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The mobile fitness coach: Towards individualized skill assessment using personalized mobile devices

Matthias Kranz [a], Andreas Möller [b,*], Nils Hammerla [c], Stefan Diewald [b], Thomas Plötz [c], Patrick Olivier [c], Luis Roalter [b]

[a] Luleå University of Technology, Department of Computer Science, Electrical and Space Engineering, Luleå, Sweden
[b] Technische Universität München, Distributed Multimodal Information Processing Group, Munich, Germany
[c] Newcastle University, Culture Lab, School of Computing Science, Newcastle upon Tyne, United Kingdom

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ABSTRACT

We report on our extended research on GymSkill, a smartphone system for comprehensive physical exercising support, from sensor data logging, activity recognition to on-top skill assessment, using the phone's built-in sensors. In two iterations, we used principal component breakdown analysis (PCBA) and criteria-based scores for individualized and personalized automated feedback on the phone, with the goal to track training quality and success and give feedback to the user, as well as to engage and motivate regular exercising. Qualitative feedback on the system was collected in a user study, and the system showed good evaluation results in an evaluation against manual expert assessments of video-recorded trainings.

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1. Introduction

Regular physical activity is important to personal health and well-being, both for the individual and the society. Encouraging people to exercise more is key to maintaining or regaining personal health but, unfortunately, difficult to achieve in practice. One barrier to exercise is that lay people often are insufficiently knowledgeable about effective and safe physical exercises. Maintaining an exercise regime over longer periods of time requires high levels of motivation. It is well established that access to a personal trainer has a significant impact on both adherence and motivation to a program of physical exercise [1], and the quality of the exercise undertaken [2]. They continuously monitor the exercises and both provide individualized advice and motivate the trainee. Personal trainers also play an important role in rehabilitation, e.g., exercise programs for muscle recovery after surgery, for which there is a need for advice regarding effectiveness and safety. Unfortunately, this is too expensive to provide over extended periods of time, and where financial factors are not a barrier, personal privacy preferences can be (i.e., the perception of the potential for embarrassment).

Smartphones, being pervasive devices, are ideal to support and contribute to regular physical exercising. *Apps* for all purposes have turned the phone to a multi-functional device, far beyond its classic domain of application. They transform the phone to a platform for a variety of applications pervading everyday life: From reading news on the go, over location-based services, games, up to specialized leisure-time and 'hobby' apps for every flavor. Musicians can turn their phone into a guitar tuner, gourmets into a wine guide, and so on. This trend is also visible in the sports domain. Increasing processing

* Corresponding author.
E-mail addresses: matthias.kranz@ltu.se (M. Kranz), andreas.moeller@tum.de (A. Möller), nils.hammerla@newcastle.ac.uk (N. Hammerla), stefan.diewald@tum.de (S. Diewald), thomas.ploetz@newcastle.ac.uk (T. Plötz), patrick.olivier@newcastle.ac.uk (P. Olivier), roalter@tum.de (L. Roalter).

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power, integrated sensors, and the ability for rich, multimodal interaction do qualify smartphones not only as personal assistants, but also as personal fitness coaches for supporting individualized training and skill assessment.

The current generation of smartphones with their wealth of sensing, communication, and computing capabilities represents an ideal platform for replicating the services of personal trainers in a way that is accessible to and affordable for virtually everyone. Enabling expert assessment of physical exercises and/or rehabilitation in everyday life (sports) situations integrates mobile interaction further into the real world and has the potential to have a substantial positive impact on people's lives.

We report on our research on an integrated human-activity assessment system, which supports lay users in their everyday life exercising routine with automatically generated expert assessments. The presented system captures the complete training process from exercise descriptions, sensor data logging, activity recognition and on-top skill assessment. This allows the user for individualized, self-determined training supported by coach-quality feedback. Our approach uses balance board training as one representative example for physical exercise support, applicable to a wide range of users and scenarios, both for fitness training and rehabilitation. In an iterative process, we developed a smartphone application that uses integrated sensors for exercise skill assessment on multiple levels for a variety of exercises. We understand skill assessment as individualized, personalized and automated feedback that allows tracking training quality and success, with the claim to replicate the expert judgments of a professional human coach.

