A Technology Platform for Enabling Behavioural Change as a "PATHway" Towards Better Self-management of CVD

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ABSTRACT

We describe a technology platform developed as part of a novel approach to technology-enabled exercise-based Cardiac Rehabilitation (CR), termed PATHway. We explain the overall concept and explain how technology can facilitate remote participation and better adherence to community-based long-term Phase III CR. The demo will showcase the user experience of interacting with the PATHway system, including navigation and manual data entry, whilst also demonstrating real-time sensing and analysis of exercise movements and automatic adaptation of exercise based on physiological response.

CCS Concepts

•Applied computing → Health care information systems;

Keywords

Cardiac rehabilitation, behaviour change, exercise

1. INTRODUCTION

Cardiovascular disease (CVD) is the leading cause of premature death (30% of all deaths) and disability in Europe and worldwide (WHO), costing the EU economy almost €196 billion a year [1, 6]. Effective Cardiac Rehabilitation (CR) can significantly improve mortality and morbidity rates, leading to longer independent living and a reduced use of health care resources. CR initially takes place in a hospital setting for 6-12 weeks after which patients are encouraged to attend ongoing community based exercise programmes. These weekly supervised exercise programmes are usually run through local CR teams or support groups and increasingly GPs are referring patients to such programmes.

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However, uptake of traditional community-based long-term (so called phase III) CR is very low (approx. 11%) with low subsequent adherence rates for those that do attend [3]. Key reasons for this include lack availability of programmes, travel time, scheduling issues, lack of peer mentoring, and low self-efficacy associated with poor exercise technique and perceived poor 'body image' (e.g. resulting in a patient not wanting to exercise with large groups of strangers) [4].

The PATHway project[1] is developing a radically novel approach to CR. The project aspires to help facilitate a paradigm shift towards empowering patients to more effectively self manage their CVD, where this self-management is set within a collaborative care context with health professionals. A central tenet is the use of behavioural change theory to drive the design of the PATHway programme and the supporting technology platform. PATHway will provide individualized rehabilitation programs that use regular, socially inclusive exercise sessions as the basis upon which to provide a personalized comprehensive lifestyle intervention program (exercise/physical activity (PA), smoking, diet, stress management, alcohol use, medication compliance) to enable patients to both better understand and deal with their own condition and to lead a healthier lifestyle. This is made possible by the development of an internet enabled sensor-based home exercise platform that allows remote participation in CR exercise programs at any time, by a small group of patients from the comfort of their own living room. This approach is timely given that others have recently proposed similar approaches (e.g. [7]) and that commercial offerings to certain components of an overall system of this nature are starting to become more widely available.

2. THE PATHWAY CONCEPT

Patient considerations are at the heart of the development of the project's technology platform and in the design of the associated behaviour change programmes. The patient journey, and how PATHway will support this, is illustrated in figure 1. This journey starts when an inactive patient suffers a cardiac event (1) (see figure 1) and is admitted to a hospital CR programme (Phase II) (2). Whilst in the hospital, the patient uses the PATHway exercise platform as part of their CR programme with other gym equipment (3), under clinical supervision (9). The platform provides a per-

[1]See: http://www.pathway2health.eu/

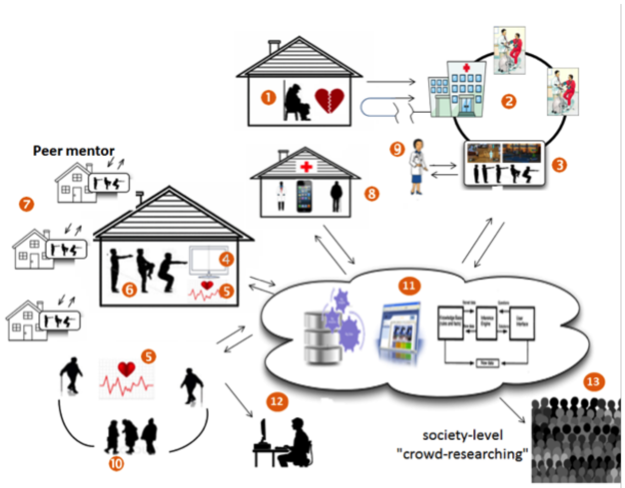

Figure 1: The PATHway concept

sonalised exercise programme delivered as either an exercise class (ExerClass) or an exercise game (ExerGame). For the former, the patient exercises with a virtual avatar that illustrates how to perform the various movements. The system senses the patient's movements and physiological signals so that the exercise programme can be adapted automatically based on patient performance. All usage of the PATHway platform is linked to secure data storage in the cloud (11). When the patient 'graduates' from the Phase II programme they are able to remotely undertake a Phase III programme from the comfort of their own home by virtue of owning a PATHway platform (4)(5)(6).

