and can thus reject a Teach-mode session that shows extensive execution variability. These choices consider the clinical routines, where therapists have only 30 to 45 min per patient for assessment, therapy, and exercise training. Thus, complex interactions with the device were avoided.

3.3.2 Train-mode operation

During Train-mode, the derived exercise models are arranged in a to-do list for the trainee to complete. This mode is intended to be used by the trainee to exercise without therapist supervision, i.e. at the rehab centre or at home. After selecting an exercise to be performed and starting the Train-mode, inertial motion data is recorded from the phone's sensors and processed in real-time to count the exercise repetitions and detect errors. While training, the smartphone system will provide acoustic feedback on the counted repetitions and notify when errors occur. E.g., if the trainee had practised an exercise with the therapist before, but starts to perform repetitions faster than during the Teach-mode, the system will provide the feedback "move slower". This feedback could prevent injuries from repetitive erroneous movements. Finally, after that the configured number of repetitions were detected, the system will ask the trainee to stop and displays a summary of the execution performance.

3.3.3 Motion exercise modelling

Based on the observation that many fitness exercises have a repetitive structure, from training with free weights to cardio fitness motion, we consider a sinusoidal motion model. For each exercise, a representative motion feature could be chosen that represents a sinusoidal pattern. The feature can be based on a single raw sensor axis or fused from several sensors, such as orientation estimates. For example, in a lateral arm abduction exercise, where the phone is attached to the wrist, the anterior-posterior orientation angle could be used as motion feature. Figure 7 shows an example waveform for several repetitions of an exercise. Advised by three therapists and after consulting COPD guidelines, we derived speed of motion (corresponding to the period frequency) and range of motion (corresponding to the feature amplitude) from the sinusoidal pattern of each exercise repetition. In Kinesiology speed and range of motion, together with their relative tolerances and the number of repetitions, are considered standard measures for exercise monitoring [41]. Estimating movement speed during exercises is useful to educate patients in breathing techniques (i.e. by exercising the patient can learn how to breathe with a correct timing). Based on these exercise quality parameters, we derived performance classes, such that the classes are applicable to various exercises that are performed by repetitive movements. During the Teach-mode, exercise repetitions are used to represent repetition range and duration parameters using two normal distributions. In the Train-mode, these model parameters are used to identify nine performance classes. The classification approach is further described in the following section.