

EMG decomposition annotation comparison method

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In order to define a fair, standard way to evaluate the performance of increasingly complex EMG decomposition algorithms, a five-step method is proposed that compares the annotations generated by a decomposition algorithm to a set of annotations accepted as “true”. The method generates and reports a confusion matrix, as well as the sensitivity, positive predictability, and accuracy of the decomposition algorithm.

I. INTRODUCTION

Electromyographic (EMG) recordings generally include the superposition of the signals from numerous motor units firing near the sensor. It is essential to decompose the EMG recordings in order to identify the action potentials produced by individual motor units. Previously, algorithms have been developed to partially automate the decomposition process when signals were acquired with in-dwelling needle or wire electrodes [1, 2]. In-dwelling electrodes tend to isolate the electrical activity of a limited number of motor units. Recent research, however, has increasingly used high spatial resolution surface electrodes [3, 4]. These systems collect signals from many more simultaneously active motor units, increasing the total number of motor units recorded and the occurrence of superpositions. To contend with the increased complexity, more robust decomposition algorithms are being created [5, 6] at a rapid pace. It is important to have a standard method of performance evaluation, but one does not yet exist. Thus, to encourage the standardization of decomposition algorithm comparisons, this paper presents a method to compare the annotation output of a decomposition algorithm with a set of annotations derived from the same EMG recording accepted as the “truth” by several collaborating researchers

II. COMPARISON OF ANNOTATIONS

The comparison method described herein requires two sets of decomposition annotations: the set accepted as the truth, referred to as the *truth file*, and the set of unknown integrity known as the *test file*. An *annotation* contains two pieces of information: the *firing time* of the EMG action potential spike (referenced to the beginning of the recording and corresponding to a time fiducial near the maximum value of a spike) and the *motor unit number*, an arbitrary integral index (the truth file and test file must refer to signals from each motor unit with these unique indices).

A. Confusion Matrix

Our formal comparison will be made using a confusion matrix, as some ECG comparison schemes use [7]. Each cell of this matrix (initialized to zero) tallies the incidents in which test file annotations correspond to annotations from the truth file, in accordance with which motor units are represented by those annotations. For example, a cell in the “Test Motor Unit 2” column and the “Truth Motor Unit 3” row would count the

number of times the test algorithm annotated action potentials that were actually from Motor Unit 3 as from Motor Unit 2. There are two special headings: column *Not Found* counts annotations included in the truth file not found by the test algorithm, while row *Not Included* tallies those found and classified into each motor unit by the test algorithm, but not the truth file. Our classification algorithm must create this confusion matrix automatically. The confusion matrix functions as a type of counter for successful matches, unsuccessful matches, and for *Not Found* and *Not Included* errors.

B. Definitions

The algorithm functions by repeatedly coupling an annotation from the test file with an annotation from the truth file. This process is called *pairing*. Pairing has two functions; first, it increments the appropriate cell of the confusion matrix to include that match. Second, it removes the paired annotations from the bank of annotations that can form possible future pairs. (Once a test annotation has been paired with a truth annotation, neither can be paired with any other annotation.)

A time length is established that determines the maximum period between a test annotation and a truth annotation in order for them to be paired. This period is called the *window*. If a test annotation falls within one window of a truth annotation, it is possible that the two can be paired. Else, they cannot be paired. A *unitary annotation* is one that has no annotations with which it can be paired. Unitary annotations will always be left unpaired, and will generate either *Not Found* or *Not Included* errors in the confusion matrix, as described above.

III. ALGORITHM

It is likely that the classification strategy that generates the test file will have assigned different motor unit numbers than are given by the truth file, since these numbers are arbitrary. This inconsistency makes it difficult to make judgments involving motor unit numbers, and thus it is prudent to defer the pairing of any annotations with multiple options for pairing until the algorithm can establish a pattern to associate each test-file motor unit number with a truth-file motor unit number. Decisions can then be made that make the optimal pairings. This algorithm seeks to minimize the number of errors reported by the confusion matrix, by pairing, whenever possible, annotations representing the same action potential spike. (Since the algorithm proceeds from left to right along the time axis, any “ties” in annotations vying for a pairing will be broken by pairing the two earliest in time.)

The following steps, shown graphically in Fig. 1, outline the rules that the algorithm follows in order to pair annotations and generate the confusion matrix. Each step is repeated until it no longer generates pairings. The next step is then used, in turn, until all steps are completed.

