A Smartphone-based Golf Simulation Exercise Game for Supporting Arthritis Patients

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***Abstract*—Arthritis is a common chronic diseases among elderly. Regular exercises help with managing the disease, but physiotherapy is costly and without monitoring there are no reliable workout records and many patients lack motivation. In this paper we evaluate exercise games and motivate the need for applications which are mobile, fun, provide monitoring, and incorporate social media features. Based on this we develop a smartphone-based golf game, which uses GPS and accelerometer sensors for collecting monitoring data and motivating patients to get active. The physical simulation uses an experimentally derived formula to convert wrist accelerometer data into driving distance. User testing demonstrates that the exercise game is entertaining and has a sufficient realism, but more game psychology concepts need to be incorporated to improve playability.**

I. Introduction

Arthritis is a chronic joint disorder and causes symptoms such as inflammation (swelling), tenderness, and cysts or nodules at the joints, which can make everyday activities difficult and painful. Arthritis is one of the most common and most costly chronic diseases in the Western world. In New Zealand alone 530,000 people suffer from the disease and annual financial costs are estimated to be 3.2 billion including health sector and indirect costs [1].

Carefully designed exercises have been shown to improve patients' condition by building up muscles which support the joints, slowing down the progress of the disease, reducing chronic pain, reduce fatigue, and reduce stiffness [23], [26], [6]. However, treatment is constrained by resources (costs and suitable supervisors), availability (time and location), and patient motivation [10], [19].

Telehealthcare has been suggested as a means to reduce healthcare costs. However, patient stations are expensive and are most suitable for collecting vital signs data for patients with more serious conditions such as heart diseases, chronic obstructive pulmonary disease (COPD), and diabetes.

In recent years smartphones have been increasingly used in healthcare applications. For example, the Apple App store offers more than 500,000 iPhone applications including health and fitness-related applications, such as pedometers [28], heart rate monitors [4], and analysis and improvement of sleep patterns [24]. Research shows that 9% of mobile phone owners have software applications on their phones that enable them to track or manage their health [13]. Smartphones are ideal devices for developing innovative health monitoring and support tools for health consumers since they are equipped with multiple sensors to detect user movements [14], and due to their ability to deliver health improvement interventions to traditionally hard-to-reach populations [2].

In this paper we present a golf simulation for promoting joint mobility and overall fitness. The application makes use of the GPS and accelerometer functionality, in order to measure walking distance and golf driving distance. Section III reviews related work. Section IV presents the design and some implementation details of our exercise game. Section V explains a key feature of the implementation, the calculation of golf driving distance from accelerometer data. Section VI presents a user study evaluating our application. Section VII concludes this paper and gives an outlook on future work.

II. Arthritis Exercises

Exercise is the single most important arthritis treatment. It keeps joints mobile, strengthens the surrounding muscles to support the joint, and it slows deterioration of cartilage by transporting nutrients to the cartilage and removing waste from it. Arthritis exercises are divided into three types [3]: motion exercises such as gentle stretching and moving joints within the maximum comfortable range; strengthening exercises building up muscle to make the joint more stable; and aerobic exercises improving cardiovascular fitness by raising patients' heart rate up to a user-specific target level for at least 20 to 30 minutes.

In order to make an exercise effective it should have the following characteristics: consistency, gradual build up of intensity, performance during remission stage (i.e., when symptoms are least distressing), adequate amount, listening to body signals, goal setting, exercising in groups, steady rhythm & smooth motions, and rest after exercises.

Exercises are best performed under supervision of a physiotherapist. Unsupervised exercises may involve incorrect exercise pattern that worsen the disease [10], [19]. Another problem with home-based treatment is a lack of motivation. Severe symptoms limit physical activities that a patient might have enjoyed in the past. This can lead to depression, bad mood and sensitivity to disturbances [5]. The second reason for lack of motivation is absence of supervision, feedback and social

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contacts, which results in patients perceiving self-exercise as no-fun activity [19].

A. Requirements

Based on the above insight an application supporting arthritis exercises must be easily accessible and usable in a wide range of environments. It should aid the arthritis patient with performing correct exercises while providing entertainment and motivation. The chosen exercise must be simple to perform, low-risk, and suitable for patients with different severity of symptoms. While exercising the application should give feedback how well the exercise was performed. This includes correctness of movement and improvement for better result. In order to increase motivation the application should give a sense of achievement, and the application should have social networking functionalities so that patients with similar conditions can exercise together.