As a basis for our research, we performed an extensive review of both commercial applications and scientific research on training support. With the assistance of a sports medicine specialist, we developed an exercise set, exercise descriptions and training plans that we evaluated in an iterative design process with a focus group. Six users performed a 20-exercise set twice a day during one week and produced 1200 exercise records. This basis was manually assessed by an expert and used as a basis and evaluation of ground truths of our assessment algorithms.

In a first prototype, a novel unsupervised and automated activity analysis approach – principal component breakdown analysis (PCBA) – is used to generate informative and easy to interpret qualitative user feedback in the form of color maps. Based on this, a second iteration then goes further and generates more precise and targeted feedback on individual qualities of the performed exercises directly on the device.

Our assessment algorithms show high accuracy in practical evaluations compared to manual judgments provided by sports medicine experts. Qualitative user feedback indicated the acceptance of our system and a notable potential for maintaining long-term exercising engagement. The analysis provided to the user is consistent to the professional analysis of a personal coach. This was confirmed in the two studies presented with the aid of an external expert. Physical interaction with training devices is facilitated using NFC-augmented (Near Field Communication) balance boards.

We show for the first time that an automated approach utilizing sensing and computing capabilities of modern mobile phones can provide expert-level feedback on the quality of physical exercises as they are regularly performed for recreation or rehabilitation purposes. This approach has great potential for the generalizability of physical mobile interaction in sports, especially in the context of the aging society, but also in the more general domain of human skill assessment of everyday activities, which is relevant for a number of therapeutical applications, e.g. skill maintenance in Dementia or Parkinson's care. Our evaluation indicates that we can keep the motivation with coach-like feedback longer than with conventional approaches.

2. State of the art

Advances in the miniaturization of (inertial) sensing technology, along with the increasing availability of smartphones as a sensing platform, have given rise to many commercial appliances, apps, and general academic interest into people's physical activity. This allows for embedded interaction [3], that is to look at new opportunities and application areas that arise for interactive systems and at novel ways for human–computer interaction (HCI) enabled thereby.

Beyond straightforward applications in medicine, where physical activity has to be quantified reliably, many lifestyle, sports and professional assessment systems have been developed. This section first explores systems that employ inertial sensors to assess different aspects of physical activity. Subsequently, the landscape of (commercial and free) health and fitness applications on smartphones is summarized in a comparative study.

2.1. Automatic assessment of physical activity

Body-worn and pervasive sensors have been employed in a large variety of recognition scenarios, identifying different types of physical activities [4–8] with satisfying accuracy. Quantifying qualitative aspects of human motion, such as motor performance, has been of intense focus in medicine, where particularly the assessment of degenerative conditions such as Parkinson's disease is of interest [9,10]. Automated skill assessment for domains where less prior knowledge is accessible is a relatively novel application of pervasive computing. Here augmentation of physical training devices with sensors has been used as the basis for monitoring outdoor sports such as skiing [11] or tennis [12], as well as indoors, such as recognition and tracking of free-weight exercises with accelerometers in a glove [13]. In the gym, sensor data from balance board training [14,15] has been used to provide feedback on the performance quality. Furthermore, body-worn inertial sensors

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Table 1
The 15 health and fitness apps considered by this review can be classified into the categories *GPS tracker*, *workout planner* and *exercise book*. The last two columns indicate the number of reviews and average ratings in the Android market.