A key aspect of a Phase III programme is the social connectivity this establishes between participants, which is extremely important in terms of mental health as well as adherence to the programme. For this reason, the PATHway platform facilitates social connections between patients whilst exercising so that peer groups can exercise and socialise together (7). Since the patient's progress and data is stored in the cloud, it is available for remote review by a clinician (12) or during a patient's regular visit to a GP (8). It should be noted that the overall framework has been designed so that it ultimately facilitates longitudinal analysis when it is scaled to large cohorts of patients (13). Over time, based on automated monitoring of patient progress and health, the system will suggest that the patient take a walk with their friends rather than the usual exercise programme, an important aspect of a patient's 'graduation' from Phase III (10).

3. TECHNOLOGY PLATFORM

PATHway is developing an end-to-end modular technology platform that will allow CVD patients to better self-manage their illness through a supportive, holistic, home-based cardiac rehabilitation (CR) programme. An exercise module will deliver an appropriate, patient determined exercise programme (both an exercise class and an ExerGame) and monitor in real-time the patient's actions and physiological response in order to provide personalised feedback via a virtual Avatar coach. This is illustrated in figure 2. A social connectivity module will enable small groups of

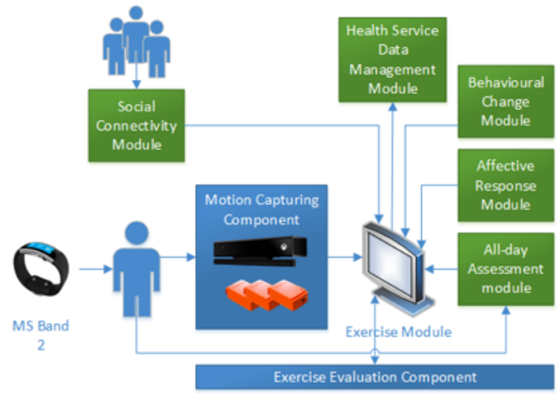

Figure 2: The PATHway technology platform

remote participants to exercise together in a virtual space providing patients with health affecting social interaction, peer support and peer mentoring. The extent to which the patient socially interacts and enjoys the exercise programme (affective response module) will be monitored. An all-day assessment module will monitor participants' physiological responses, sitting behaviour and physical activity levels during and after exercise, and aggregate and abstract this data over time to provide pertinent feedback to the health professionals via the health service data management module.

All collected patient data will be structured to seamlessly and securely link with their medical records, where permission is granted. The delivery of timely and relevant information to the patient will be driven by best practice in, and modelling of, behavioural change through a behavioural change module based on Social Cognitive Theory [2] and the behaviour change wheel [5]. Behavioural change will not only focus on increasing exercise adherence, but will take a holistic approach to improving a healthy lifestyle, by additionally targeting improved dietary habits, smoking cessation, and alcohol moderation. Similarly, PATHway social interaction and peer support will be utilised to improve these healthy lifestyle components.

4. DEMONSTRATION

We propose to demonstrate the PATHway technology platform, primarily focusing on the exercise module and in particular: a) the motion capture, b) the exercise evaluation, c) the physiological data and d) interface components.. The demo, consisting of a large screen, a PC, a Microsoft Kinect and a human subject wearing a wrist-worn physiological sensor, will showcase the user experience of interacting with the system. This includes navigation and manual data entry, real-time sensing and analysis of exercise movements and automatic adaptation of exercise based on physiological response e.g. by choosing an exercise with lower intensity based on a change in the user's heart-rate. It should be noted that the demonstration showcased here is just one aspect (in fact an early prototype) of a much more sophisticated system that is under continuous development. There are many other aspects of the PATHway system that are not described in this submission, including a customised wearable sensor platform which has the capability to automatically detect cardiac and respiratory events and an over-arching decision support system to allow for personalisation and adjustment of the exercise program.

