

EMG analysis of complete denture wearers using a three-dimensional representation of the time behavior of AR model parameters

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Abstract—Three-dimensional representation to screen the adaptation process of individual dentures is presented. In the parametric analysis of electromyographic (EMG) signals, we have to deal with the complicated behavior of a lot of parameters in the time domain. We have employed the less-biased time varying AR model parameters estimated by locally quasi-stationary processing. Hence, we propose the time-suppressed representation of the behavior, projecting the time series of less-biased time-varying vectors onto three standard planes. The vector is composed of the k parameters, $K^{(i)}$ for $i = 1, 2, 3$. Therefore, the mutually perpendicular coordinates are $K^{(1)}$, $K^{(2)}$ and $K^{(3)}$. Significant changes which appear to result from the muscle dynamics are observed in the $K^{(2)}-K^{(3)}$ plane, as the masticatory function is recovered.

Key words: parametric analysis; autoregressive model; time-varying; geometrical representation; EMG; denture adaption process.

1. INTRODUCTION

Recently, analysis of muscle dynamics has been desired for a variety of biomedical applications, including sports science, prosthesis control and functional electrical stimulation. This has been supported by miniaturized measuring instruments and digital signal processing techniques. In kinematics, it is popular to measure each body segments with optical instruments. However, we have analyzed movement in terms of muscle dynamics by digital signal processing techniques.

Surface electromyographic (EMG) signals, which are usually applied in a clinic, are inherently non-stationary during dynamic movement. This makes the understanding of muscle dynamics quite difficult. In the stochastic approach, a series of EMG samples taken at a fixed rate is divided into locally stationary intervals. Xiong *et al.* [1] showed the changes of variances of EMG samples over the successive intervals. Hannaford *et al.* [2] proposed a short time Fourier analysis to deal with fast movement. The stochastic approach is basically significant for the random process, but the alternative approach of modeling signals by deterministic time-varying parameters seems to be more attractive.

The parametric analysis of surface EMG signals has often been used in prosthesis control. Graupe *et al.* [3] introduced an autoregressive moving average (ARMA) identification method for the discrimination of movements. Sherif *et al.* [4] proposed an autoregressive integrated moving average (ARIMA) representation for fast movement. We have proposed a less-biased estimator, expressing the behavior of time-

varying AR parameters as a linear time function in each interval [5]. This is the locally quasi-stationary method. The AR model has been known as a powerful model to estimate the formants in speech signals.

The reflection coefficients (RCs) are the most convenient of the several kinds of AR parameters, because the values are not affected by the order-update procedure: only the estimate of the last order is joined in the previous parameters. We have called the RCs estimated by our method k parameters. The k parameters derived from masseter muscles showed remarkable behavior in the time domain around some phases in a rapid open–close (tapping) movement. However, there are too many parameters to understand the complicated properties of the time behavior. Thus we reduce them to the dominant three parameters. This will help represent muscle dynamics by using the time behavior.

In practice, we employ the projection of the time series of time-varying vectors onto three standard planes; the time-varying vector at each time instant is composed of the dominant three parameters. Representation like this is also found in the phase analysis of a non-linear system: a two-dimensional graph between mean-squared EMG signals and muscle tension is one of the examples. Using the proposed representation, screening the adaptation process for individual dentures could be considerably easier.

2. SURFACE EMG MEASUREMENT AND PARAMETER ESTIMATION

We used 9 mm diameter bipolar surface electrodes. They were placed on the skin over the masseter muscles. The distance between the two electrodes was 25 mm. The surface EMG signal was sampled by a 12-bit analog-to-digital converter at a sampling rate of 5 kHz. The signal was divided into successive intervals: each overlapped interval was 150 samples long and was moved one by one. We estimated the k parameters in each interval. Consequently, the time series of the sets of k parameters over successive intervals was obtained.

Dental treatment was carried out on five patients over 6 months until they recovered their masticatory function. We analyzed several strokes of tapping movement at each stage almost periodically over the global treatment term.

3. TIME BEHAVIOR OF k PARAMETERS DURING TAPPING MOVEMENT

The physiological meanings of the k parameters have not been clarified yet compared with the acoustic meanings of those in speech signal processing. However, they showed remarkable time behavior around some phases in rapid movements.

The k parameters were evaluated under various conditions such as tapping movement, ballistic contraction, fatigue and mastication. Referring to Fig. 1(a), the features clearly appear around both ends of a open–close movement and the *silent period* (SP). With the conventional methods, the specific feature was not found around the SP. The sign of $K^{(3)}$ changes from negative to positive after the SP; the sign is positive during heavy contraction. In addition, the time behavior of k parameters seems to be related to the muscle dynamics concerning recruitment of motor units [6].

