3.1 Introduction

Cardiopulmonary fitness is a well-known condition for our long-term health and wellness [25]. In particular, patients suffering from the widespread cardiovascular diseases (CVD) and chronic pulmonary obstructive disease (COPD) can benefit from physical training. Nevertheless, CVD and COPD patients have special requirements regarding fitness training, related to their physical ability, determining type and intensity of exercises, and practical systems to support them. For example, generally healthy people could regularly jog and run, and even over-train without immediate health consequences. In chronic patients, both over-training and undertraining could lead to quick and detrimental worsening of the health condition, resulting in exacerbations and hospitalisation, or death [26]. In addition, chronic patients often fear to exercise wrongly [27], if not under therapist supervision. While therapists can recommend exercises for the patient's independent training, both therapist and patient have no means to assess the exercise performance during independent training. Ubiquitous and on-body systems could enable patients to perform additional physical training on their own, in addition to the supervised training with a therapist. Fitness and sports studies revealed a series of challenges for monitoring and coaching, when using ubiquitous and on body sensing systems. In a recent survey, Kranz et al. [28] identified usability improvement, instruction quality, and long-term motivation as core design aspects of fitness training systems. Usability improvement refers to reduced labour in maintaining log-books or other manual records during training. Instruction quality refers to the guidance a trainee is provided with, to adequately execute an exercise. We believe that system feedback could prevent injuries, or worsening conditions in patients. During rehabilitation exercise training, for example, different errors can co-occur and should be identified accordingly. Moreover, it is essential that an error estimation algorithm can handle different exercises with minimal adjustments to support training variety. Adequate feedback depends on individual skills and fitness level, which is particularly varying in chronic patients corresponding to their rehabilitation progress. Thus, error estimation algorithms should be adjustable to a patient's individual capability level. Until now, many error monitoring approaches focused on individual exercises or specific multisensory training devices that helped to stratify error conditions. However, attaching multiple devices is often too difficult for patients to train individually. While on-body sensors could be comfortable during exercise training, their cost and handling is challenging for patients. The widespread adoption of smartphones provides a platform for healthcare applications that is directly available to patients. In this work, we introduce a smartphone-based motion rehabilitation training system, intended for individual exercising of chronic patients. The system processes motion sensor data online on the phone and provides real-time acoustic feedback regarding the exercise performance and quality. We investigate whether exercise model parameters describing typical rehabilitation exercises can be derived from a smartphone's internal sensors to reliably support patient training and provide real-time feedback. In particular, this work provides the following contributions: 1. we introduce a training approach, where the trainee has to attach a holster carrying the smartphone only. After an initial rehabilitation exercising session with the therapist (Teach-mode), individual training (Train-mode) can be performed. 2. We validated our system with healthy individuals performing six limb movement exercises as they are commonly prescribed for COPD patients. We model errors using motion parameters and classify nine performance classes (including "correct" and eight error conditions). Subsequently, we evaluate our system in an intervention