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

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Introduction

- Physical therapy often requires repeating certain exercise movements.
- Patients first perform the required exercises under supervision in a hospital or rehabilitation center.
  → PARTIAL AND SUBJECTIVE FEEDBACK
- Most patients continue their exercises at home.
  → NO FEEDBACK
- The intensity of a physical therapy session is estimated by the number of correct executions.

OBJECTIVE : *to detect and evaluate all exercise executions in a physical therapy session by using wearable motion sensors based on template recordings*

Dataset

- 5 wearable motion sensors, each containing a tri-axial accelerometer, gyroscope, and magnetometer
- 8 exercise types performed by 5 subjects
- Each exercise is assumed to have 3 execution types: one correct and two erroneous (fast and low-amplitude execution)
- one template for each execution type of each exercise of each subject
  → 120 TEMPLATES IN TOTAL
- To simulate a physical therapy session, for each exercise, each subject performs the exercise 10 times in the correct way, then 10 times with type-1 error, and finally 10 times with type-2 error. Between these 3 blocks, the subject is idle. → 1,200 TEST EXECUTIONS IN TOTAL

EXECUTION TYPES:

- **correct**
- **type-1 error** (executed too fast)
- **type-2 error** (executed in low amplitude)

5 *subjects* × 8 *exercises* × 3 *execution types* × 1 *of 3 executions selected* = 120 *templates*

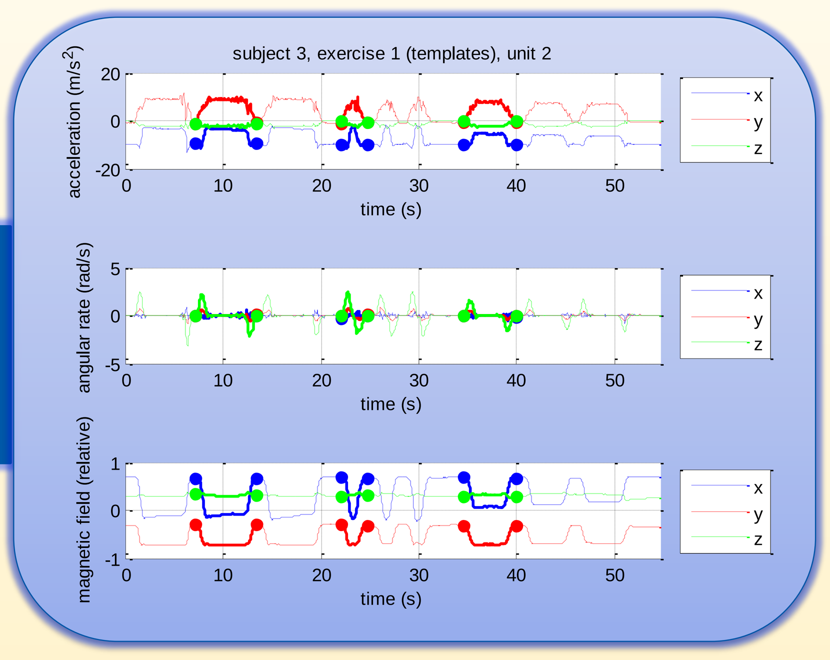
5 *subjects* × 8 *exercises* × 3 *execution types* × 10 *repetitions* = 1,200 *executions*

EXPERIMENTS SIMULATING A PHYSICAL THERAPY SESSION

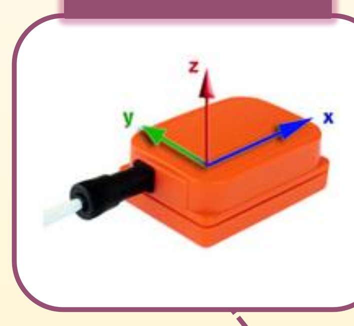
For each exercise, each subject has simulated a therapy session by executing the exercise

- 10 times in the correct way,
- waiting idly,
- 10 times with type-1 error,
- waiting idly, and then
- 10 times with type-2 error.