4. REPRESENTATION OF THE TIME BEHAVIOR OF $K^{(1)}$, $K^{(2)}$ AND $K^{(3)}$

In order to recognize the features in the graphic description, we introduce the three mutually perpendicular coordinates composed of $K^{(1)}$, $K^{(2)}$ and $K^{(3)}$. Accordingly, defining the time-varying vector consisting of the dominant three parameters in a

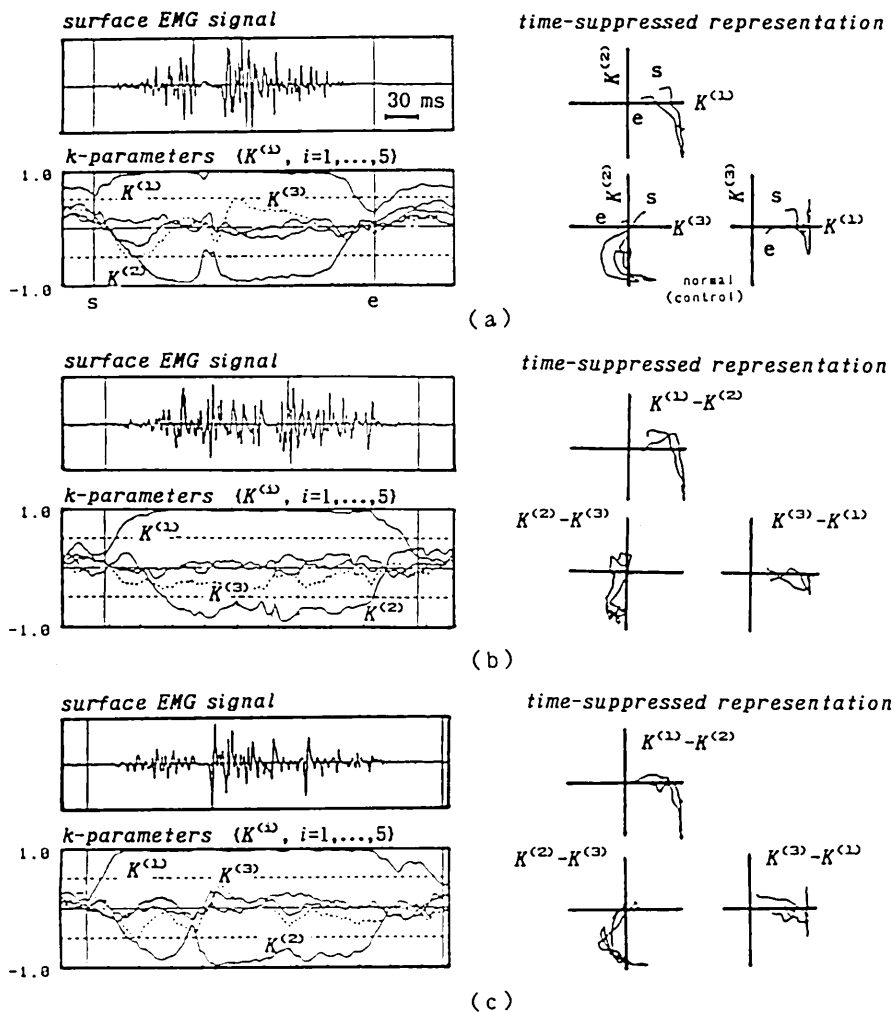


Figure 1. Time-suppressed representation during tapping movement. (a) Subject with complete dentition. (b) Result just after insertion of denture. (c) Result at 6 months after insertion.

stroke, the features are described with the locus of the time-varying vectors on the three standard planes. Empirically, the $K^{(2)}-K^{(3)}$ plane was applicable. This time-suppressed representation was effective in suppressing the individual differences due to the open-close speed. The representation will allow the analysis of the adaptation process for individual dentures.

The results indicated that at just after the insertion (Fig. 1(b)) the long and narrow pattern along the vertical line ($K^{(2)}$ axis) changed shape into a crescent-like pattern after 6 months (Fig. 1(c)). The remarkable pattern after 6 months was caused by the enlargement of the values of both $K^{(2)}$ and $K^{(3)}$ and the significant time behavior of $K^{(3)}$ as depicted in Fig. 1(a). According to our experimental results, this change suggested the recovering of masticatory function. That is, the appearance rate of the SP during tapping movement increased at the same time as the pattern came to resemble that of the subjects with complete dentition [7]. We also evaluated the recovering of

masticatory function with both the duration and integrated EMG signals during the four distinct phases (before SP, latency of SP, SP and after SP). The results of other subjects were almost the same as those of the subject in this example.

5. CONCLUSION

In order to screen the adaptation of individual dentures in terms of muscle dynamics, we propose the three-dimensional representation of the time-varying vectors during tapping movement. The time-varying vector consists of the first three k parameters, which are less-biased RCs obtained from the surface EMG signals. Significant changes relating to muscle dynamics were observed over the recovery process of masticatory function.

As a result, the time-suppressed representation may be useful to see if patients recover their masticatory function in the individual dentures. The $K^{(2)}$ – $K^{(3)}$ plane may be applicable. Finally, note that the effectiveness of the proposed representation was achieved with the less-biased parameter estimation (locally quasi-stationary method).

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