study with seven COPD patients. We assess system recognition performance regarding exercise and performance classes. 3. In further analyses of the COPD patient study data, we determine patients’ training performance, error trends, and feedback efficacy. Furthermore, we compare the therapist training error assessment against the sensor-based measurements. We confirm that the smartphone-based training system can achieve similar performance than when assessed by a therapist. Our approach integrates into this clinical rehabilitation routine by incorporating a Teach-mode, where training is performed under therapist supervision. During Teach-mode, our system derives motion parameters that are subsequently used during the Train-mode to estimate training performance and quality. Hence, the system could serve as a novel tool for therapists and their chronic patients to improve training options, both in the rehab centre and at home. The smartphone serves as single training device, thus reducing starting barriers for rehabilitation training, including cost, availability, and handling of devices.

3.2 Related works

A few works assess the quality of exercise activities being performed, especially for clinical applications. Analysing exercises performance is usually done by means of cameras [29], depth cameras [30] or optical motion capture systems in combination with passive markers (Vicon, OptiTrack). In general vision-based systems allow users to easily extract a human skeleton automatically, but require constrained environments to install and calibrate cameras. Various ambient and on-body device developments identified opportunities for continuous training and coaching in fitness and sports outside the lab, such as the Ubifit Garden [31], MOPET system [32], and Triple- Beat [33]. Smartphones are being widely deployed and provide several integrated sensors to analyse data in real-time and provide training performance feedback. Thus, smartphones could be used as stand-alone systems to minimize costs hurdles in applications. For example smartphones were used as a mobile exercise skill assessment tool (GymSkill) to support personal health and fitness [34]. GymSkill monitors exercise quality performed on a balance board and provides feedback according to various parameters including regularity of movements. Muehlbauer et al. [35] exploited arm worn smartphones to recognize and count upper body resistance training exercises from acceleration sensors. In [36] the authors introduced an algorithm based on dynamic time warping, which uses acceleration data to evaluate the number and duration of correctly recognized repetitions. The application provided real-time feedback on the duration of repetitions and was studied in healthy individuals. Further parameters, including the range of motion and efficacy of the feedback were not considered. Wearable distributed sensors and other dedicated devices were used in several exercise and sports studies. Strohrmann et al. [37] assessed performance level, training assistance and fatigue monitoring of runners. Tseng et al. [38] used accelerometers and compass sensors in a rehabilitation game to increase motivation. The system provided scores on movement quality. A fixed rule-set was used to recognise activities. Chang et al. in [39] proposed a system to recognize motion patterns and count repetitions of a limited set of free-weight exercises using acceleration data from a glove and a chest belt. The system did not provide feedback on execution quality since start and end of a repetition were not detected. Although their counting algorithm showed good results, it needed re-training to obtain accurate results for different exercise speeds. Moreover, training data was required to obtain pattern models off-line. Velloso et al. [40] used five Xsens sensors and a Kinect camera to derive pattern models during an