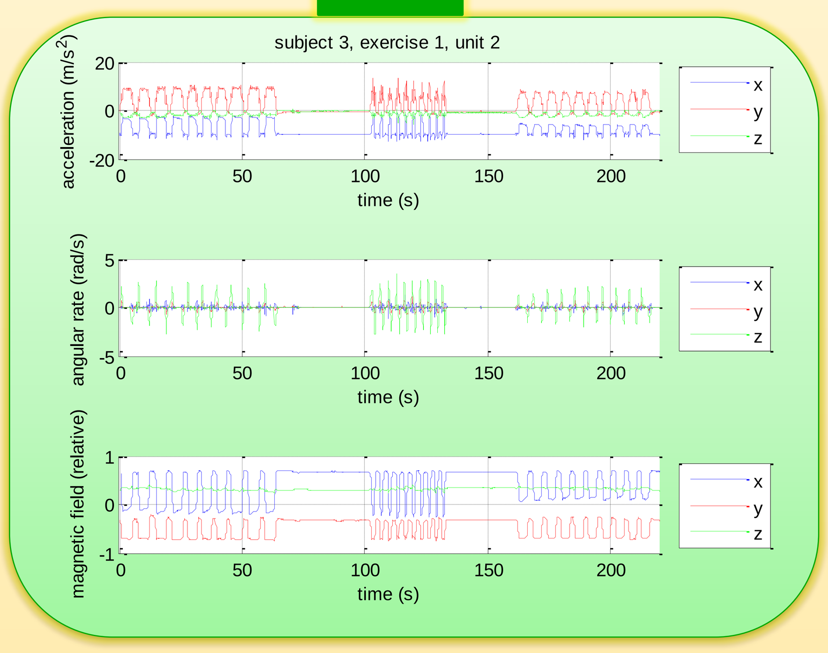
TEMPLATES



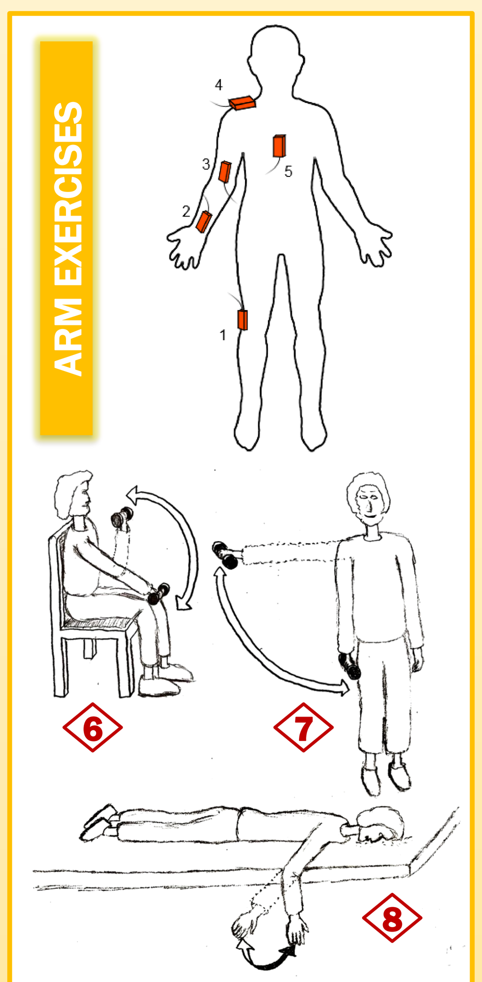
XSENS MTx SENSOR UNIT



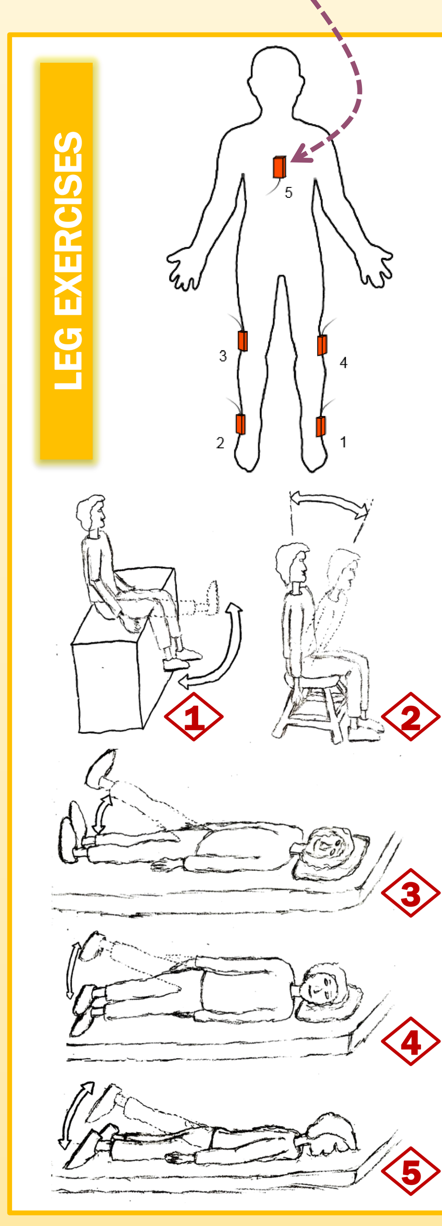
TEST



ARM EXERCISES



LEG EXERCISES



Algorithm

- *Standard DTW*
  - measures the similarity between two signals that are different in time or speed
  - matches two signals by transforming their time axes nonlinearly to maximize the similarity
- *Multi-Template Multi-Match DTW (MTMM-DTW)* has been developed based on DTW to
  - detect multiple occurrences of multiple template signals in a long test signal
  - both detect and classify the occurrences