III. Literature Review

A good example of a successful "game" combining physical activity, GPS information, aspects of social networking, and real-world data is Geocaching [21]. Geocaching is a real life treasure hunting game where users have to find or hide a physical container called "Geocache". Users can share their experience via social networking sites such as blogs, forums, and Facebook. Worldwide there are more than 1,700,000 hidden Geocaches and 5 million active Geocachers. The attractiveness of geocaching has several reasons: (1) it involves physical activities such as hiking and cycling. (2) There is a large community for sharing experiences, and getting tips and acknowledgment. (3) There is a large and increasing number of geocaches worldwide with different difficulty levels, so users can choose the level of challenge they desire. (4) The experience is non-repetitive - every geocache is different. (5) Many geocaches involve surprises in the form of exciting locations (an unknown waterfall or cave) or riddles. These characteristics make Geocaching a unique outdoor game that many participants never get tired of playing.

Numerous smartphone application exist to measure users' physical activity by using the accelerometer or GPS sensor. Walk'n'Play is an iPhone-based walking game, which uses social network features and a simulator to encourage users to compete and burn more calories [8]. Motivation is further increased by allowing users to set short, medium and long term goals and tracking progress towards them.

"Nike + iPod" is a similar application [20], but requires special "Nike+" shoes with a sensor pouch under the insole. The application gives users more information than Walk'n'Play, including distance travelled, calories burned, calorie burn rate, time and pace. Via the iPod connection users can set up special play lists to increase motivation during workout [11]. Other offerings in this range include a "Fuel band" using accelerometers to estimate physical activity, applications for the Kinect sensor, and an online community for Nike+ users.

Droidglove is a game-like application for wrist rehabilitation exercises [9]. Exercises are selected by a therapist and loaded into a smartphone. When users perform the exercises the correctness of the motion is evaluated based on the accelerometer data. Motivation is increased by representing exercises as a game, where the score reflects the similarity with the recorded correct exercise motion.

Wii Fit and Wii Sports are console video games that simulate sports performances for workout using an accelerometer equipped joystick called the "Nun chuck" and a pressure sensitive "Balance board". The balance board is capable of estimating users' weight and BMI (Body Mass Index), and it allows strength training, aerobics, yoga and balance exercises. In May 2010 the Wii Fit was the world's third best-selling console game in history. Disadvantages include the limited game play, which results in a reduction of interest and participation over time [27], and that simulated exercises are not as effective as the real outdoor exercises [16].

A large number of computer simulations for golf exist. Most of them require the user to stand/sit in front of a screen and record shots using console input (strength, direction), accelerometer-based controllers (e.g., Wii) or optical tracking (e.g., Kinect) [12]. Smartphone-based offerings include golf swing analysers [18], and golf simulations using displays of 3D terrains where shots are performed using touch input or accelerometer data [15]. We could not find any game using GPS information and requiring the user to walk within the real environment.

IV. Design & Implementation

A. Game Play

Golf is a recommended activity for Arthritis sufferers since it involves walking and smooth motions for a moderate amount of time with adequate resting periods inbetween [25]. We hence decided to simulate a golf game. Users have to perform two types of exercises: a swing (while holding the iPhone) to simulate a drive or put, and walking to the current position of the ball. The user can control the distance of a shot by changing the speed of a swing and by using a driver, iron or putter. The driving distance is computed using accelerometer sensor data (see section V). We do not compute the direction of a swing since many low-end Android smartphones do not posses gyroscopes and compass sensors. We hence consider every swing to be in the direction of the hole.

We use the GPS sensor to measure the distance a player is walking. This is achieved using Google "mapView", which is part of the GPS API of the Android SDK. The player continues to perform a shot and walk until the hole is hit. A hole is hit once the ball's position is within 10 meter of the hole (this was motivated by the limited accuracy of the GPS and accelerometer sensor). A game consists of three, six or nine hole courses, where the holes are classified as par 3, par 4 or par 5 depending on distance. Users can play against each others or play alone and try to improve their own score. The player with the lowest number of shots wins.