4.1 Motion Capture

The motion capturing component is responsible for capturing the human motion as accurately as possible and providing the spatial information of the human body in real time (30 Hz). A single Microsoft Kinect sensor or a Kinect fused with data from Wireless Inertial Measurement Units (WIMUs) can be used, where the latter are optional for more accurate motion analysis. In particular, 1-3 WIMUs can be placed on the body (thorax and forearms) to enhance the accuracy of the skeleton tracking, especially when self-occlusions are present. The inertial sensors increase the tracking stability by removing outliers of the Kinect estimated joint positions during fast movements or temporary occlusions. Using WIMUs in motion capturing is achieved by rotating the related joints of the Kinect skeleton according to the subsequent rotational information provided by the sensors. The global frame of reference is defined by the Kinect sensor, while the rotational offset Q_{off} of the inertial sensors is extracted by $Q_{off} = Q_W^{-1} \otimes Q_K$ where Q_W and Q_K are the WIMU and the related Kinect joint orientations, respectively.

4.2 Exercise Evaluation

The role of this component is to evaluate the exercises performed by the patient in comparison with the corresponding pre-recorded exercises used as reference returning numerical and textual feedback concerning the patient's performance. The approach detects and counts exercise repetitions (action detection), measures the related accuracy by evaluating the performed repetition in comparison with a "prototype" activity, and provides cumulative accuracy. In particular, the aim of the component is to recognize and extract analytics concerning the physical exercising. The pipeline of this analysis consists of two phases: i) the action detection; the detection of the time interval during which a repetition of a specific exercise is performed and ii) the exercise evaluation; the evaluation of each exercise repetition, compared to reference motion data. The repetition detection algorithm is a continuous indicator based on multiple machine-learning techniques which extracts the progress of a person to reach a specific pose in percentage (confidence). Thus, weighting specific poses/key-frames allows for repetition detection. Sequentially, considering the time interval of a repetition, the included motion data are compared to pre-recorded reference motions by using and comparing motion features, i.e. relative angle, angular velocity and acceleration per joint over time, using dynamic weighting.

4.3 Physiological Data

A wrist-based sensor was preferred to monitor the patient's heart rate for a variety of reasons, including ease of use. A key requirement was access to the raw recorded signals, access to patient daily activity summary and high measurement accuracy. The Microsoft Band was ultimately chosen as it contains 11 sensors and provides direct access to the raw data from optical heart rate sensor, accelerometer, gyroscope, ambient light sensor, skin temperature sensor, UV sensor, galvanic skin response and barometer. Furthermore, the SDK provides access to the vibration motor which enables haptic feedback to the patient in the future.

4.4 Interface

Considering the target user group, the PATHway platform was developed to be an attractive user environment with a user-friendly, understandable interface. Forms and shapes of buttons, content areas and icons are reduced, simplified and stylized to enable clear graphical communication. All shapes of the interface are rounded down to achieve an organic and soft visual impression to engender a natural and soothing effect to the user.

4.5 Demo Walkthrough

Various system screen captures are shown in figure 3. Figures 3(a) & 3(b) show the login screen and an example of using the system. Interaction in the system can be either hands-free based on gesture recognition or via a keyboard and mouse. Note that for privacy reasons, a member of the project team is shown in figure 3(b) rather than a patient. The user can select the behaviour he/she would like to change (figure 3(c)). An example of the recommended goals for the patient in the case of smoking cessation is shown in figure 3(d). The user can select a physiological sensor, in this case the Microsoft Band (figure 3(e)) and "pairs" this with the system. Patient safety is of paramount concern and for this reason each ExerClass is preceded by a prescreening process based on resting heartrate as shown in figure 3(f) (note: the final version of the system will prescreen other key indicators such as blood pressure). The ExerClass is illustrated in figure 3(g). It proceeds by the coach avatar performing an exercise programme, including warm up and cool down, and the patient exercises along as if in a physical class. The patient's movements and physiological signals are monitored so that personalised feedback can be provided, an example of which is illustrated in figure 3(h).

5. CONCLUSION

We believe that the PATHway concept and associated technology platform has the potential to deliver significant cost savings to the healthcare system, and thereby help direct more appropriate utilization of healthcare resources. In the future, the system will ultimately support up to 4 simultaneous users interacting verbally whilst exercising, facilitating social connectivity as part of the ExerClass. The system will also provide the option of an ExerGame as an alternative to an ExerClass, where exercise is performed in a gamified environment and successful completion/performance of a movement results in achievement of a game objective. One ambitious future objective of the project is to automatically determine whether or not a patient is enjoying an exercise programme so that the exercise programme can adapt to an individual based on their enjoyment levels.