Category	Name	Developer	Version	Downloads	Rev.	⋆
GPS tracker	AndAndo	Javi Pacheco	1.37	50.000–250.000	6342	4.5
GPS tracker	Cardio trainer	WorkSmart labs inc.	3.3.0	>250.000	28326	4.5
GPS tracker	miCoach	Adidas	2.0	>1.000.000	11843	4.5
GPS tracker	RunKeeper	Fitness keeper inc.	2.4.1.10	>250.000	5364	4.6
GPS tracker	runtastic	runtastic	1.4	50.000–250.000	529	4
GPS tracker	Sports tracker	Endomondo	3.3.2	>250.000	5999	4.5
GPS tracker	Sports tracker	Sports tracking ltd.	1.8.5	>500.000	15963	4.5
Workout planner	Ab workout free	Daniel Miller	1.0	5000–10.000	12	4.5
Workout planner	Abs & core	PumpOne	1.0	100–500	5	4.5
Workout planner	Body fitness	Health team	1.2.0	50.000–250.000	662	4
Workout planner	C25K lite	Guy Hoffmann	1.1.2	10.000–50.000	232	4
Workout planner	JEFit	JeFit inc.	3.2.1208	>250.000	6342	4.5
Workout planner	Workout coach	Culleware	2.01	10.000–50.000	79	3.5
Exercise book	Fitness expert	R4z0	1.5	5000–10.000	32	3
Exercise book	Pilates	Saulius	1.0	5000–10.000	57	3
Exercise book	Yoga	SusaSoftX	1.4	50.000–250.000	293	4

running [18]. Beyond applications in sports, similar systems have been employed to assess professional skills, e.g. in surgery using a sensor-enhanced glove [19] or to assess metal filing skill [20], that have applications in training and evaluation.

UbiFit Garden [21] brings activity recognition to the smartphone. For a certain amount of physical activity, flourishing flowers appear on the phone's display as a motivational component. BALANCE [22] estimates the calorie expenditure in everyday life, contributing to long-term wellness management. Both smartphone solutions rely on additional sensors worn on the body.

A multitude of commercial health devices and sensors, such as oximeters and heart rate monitors, formerly reserved for professional use, are now available and can be connected to smartphones. GPS watches, pedometers and heart rate monitors, allow recording and tracking of physical activity. For home use, hardware platforms like Nintendo Wii or Microsoft Kinect encourage users to physical activity, without focus on correct execution. Activity loggers like activPal[1] or FitBit[2] monitor health-related data and help create an activity profile. However, those solutions build upon dedicated systems or external sensor hardware. Since we want to motivate smartphone solutions working the real world without the need for additional hardware, the state of the art in health and fitness assistants on the smartphone is investigated subsequently.

2.2. Comparative review of smartphone apps for health and fitness

We evaluated the design space of current (beginning of 2011) popular health and fitness smartphone apps in a comparative review. For our review, we considered applications from the *Health and Fitness* category in the Android Market. A comparison with other app repositories (iTunes App Store and Nokia OVI Store) revealed that the offerings on different platforms are very similar. We chose Android for our review, being the platform with the highest coverage in 2011 and the fastest growing one. The heterogeneity of Android devices makes the platform also very suitable for fitness support, as the user can select a device adequately for personal needs (e.g. a small and light one on the run, and larger-screen devices for indoor usage).

In order to reflect the highest quality and most satisfying apps available at investigation time, we used the *Most Popular* list in the Android Market and only considered apps with at least 3-star user ratings. We chose 16 apps as a representative sample for this review according the procedure described above. Except Workout Planner, which costs $1.99, all apps were available for free. Endomondo Sports Tracker, SportsTracking Sports Tracker, Adidas miCoach, RunKeeper Free, Cardio Trainer, AndAndo, JEFit, C25K, Daily Ab Workout Free, Body Fitness, Abs & Core, Workout Coach, Fitness Expert, Pilates, and Yoga (see Table 1). Some of them offer additional functionality in a pay version, but do not show a *qualitative* difference.

2.2.1. Heuristic evaluation

Quality assessments were created in a heuristic evaluation of the selected apps, performing a three-step analysis:

1. The core task functionality was tested (task-focused walkthrough).
2. Optional features were explored (explorative walkthrough).
3. The descriptions by the app developers in the Android Market were compared to the actual functionality.

[1] http://www.paltech.plus.com/products.htm.

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Four heuristics were used to cover the most important aspects of mobile health and fitness support, which are explained below.

App utility and usability for regular training. The usability for daily application in context of the supported activities was evaluated. Factors observed in this area are the adequacy of interaction (size of controls, appropriate output, comprehensibility) and the customizability, i.e. whether the user can tailor the app to his needs. It was also assessed whether the app makes 'smart' use of data (reuses once entered information, infers information from known data to minimize explicit input).

