Automated Evaluation of Physical Therapy Exercises by Multi-Template Dynamic Time-Warping of Wearable Sensor Signals

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Abstract – In this study, a novel algorithm, multi-template dynamic time-warping is proposed to detect all of the occurrences of multiple templates in a signal. The algorithm is used for automatically detecting the individual executions of given exercise movements in a physiotherapy session and evaluating them to provide feedback to the patient and the doctor. Accelerometer, gyroscope and magnetometer data of 1,320 exercise executions is recorded and a classification accuracy of 88.65% is obtained by the proposed method.

SUMMARY

Physical therapy is a widespread rehabilitation type that is applied to many patients of different disorders. The patients mostly need to repeat one or more exercise movements advised by the specialist in physical therapy sessions. In hospitals or rehabilitation centers, specialists monitor the patients and provide feedback about their performances. However, they often alternate between the patients and cannot monitor each patient continuously. They cannot count the number of correct executions for each patient, and hence cannot estimate the intensity of the therapy session. They provide subjective and qualitative feedback. Moreover, most patients continue their physiotherapy exercises at home with no feedback at all, once they learn how to do.

For this purpose, an autonomous system that detects and evaluates physical therapy exercises using five wearable sensor units containing accelerometers, gyroscopes, and magnetometers is developed. An algorithm that detects all the occurrences of one or more template signals (exercise movements) in a long signal (physical therapy session) with allowing some distortion is developed based on dynamic time warping, which is a method of matching two signals by transforming their time axes nonlinearly (see Fig. 1) [1, 2]. The proposed algorithm classifies the executions in one of the exercises and evaluates them as correct/incorrect, giving the error type if there is. It also provides a quantitative measure of similarity between each matched execution and its template.

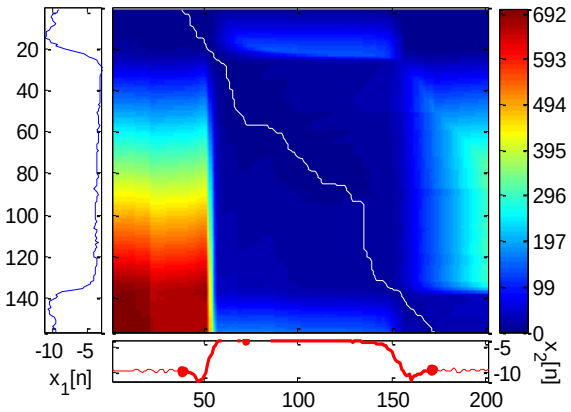

Fig. 1: Template matching by dynamic time-warping.

To evaluate the accuracy of the algorithm in physical therapy, a dataset consisting of one template execution and ten test executions of each of the three execution types of eight exercises performed by five subjects is recorded, having totally 120 and 1,200 exercise executions in the training and test sets, respectively, as well as many idle time intervals in the test signals. The proposed algorithm detects 1,125 executions in the whole test set. 8.58% of the 1,200 executions are missed and 4.91% of them are detected in excess (see Fig. 2). The accuracy is 93.46% for exercise classification and 88.65% for both exercise and execution type classification (see Table 1). Hence, the proposed system may be used to both estimate the intensity of the physical therapy session and evaluate the executions to provide feedback to the patient and the specialist.

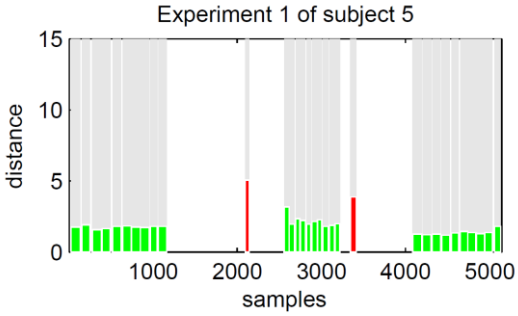

Fig. 2: Output of the algorithm for an experiment, showing each execution as a bar along time. Green and red bars indicate correct and incorrect classifications or detections, respectively.

TABLE 1: EXPERIMENTAL RESULTS

number of detected executions	1125
number of actual executions	1200
accuracy of exercise classification	93.46%
accuracy of exercise and execution type classification	88.65%
misdetection rate	8.58%
false alarm rate	4.91%
sensitivity	91.42%
specificity	95.09%

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