long past time-series data of the myoelectric signal.

Firstly, the effect of electrode position on recognition performance was analyzed. As shown in the previous section, the myoelectric signals of CH. # 1, 2 and 3 which were placed along the iliac crest were similar. On the other hand, the myoelectric potential of CHs. #4 and #5 which were apart from the iliac crest was smaller. Therefore, CH #1 and CH #5, which were the representative examples of each area, were used as test data for the learning machine. Then, the recognition rate and response performance were evaluated by using the data of CH #1-#5 as the test data.

As the evaluation index on the recognition rate, the difference between test data output and teaching data per time, *Error*, was used as the following equation;

$$Error = \Sigma\,(EMG_{test} - EMG_{teach})/t_{rollover} \quad (1)$$

where EMG_{test} is the test data, EMG_{teach} is the teach data and $t_{rollover}$ is the time length for rollover movement.

As evaluation index on the response performance, the response time, $t_{response}$, is the time from the start of the rollover movement to the recognition of the rollover movement by the neural network:

$$t_{response} = t_{recognition} - t_{movement} \quad (2)$$

where $t_{recognition}$ is the time when the rollover is recognized and $t_{movement}$ is the time when the rollover starts.

In this paper, the difference between response time at #1 and that at other channels were calculated to analyze the effect of the channel position.

Secondly, the effect of electrode orientation on recognition performance was analyzed. The evaluation indexes were the same as those in position effect evaluation. The values of each index were calculated by applying the values when teach data was used as the test data, because the recognition performance was best when teach data was used as the test data.

C. Result

Table 3 shows the Error, which is the index of recognition rate, when the data of CH #1 and #5 is learning data. In addition, Table 4 shows $t_{response}$, which is the index of response performance, when the data of CH #1 and #5 is learning data. Significant difference to the CH. #1 value was evaluated by Student t-test ($p<.05$) at every data point.

It was confirmed in Table 3 that the recognition at CH. #1,

Table 3 Relationship between Error and electrode position.

		Test data				
		1ch	2ch	3ch	4ch	5ch
Learning data	1ch	0.117± 0.078	0.113± 0.069	0.132± 0.091	0.259± 0.130*	0.196± 0.110*
	5ch	0.134± 0.072	0.109± 0.060*	0.140± 0.084	0.268± 0.122*	0.230± 0.091*

Note that values is average±S.D. and unit is %. "*" shows the significant difference to the data of 1ch.

Table 4 Relationship between response and electrode position.

		Test data				
		1ch	2ch	3ch	4ch	5ch
Learning data	1ch	0	10 ±44	-11 ±64	172 ±137*	15 ±84
	5ch	0	25 ±44*	5 ±58	113 ±89*	15 ±72

Note that value is average±S.D. and unit is %. "*" shows significant difference to the data of 1ch.

#2 and #3 was more accurate than that at CH. #4 and #5 when either Ch. #1 or Ch. #5 was the teaching data. A similar tendency was confirmed at both the teaching data. In addition, the result of Table 4 was similar to that of Table 3. For example, the response time of CH.#4 was quite larger than that of CH. #1, #2 and #3.

Secondly, the effect of electrode orientation is summarized at Table 5. As shown in Table 5, the recognition result was "small error and stable" in any test data when the learning data was -23, 23 or 45(deg). On the other hand, the recognition was "small error and stable" when the test data at 0, 23(deg) was used. About response performance, some of the rollover movements were not recognized when the teaching data was data at -45(deg) (6 out of 10 times) and 90(deg) (2 out of 10 times) and the test data was the data at 0(deg) and 23(deg).

D. Discussion

The measured myoelectric signal at CH. #4 and #5 was smaller than that at CH. #1, #2 and #3. In the ON/OFF learning, the larger myoelectric potential was recognized as ON when the smaller signal was used as learning data of ON. On the other hand, it is difficult for the smaller signal to be recognized as ON when the larger signal is used as learning data of ON.

Therefore, the effect of electrode position on recognition performance was low, and the attachment position therefore does not need to be strictly fixed. However, it was recommended that the electrode be placed at CH. #1, #2 and #3 which was the position along the iliac crest. On the other hand, the effect of the electrode orientation was larger than that of the electrode position. An electrode orientation from -23(deg) to 23(deg) was suitable for accurate and quick recognition, because this orientation was in a parallel direction to the fibers of the IO muscle.