B. User Interface

The user interface must be suitable for a wide variety of users, i.e., have an intuitive and clear layout, and be easy to use. Elderly often suffer from near sightedness and reduced dexterity. Our interface uses therefore extra large buttons with high contrast boundary and large fonts. Each screen has at

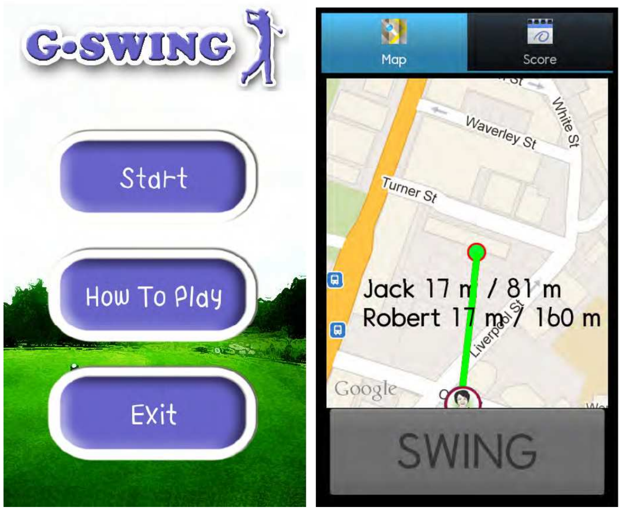

Fig. 1. The title menu of our golf simulation (left) and map data showing the player and ball location (right).

most three buttons, which are usually arranged linearly and centered as illustrated by the title menu shown on the left of figure 1.

Instructions are displayed using a swipe layout, which enables users to read them similar to a small booklet

A user can perform a swing by placing both thumbs on the screen and holding the phone in the same angle as a real Golf club. Once the device is ready a green bar appears together with a label "GO!!" and a vibration signal. After the swing has been performed the distance of the shot is displayed (see figure 2).

In order to make the game more interesting and allow competition between multiple players we designed two simple "virtual golf courses" within Google Map. The map display indicates the players, ball and hole position as illustrated on

Fig. 2. After selecting a club a "Go" label and vibration signal indicates that the device is ready for a shot (left). After the shot the driving distance is displayed (right).

the right of figure 1. The "SWING" button in the figure is enabled once the user reaches the golf ball (i.e., has walked the driving distance). Future extensions could allow users to create their own "virtual golf course" and share them online with other users. In particular the virtual golf holes could be placed at interesting locations (similar to geocaching) and thus create attractive walking routes for exercising.

V. Driving Distance Measurement

An interesting aspect of this research is the computation of golf driving distance from the smartphone's accelerometer sensor. The distance travelled by the golf ball depends on the speed of the club head, the mass and elasticity of the golf ball and club head, and the center of impact of the club head. Critical are also the angle of the club face (loft), which controls the ball's trajectory, and the ball's spin, which creates a lift and can improve distance by 50% compared to an equivalent ball struck in a vacuum. In addition environmental factors such as air resistance (height of the golf course above sea level) and wind effect the results.

The physics of golf is well researched [22]. However, most of the parameters required to compute the driving distance are unknown in practice or difficult to determine without specialised knowledge and equipment. We therefore decided to experimentally determine the relationship between wrist acceleration (when holding a smartphone) and the driving distance.

We performed a user study with 10 participants with different experience levels (8 male/2 female, 9 right-handed/1 left-handed, handicap -2 to 13, age 17 to 49, maximum range 210m to 270m). Participants had to perform shots using different clubs. Drivers used were a Titleist 9.5 Degree for male participants and a R9 Supertri 60g Regular shaft 10.5 Degree for female participants. As iron we used two Number 6 Irons 32 Degree (Taylormade R11 for male participants and Taylormade RBZ for female participants). A Samsung Galaxy S smartphone with Android 2.3.3 OS was taped on the participants' upper arm below the wrist as shown in figure 3.

Each participant performed 10 shots - five with a driver and five with an iron. Different clubs were used for male and

Fig. 3. Smartphone attached to the upper hand for measuring wrist acceleration.

female participants. Each participant was told to strike the ball with varying strength ranging from moderate to full strength. A marker was placed on the tee where shots were taken. The balls were collected one at a time and the driving distance was measured using a Bushnell Tour V2 golf laser rangefinder, which has an accuracy of ± 1 yard ($\approx$ 91cm). For the iron club we got 40 valid measurements and for the driver 23 valid measurements. Invalid measurements included shots which ended in bushes or the neighbouring creek, and instances where we were unable to perform correct measurements since customers were waiting at the tee. The results of this experiment are displayed in figure 4.