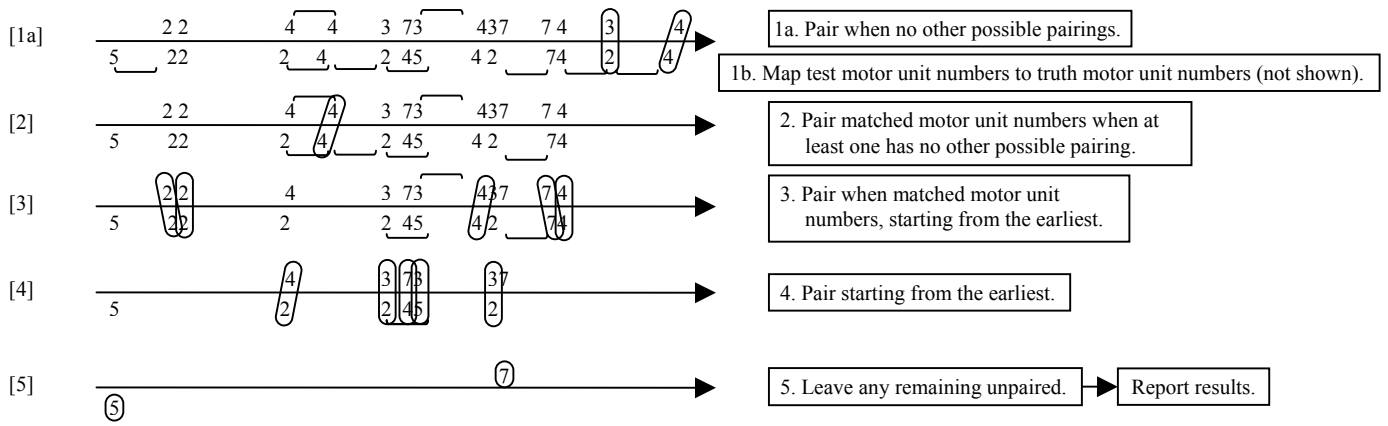


Fig. 1. An example of the algorithm applied to a pair of annotation files. Digits on the timeline indicate motor unit firings, brackets above or below the line denote window widths, circles denote pairings, and the step being followed on each line is shown in brackets to the left. (The confusion matrix is not shown, nor is motor unit mapping taken into account while following steps 2 through 4, for the sake of simplicity.) A flowchart of the algorithm is shown to the right of the example.

Step 1a: Pair a test annotation with a truth annotation when neither has any other possible pairing.

On the first pass, step 1a is applied to all annotations in the annotation files. Step 1a generates an initial confusion matrix, which is considered to have established a pattern.

Step 1b: This pattern is then used for a one-time mapping of each motor unit number from the test file to a motor unit number from the truth file.

This mapping begins with the test-file motor unit number that exhibited the largest number of matches with a truth-file motor unit number and maps them.¹ This process repeats until all the test-file motor unit numbers are mapped. Each test-file motor unit number can be mapped to only one truth-file motor unit number, and vice versa. If the truth-file motor unit numbers are exhausted before a test-file motor unit number is mapped, the test-file motor unit number will not be mapped.

Step 2: Pair a test annotation with a truth annotation if there is no other annotation with which at least one of them can be paired and they have matched mapped motor unit numbers.

Step 3: Pair each remaining test annotation with the earliest possible truth annotation, if the mapped motor unit numbers match.

Step 4: Pair each remaining test annotation with the earliest possible truth annotation.

Step 5: All remaining annotations are unitary, and are left unpaired. Tally each unitary annotation in the appropriate *Not Found* or *Not Included* cell in the confusion matrix.²

After these steps have been followed, the algorithm reports the results of the motor unit number mapping, the confusion matrix generated, and several calculations indicating how well the test annotations matched the truth annotations. These calculations include sensitivity (the fraction of each motor unit's

action potential spikes that are detected correctly), positive predictability (the fraction of detected action potential spikes for each motor unit that were correct), and accuracy (the ratio of correctly detected action potential spikes to the total number of detections and action potential spikes) [8].

IV. CONCLUSION

The results of the algorithm are a quantitative reflection of the degree of coincidence between the test file and the truth file. It serves, thus, as an evaluation of the performance of the decomposition algorithm used to generate the test file.

This comparison method is intended as a first effort at standardizing the comparison of EMG decomposition annotations. Although the algorithm has not been tested extensively, it is hoped that testing will be done in the future, the method will be improved, and the field of EMG annotation will become more standardized.

REFERENCES

- [1] Mambrito B, De Luca CJ, "A technique for the detection, decomposition and analysis of the EMG signal," *Electroencephalogr Clin Neurophysiol.*, vol. 58, no. 2, pp. 175-88, August 1984.
- [2] De Luca CJ, "Precision decomposition of EMG signals," *Methods Clin. Neurophysiol.*, vol. 3, pp. 1-28, 1993.
- [3] Farina D, Merletti R, Enoka RM, "The extraction of neural strategies from the surface EMG," *J. Appl. Physiol.*, vol. 96, no. 4, pp. 1486-95, 2004.
- [4] Pozzo M, Bottin A, Ferrabone R, Merletti R, "Sixty-four channel wearable acquisition system for long-term surface electromyogram recording with electrode arrays," *Med. Biol. Eng. Comput.*, vol. 42, no. 4, pp. 455-66, July 2004.
- [5] Chauvet E, Fokapu O, Hogrel JY, Gamet D, Duchene J, "Automatic identification of motor unit action potential trains from electromyographic signals using fuzzy techniques," *Med. Biol. Eng. Comput.*, vol. 41, no. 6, pp. 646-53, November 2003.
- [6] Gazzoni M, Farina D, Merletti R, "A new method for the extraction and classification of single motor unit action potentials from surface EMG signals," *J. Neurosci. Methods*, vol. 136, no. 2, pp. 165-77, July 2004.
- [7] Roberts, FM, Povinelli, RJ, Ropella, KM, "Identification of ECG arrhythmias using phase space reconstruction," in proceedings of *Principles and Practice of Knowledge Discovery in Databases (PKDD'01)*, Freiburg, Germany, 2001, pp. 411-23.
- [8] Association for the Advancement of Medical Instrumentation, "Ambulatory electrocardiographs," ANSI/AAMI EC38, American National Standard Institute, Arlington, VA, USA, 1998.

¹ If ties occur, the lowest-valued indices are chosen.

² Implementations of this algorithm may tally unitary annotations at any convenient time. For simplicity, this paper only requires this tallying as a final step, as the end is the only time at which it is necessary for it to be carried out.