Instructional quality of apps. It was examined how well the instructions serve to enable autonomous training guided by the mobile device. This includes the comprehensibility and extent of instructions, sufficient level of detail, etc.

Sensor data usage. We evaluated to what extent sensor information is recorded and used by training and fitness applications. This includes sensor data recording for later review (e.g. GPS traces, acceleration data), inference of activity types, assessment of exercising skills, and incorporation of recent developments of Pervasive Computing, e.g. location determination to adapt training to indoor and outdoor environments, context-sensitivity and multi-user interaction.

Motivation. It was examined how well an application is suited to generate and maintain long-term motivation and engagement, through e.g. diversity in the training experience, cooperative training (social incentive), and feedback provision on the training progress to maintain extrinsic motivation.

2.2.2. Results and discussion

We identified three categories of applications: GPS trackers, workout planners, and exercise books, each of which might include an option to connect, share or otherwise use the data in the context of social networks.

GPS trackers. Apps in this category (see Table 1) annotate outdoor activities like running or cycling with location information. After the training, the GPS traces can be reviewed. Further information from the phone's built-in sensors, such as accelerometer or magnetometer data, is usually not included. Some do, however, allow the connection to e.g. heart rate monitors and adapt training instructions to the heart rate (miCoach).

Workout planners. These apps accompany goal-directed workout such as bodybuilding or weight training. They typically contain exercises organized by body parts or muscle groups and log exercise performances (quantitative, not qualitative). While the functionality and usability of apps in this category greatly varies, none offer exercising monitoring in terms of quality or individual performance.

Exercise books. These apps provides a browsable compendium of exercises, with usually the least functionality, compared to the other genres, but the deepest background information on correct exercise performance and health-related issues.

Summarizing our findings of the evaluation, the following points can be concluded.

- The diversity of health and fitness apps is limited, despite a great number of apps in the respective category in the Android Market. Mobile fitness apps either focus on the recording part (which we called GPS loggers), or the instructional part (which we called exercise books). GPS loggers record location information so that a trace of the cardio activity becomes visible. A combination of exercise description and logging are workout planners, which often combine the weak parts of both sides: They just log *that* a certain exercise was performed, and instructions are not as detailed as in the exercise book category. The ideal would be combining the advantages from all three categories.
- GPS loggers have the highest popularity (according to the number of downloads) in the Android Market. The reason probably lies in the high popularity of running, cycling and similar activities and the variety of supported activities by these apps. It can also be seen as an indicator in favor of a comprehensive approach of supporting fitness in different situations and locations. Body Fitness already picked up this idea by integrating both workout and cardio into one app, as well as supplements like a BMI (Body Mass Index) calculator and recipes. However, apps do not support yet pervasive training (at home, in the office, outdoors, …) with activity recognition and contextually suited exercises.
- Multi-user support is not yet integrated, but could be enabled by the creation of user profiles on the device could enable multi-user support also for logging applications and workout planners.
- Few applications are compatible with sports hardware, such as heart rate monitors or wearable sensors. Neither do smartphones use the built-in sensors in current health and fitness applications, although almost all modern smartphones integrate accelerometers, magnetometers and gyroscopes. Device sensor usage could comfortably enable more functionality, without the need to buy, connect and synchronize hardware.
- While some apps allow uploading training information to a portal for later review, none provide individualized, immediate and thereby motivating feedback directly on the phone on the exercise just performed.
- The 'advice' provided by current systems such as e.g. the Adidas miCoach is on a more general level and requires educated interpretation and therefore is not really comparable to expert-like assessment of the individual exercises.
- Current health and fitness apps only partially focus on long-term motivation so far. Social connections, e.g. to beat a friend's results or to challenge a stranger, can be a motivational factor. The Facebook and Twitter integration offered by some apps is presumably rather motivated by promoting the app. Information on long-term usage is missing in any of the reviewed app's descriptions in the Market. If an app would explicitly address motivation, this could be an enormous benefit for advertisement. We believe that adding individualized and personalized feedback could increase the long-term

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2.3. Lessons learned and recommendations

Based on this review, we deduce some general guidelines for future health and fitness apps. The evaluation results show great potential for improvement in the reviewed disciplines usability, instruction quality and fostering motivation. Sensing and context information hereby both play an important role.