Since the driving distance depends predominantly on the club speed, we integrated accelerometer values over the relevant swing period. The start of a swing is defined by accelerometer values exceeding a low threshold after the “Go” label is shown and the vibration signal is given. The swing can be divided into three phases: the “back swing” where the player swings the club backward, the “reverse phase”, where the club reaches is maximum height and reverses direction, and the “forward swing” where the club is swung forward and the ball is hit. The three phases are identified by analysing the maximum and minimum accelerometer values and the period of sign change. The accelerometer values over the forward swing phase are integrated using a simple Trapezoid rule in order to obtain the angular velocity values shown in figure 4.

Figure 4 shows that the relationship between angular velocity and driving distance is roughly linear. While a logarithmic relationship could have been expected due to air resistance, it seems that for long shots the factor is negligible or masked by other factors such as wind or lift from spin.

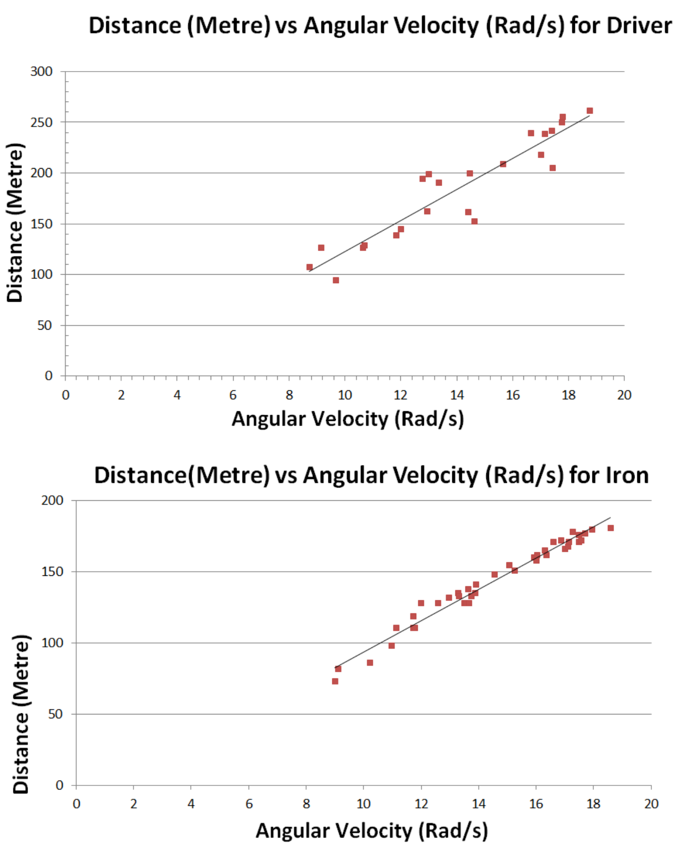

Fig. 4. Driving distances for shots performed with a driver (top) and iron (bottom) with the least-square linear fit indicated in black.

The ball distance depends on the type of club. For the driver we found that the distance is estimated by the formula

$$distance = 15.2 * angularVelocity - 19.1$$

and for the iron it is given by the formula

$$distance = 10.7 * angularVelocity - 6.0$$

VI. Results

Our evaluation has concentrated so far on technical aspects (device independence), usability, and realism.

A. Device Independence

In order to be useful in practice the application has to work on a wide variety of Android smartphones. We tested our game using a Huawei U8100, Samsung s5620, Samsung I9000, HTC One X809, and Motorola Droid 2. All of these devices contain GPS and accelerometer sensors, and they range in price (June 2012) from NZ$ 127 to NZ$ 929. The application worked fine on all devices, but there was some delay with downloading Google map data with the Huawei U8100.

B. User Evaluation

We evaluated our application using ten golf players (3 male/7 female, age 19 to 62 (mean 37.7)). None of them suffered from arthritis. The purpose of the study was to evaluate usability and realism. The study was conducted at the Whitford Park Golf Club, located in a rural area about 25km south-east of Auckland, New Zealand. A virtual 3 hole golf course was overlaid on the Google map data of the real golf course. Participants were given an Android phone and a short explanation of the application, and then had to complete the virtual golf course.