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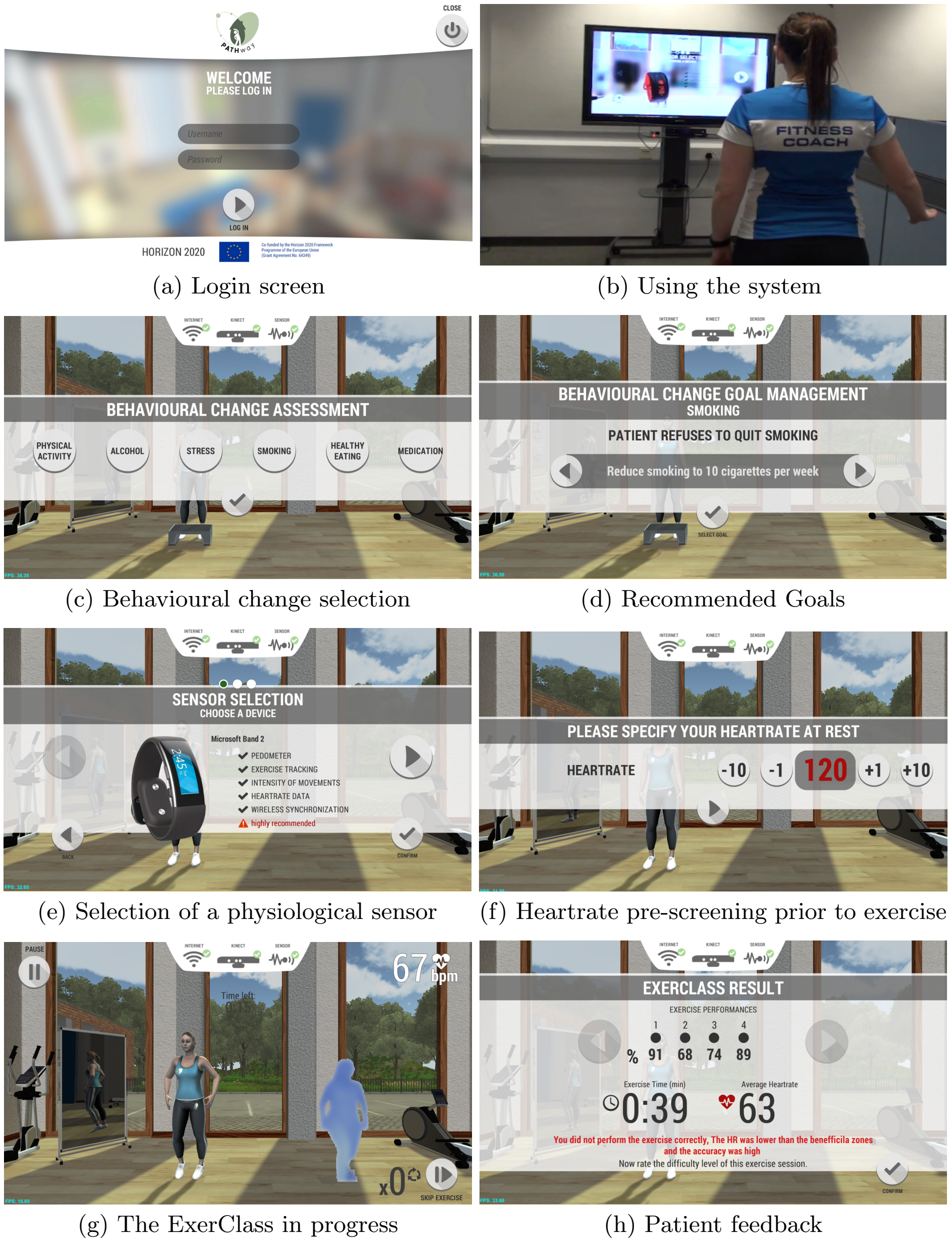

(a) Login screen

(b) Using the system

(c) Behavioural change selection

(d) Recommended Goals

(e) Selection of a physiological sensor

(f) Heartrate pre-screening prior to exercise

(g) The ExerClass in progress

(h) Patient feedback

Figure 3: Screen shots of interactive demo

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