Usability improvement. Unnecessary interaction with the device can be reduced e.g. by activity recognition. Research investigated activity detection with wearable sensors [4–6,23]. These techniques need to be tailored to smartphones, which are already equipped with a multitude of sensors. Evaluating acceleration and gyroscope data, could make the recognition of the performed activity possible, making a manual activity selection in the app obsolete. Also the activity-related calorie expenditure can thereupon be estimated. This results in a far more accurate determination of burnt calories after cardio training, as e.g. pauses or speed changes are taken into account.

Instructional quality. The quality of exercise instructions can be improved through well-founded information and physiological correctness. Moreover, the combination with skill assessment and targeted feedback could be a large step towards self-determined, autonomous training. In physiotherapy or rehabilitation, the *correct* exercise performance is important for the healing process. The presence of a doctor or physiotherapist is not always possible, and permanent supervision not comfortable. Accurate exercise assessment based on sensor information and individualized feedback supports correct exercise accomplishment. Mobile phone feedback could thus be a valuable extension – but no replacement – to physiological care.

Long-term motivation. We pointed out the importance of intrinsic motivation for upholding regular physical activity. The integration of feedback in sports and fitness applications adds to establish long-term motivation and engagement in various ways. First, a training assessment for singular exercises in the form of a score ('you reached 85/100 points') motivates beating this value and improving further to reach perfection. Second, a history of training results allows tracking improvement, acknowledging that regular training 'pays off'. More sophisticated skill assessment, which we report on, could even enable targeted feedback. Apps could identify aspects of exercises with potential for improvement or indicate body parts that need particular training. Based on this analysis, the app could suggest suitable exercises addressing 'sticking points' and create a tailored training plan. Training assistance would become more efficient and help to reach goals faster.

The integration of playful aspects and connection to social networks can further contribute to long-term motivation. Some applications already upload training results to Facebook, but real cooperative training needs to go further. Viewing friends' high scores, and beating competitors make physical activity more fun than solitary training. These apps, though, miss a professional assessment of the training quality. We try to close this gap by the presented research.

A step into this direction are apps such as Nike Training Club,[3] an iPhone app (workout planner) combined with a social network, advertising with long-term motivation, but it does not incorporate automated activity recognition. Based on skill assessment, apps could also propose individualized training goals so that they are challenging, but not frustratingly hard. This also has an impact on social sports apps, as then relative comparisons between users would be possible. This, we do argue, will further support long-term motivation.

Intelligent exercise assessment and monitoring is also relevant for elderly people, e.g. in an Ambient Assisted Living context. The smartphone application could be a reminder and a motivational factor to support physical activity, which is important for health risk reduction.

3. GymSkill: automated assessment for balance board training

With GymSkill [24,25], we present a smartphone application that addresses the shortcomings described above and introduces individualized exercise skill assessment fully based on integrated sensors. We describe the iterative design process, qualitative user feedback and quantitative validation of our assessment algorithm.

3.1. Balance board training

We chose balance board training as a representative discipline for physical exercising support, applicable to a wide range of young and old users, both for fitness training and rehabilitation [26,27]. With help of a sports medicine specialist, a set of 20 exercises was conceived and fed into the GymSkill application.

3.2. The GymSkill application

GymSkill is implemented as an Android application and consists of an exercise database, sensor data recorder and the skill assessment presentation (see Fig. 3). During the performance, the smartphone (app running) is placed on top of the balance board (see Fig. 1) so that it can record all of its movements. The user begins her training by selecting an individual exercise or a complete training plan (see Fig. 4). Each exercise is explained step by step in text and pictures. During the actual performance, the phone records accelerometer and magnetometer data as a basis for the assessment which is presented to the user after completion of each exercise. GymSkill is freely available in Google Play as a research app under the name 'GymSkill'.

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