After completing the game users had to fill out a survey investigating usability, enjoyment, effectiveness, and realism.

The first part of the survey consisted of the following four statements which participants had to respond to using a 7-level Likert scale ranging from -3 (strongly disagree) to +3 (strongly agree). The statements and mean values and standard deviations of the responses were as follows:

	Mean	σ
The user interface was easy to use	0.4	2.37
The golf simulation was realistic	0.3	2.21
The game motivated me to walk more	0.0	1.70
I enjoyed the game	1.0	1.76

The results show a large variation in responses, which were split roughly evenly between agreement and disagreement. The usability and realism were considered acceptable, but not fully satisfactory. One criticism was the long time it took to load a map, due to the fact that at the golf course only a 2G network was available. On average the application did not motivate users to walk more. However, five out of ten participants stated that they were at least slightly more motivated. The most positive response was recorded regarding enjoyment of the game.

The second part of the survey contained performance statistics:

	Mean	σ
Time to start playing (in min)	4.4	2.5
Time to complete first hole (in min)	9.5	2.8
Average number shots per hole	5.6	1.2
Average distance walked per hole (in m)	365	48
Time to complete virtual course (in min)	24.5	6.9

The average time from receiving the device to start playing was 4.4 minutes. Most of this time was spend with reading the instructions. Once users started playing the time requirements were similar to a real golf game. Three participants commented that "each game is taking too much time". However, one participant liked this fact: "I like the way this application takes time to finish the game. Similar to real Golf."

In order to understand the responses better the survey contained a comment section. With regard to usability one participant commented that he found the instructions for performing a shot difficult to understand. Two of the participants didn't like the interface for reviewing their and their partners performance: "It was hard to concentrate on the review while playing real Golf". Four participants stated that the application was too easy to captivate them. In particular our application has no realistic simulation of putting - only the distance is measured, but no direction. Existing golf games use 3D views of the terrain and enable users to specify putting direction using a variety of game controllers (e.g., [12]).

Evaluating our application with regards to game psychology uncovers the following shortcomings [7], [17]:

- **Game width:** a game should address multiple basic human needs such as self-esteem, cognitive needs, self-actualisation, and transcendence (the need to help others). Game width could be improved by giving feedback such as praise, encouragement, and corrections; having more social interactions (help and encourage other players); and by increasing the level of difficulty (adding time limits, obstacles, random events).
- **Imitation:** a game should enable the player to constantly learn. This could be achieved by enabling a player to learn how to avoid obstacles or how to react to unexpected events.
- **Emotional impact:** common ways to achieve an improved emotional impact are visual and sound effects and rewards (high score lists, virtual badges).
- **Pacing and difficulty:** our game needs an increasing level of difficulty, while still being suitable to a large number of users with different experience level.

VII. Conclusions and Future Work

We have developed a smartphone-based golf simulation using GPS and accelerometer sensors to encourage arthritis patients to get physically active. The application uses Google map data and social media aspects to allow users to compete while walking in their neighbourhood. According to our literature review this is the first golf simulation supporting users to walk in the outdoors (most existing games use static user locations in front of a screen, e.g., by using the Wii or Kinect controller). We have presented a simple algorithm based on experimental data to compute driving distance from accelerometer data.

So far we have only tested technical and interface aspects in order to improve the application before conducting patient studies. The current interface is acceptable, but more experiments must be conducted to improve usability. The realism of long shots and game duration is good, but we do not have an acceptable simulation of putting. While it would be possible to use 3D views of simulated terrain and touch input to specify putting direction, we would like to use real environment information (similar to geocaching).

Our evaluation shows that the game concept and technical aspects of the implementation are suitable for a game for arthritis patients. A discussion with an exercise therapist confirmed that the game concept, the required motions (walking and swinging), and the duration of the game are suitable. Our application collects data on walking distance and swinging motion and allows analysis of performance over time.

Future work will concentrate on improving the game play using concepts from game psychology, while also integrating information relevant to arthritis patients (encouragement and information relevant to the disease). Equally important is the improvement of social media aspects. We want to allow users to create virtual golf courses in their neighbourhood, add interesting features, and share them with other users online.

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