V. Conclusion

We have been developing a robotic trunk orthosis to support rollover movement of bone cancer metastasis patients. In this support system, the myoelectric signal is used to recognize the start timing of the rollover movement. However, the characte-ristics of the myoelectric signal can change easily in long-term use and from electrode misalignment. In this paper, the effects of long-term use and electrode misalignment were analyzed in the rollover movement. The results indicated that continuous usage of less than 18 hours was suitable. In addition, the electrode was required to be attached around the ASIS from 0 to 23 (deg) to obtain large potential and quick response signal.

In future, the robustness of the developed algorithm and the system in the real-life situation of a terminal care hospital will be analyzed and evaluated.

Table 5 Relationship between error and electrode orientation

		Test data						Avg. ±S.D
		-45 deg	-23 deg	0 deg	23 deg	45 deg	90 deg	
Learning data	-45 deg	0.0	9.0	10.3	9.1	11.7	3.0	7.2 ± 4.2
	-23 deg	6.9	0.0	1.6	1.8	0.6	-1.0	1.7 ± 2.5
	0 deg	2.3	9.4	0.0	-0.9	13.2	7.4	5.2 ± 5.1
	23 deg	4.0	1.1	0.1	0.0	-0.4	1.1	1.0 ± 1.4
	45 deg	5.0	1.4	2.9	2.5	0.0	0.0	2.0 ± 1.8
	90deg	1.5	12.4	6.2	3.7	7.1	0.0	5.2 ± 4.1
Avg. ± S.D.		3.3± 2.3	5.6± 4.9	3.5± 3.7	2.7± 3.2	5.4± 5.6	1.8± 2.8	

References

[1] T. Hayashi, H. Kawamoto and Y. Sankai, Control method of robot suit HAL working as operator's muscle using biological and dynamical information, Proc. IEEE/RSJ IROS, Edmonton, pp. 3063- 3068, 2005.

[2] J. Furusho, Ch. Li, Sh. Morimoto, M. Tokuda, T. Kikuchi and Y. Hashimoto, Development of shear-type MR brakes and their application to ankle foot orthoses, Proc. IEEE/ICME Int. Conf. on Complex Medical Engineering, Beijing, pp. 1283-1287, 2007.

[3] S. Kawamura, Y. Hayakawa, M. Tamai and T. Shimizu, A design of motion-support robots for human arms using hexahedron rubber actuators, in: Proc. IEEE/RSJ IROS, Grenoble, vol. 3, pp. 1520-1526, 1997.

[4] T. Ando, J. Okamoto, M. G. Fujie, "The development of roll-over support system with EMG control for bone metastasis patients", Proceedings of 2007 IEEE ICRA, 2007, pp. 1244-1249

[5] T. Ando, Y. Kobayashi, J. Okamoto, M. Takahashi, M. G. Fujie, Intelligent Trunk Corset to Support Rollover of Cancer Bone Metastasis Patients, *IEEE/ASME Trans Mechatronics*, 15(2), 181-190, 2010.

[6] T. Ando, J. Okamoto, M. G. Fujie, Micro Macro Neural Network to Recognize Rollover Movement, Advanced Robotics, 2011, 25 (1-2), 253-271

[7] Kizuka, Kiryuu, Masuda Sadoyama, Surface Electromyogram, (Ed) Society of Biomechanism Tokyo Denki University Press, 2006, pp.59-62 (in Japanese)

[8] T. Tsuji, H. Ichinobe, K. Ito, M. Nagamachi, Discrimination of Forearm Motions from EMG Signals by Error Back Propagation Typed Neural Network Using Entropy , Journal of SICE, Vol.29, No. 10, pp.1213-1220, 1993 (in Japanese).

[9] T. Ando, J. Okamoto, M. Takahashi, M. G. Fujie, EMG based Design and Evaluation of Micro Macro Neural Network for Rollover Support Trunk Orthosis, 2010 IEEE ICRA, 2010, 2916-2921