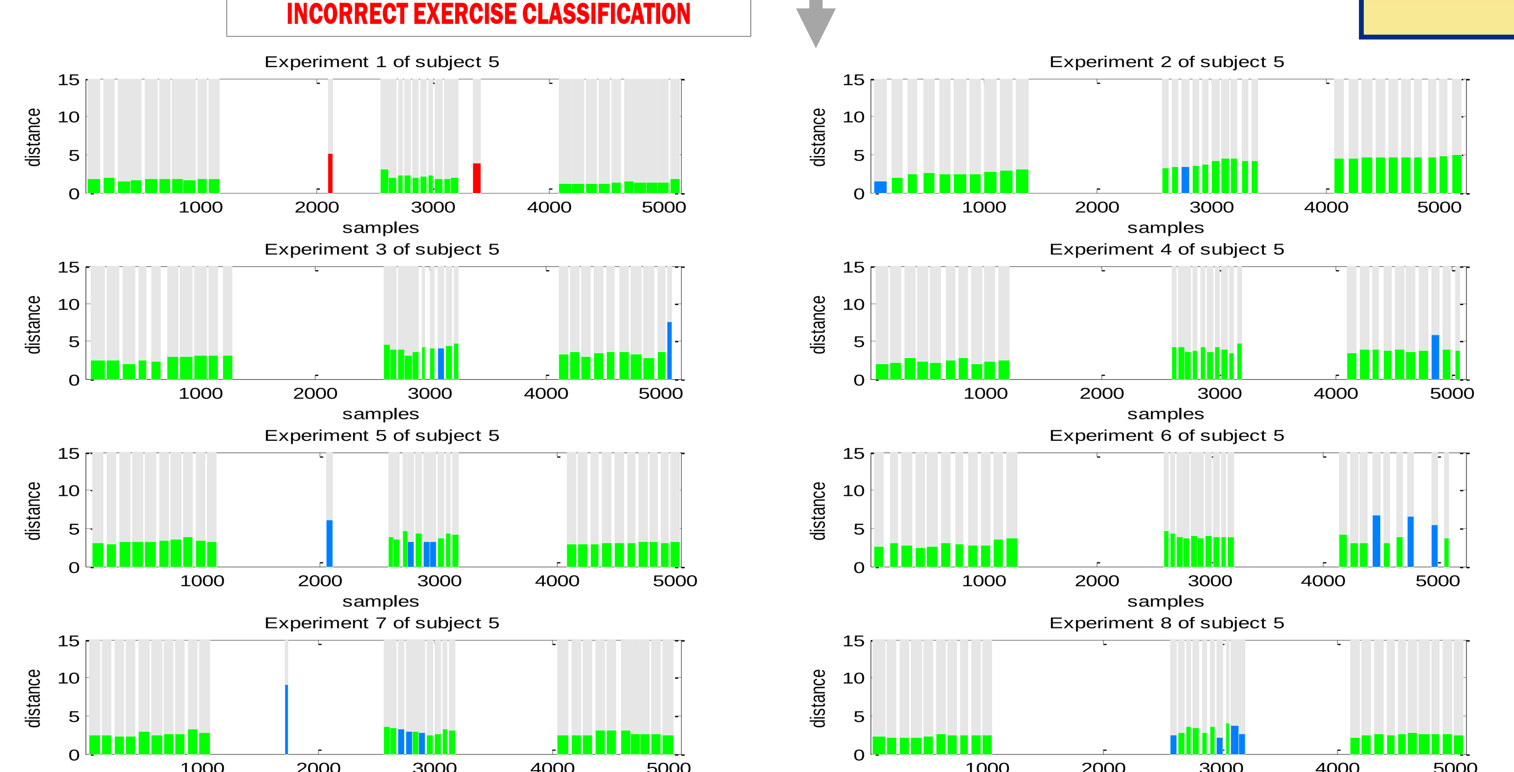
Features of MTMM-DTW:

- The number of templates, occurrences, their positions, and lengths of the template and test signals may be arbitrary.
- The signals may be multi-D.
- A threshold factor can be selected to prevent relatively short matches compared to the matching template.
- The amount of overlap between the matched subsequences can be adjusted.
- Any modification to the DTW algorithm may be used in MTMM-DTW.

Experimental Results

- We apply the proposed MTMM-DTW algorithm to each test signal with the 24 template signals of the same subject for 8 exercise types × 3 execution types.
- Each detected exercise must be at least half the length of the matching template.
- Detections with a normalized DTW distance larger than 10 are omitted.

Number of total executions	1,200
Number of executions detected	1,125
Accuracy of exercise classification	93.5%
Accuracy of exercise and execution type classification	88.7%
Misdetection rate (MDs / positives)	8.6%
False alarm rate (FAs / negatives)	4.9%
Sensitivity	91.4%
Specificity	95.1%



Conclusion

- The proposed system can be used in tele-rehabilitation to provide feedback to the patient exercising remotely and assessing the effectiveness of the exercising session.
- In previous systems, each execution is recorded separately or cropped manually.
- Our system
  - automatically detects the individual executions and idle time periods,
  - classifies each execution as one of the exercise types,
  - evaluates its correctness, and
  - identifies the error type if any.

References

[1] A. Yurtman and B. Barshan, **"Automated evaluation of physical therapy exercises using multi-template dynamic time warping on wearable sensor signals,"** *Comp. Meth. and Prog. Biomed.*, 117(2):189–207, Nov. 2014.

[2] P. Tormene, T. Giorgino, S. Quaglini, and M. Stefanelli, **"Matching incomplete time series with dynamic time warping: an algorithm and an application to post-stroke rehabilitation,"** *Artif. Intell. Med.*, 45(1):11–34, Jan. 2009.