Development of Exergame-based Virtual Trainer for Physical Therapy using Kinect

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Abstract. We present the development of a virtual trainer for use by physiotherapists and patients in exercise based physiotherapy programmes. It allows a therapist to tailor exercise requirements to the specific needs and challenges of individual patients. Patients can select different programmes and follow a coach avatar to perform recorded exercises based on their needs. The Microsoft Kinect has been implemented as a means to track user's body movements. This enables immersive and natural interaction between the user and virtual tuition world. Most importantly, the recorded skeletal joint data facilitates quantitative analysis and feedback of patient's body movements. The proof of concept has been implemented and tested by 15 volunteers. Preliminary study shows the potential of using Kinect as a low cost solution for virtual physiotherapy training at home or clinic settings.

Keywords: Virtual physiotherapy, serious games, Kinect, rehabilitation.

1 Introduction

Rehabilitation programmes involving physical exercise and assistance with carrying out daily living tasks are undertaken by patients recovering from serious medical conditions, such as stroke, brain or physical injury. Supervised physiotherapy or occupational therapy start before discharge from hospital and continue when the patient returns home. Such clinic based approaches are expensive for the health service to provide. Numerous barriers (e.g. physical, economic, social and psychological factors) have been identified which prevent people from regularly participating. In view of increasing demand for healthcare services and modernisation of healthcare provision, there is an urgent need for the healthcare system to make use of technological advances to deliver a more accessible and cheaper alternative to conventional physiotherapy and occupational therapy [12].

A lack of motivation has been identified as a major problem in therapy sessions, often caused by the repetitive nature of exercises [2]. Computer games have shown the potential to improve patients' adherence in rehabilitation [3]. Investigations have been carried out into the use of interactive multimedia and off-the-shelf games for physical rehabilitation [11, 12]. It was found that whilst positive results were present, various issues were identified. A main problem is that many games were not designed with rehabilitation in mind, therefore they do not specifically target the problems that patients have. Off-the-shelf games could actually cause frustration and anger in the person undergoing rehabilitation due to the fact that the gameplay can be too difficult and not adjustable to suit individual situations.

We aim to develop a low-cost virtual training computer application for patients who need to undertake regular physical exercise or cognitive tasks at home. It will enable people to follow a course of personalised rehabilitation exercises. The design of the virtual trainer will adapt to individual needs, differences and progress of user's therapy regime. State of the art motion sensing device Kinect is employed as a means of capturing player's movements, ultimately allowing for gestures and movements to become the gameplay input and to be analysed quantitatively for feedback. The proof of concept game "Theraplay" has been developed and tested [1]. The clinical scenario we target is rehabilitation of elderly people, but the concept of design is applicable to other problems in physiotherapy or occupational therapy, such as stroke and injuries which can be improved by regular and targeted exercise.

2 Design for users experiencing age-related changes

2.1 Visual cueing

Older people are likely to suffer from some degree of visually impairment. Visual cues can significantly improve the performance of participants to perform movements. When walking along a path marked by lines or markers, participants took longer strides with each step as well as a quicker speed [12]. Though the exact cause for this improvement is not clear, the landmarks gave the user an idea of how far they are stepping. It has also been reported that using large musical symbols and mirroring user's movements visually on screen were much more appealing and encouraging in a dance game [2]. It is interesting to find that intuitive visual feedback of player's movements seems to be an effective way to engage the player.

2.2 Player-controller: natural interaction through body movement

It has been a concern that elderly or impaired people have trouble adjusting to the use of new technologies, especially any advanced functions [7]. It is important to keep them in their comfort zone and use something they are familiar with, since they already suffer from restriction due to their disability and age. Further restriction (e.g. performing exercises unaided, complex equipments and intrusive sensors) should be avoided [2, 8]. Although the Nintendo Wii is perceived to be a possible tool for use with the elderly due to its success with younger people, the Microsoft Kinect does not require any form of a hand-held controllers or body worn sensors. The concept of using natural body movements and gestures of the player as gameplay controller is a new trend in exergaming, and a promising feature for people with physical, cognitive or age-related changes and impairments. Investigation of the suitability of the new technology for rehabilitation has been carried out, for example as demonstrated by the Rehabilitation Gaming System [4].

2.3 Design guidelines

Guidelines were stated by Gerling et al. [7] for the creation of a rehabilitation game for older users. One significant point made from these guidelines is that a bigger tolerance for gesture execution should be allowed rather than having to be very precise. Fatigue should be managed through pacing, as lack of stamina is typical of such a user group. Dynamically addressing difficulty was again brought up in this report. Simple gestures that map to real world manoeuvres are preferable in supporting gesture learning, as these people may have very limited or no experience with games.

It was found that more than 50% of the problems were due to usability related issues [6, 10]. In particular,

- learn-ability: how difficult it is to learn to use a device, to understand and to integrate functioning instruction.
- efficiency: the extent to which technological applications satisfy users's needs, avoiding frustration and dissatisfaction.
- memorability of device's functions: a measure of this can be obtained by considering the time needed to perform a previously experienced task.
- errors: how often the product can induce errors, and how easily it recovers from these errors.
- satisfaction: users' attitude and adoption of technological applications which could be influenced by the pleasure derived from their usage.

Considering the problems that come with old people, reducing the number of options, the speed of game elements and required reaction time could positively affect the demand for cognitive resources and information manipulation [5]. Guidelines for elderly entertainment should consider: therapy appropriate range of motion and focus diverted exercise matching with individual motor skills, meaningful tasks, appropriate cognitive challenges, simple objective and interface, motivational feedback, creation of new learning, and sensitivity to decreased sensory acuity and slower responses .

3 Implementation of virtual trainer Theraplay for physical therapy

Based on our study on design for elderly people, a imitation game, namely virtual trainer "Theraplay", was developed by making use of the prevailing Kinect technology. Such an application aims to provide an assistive tool for people who need to take regular physical exercise at home.

3.1 Motion tracking and gesture recording using Kinect

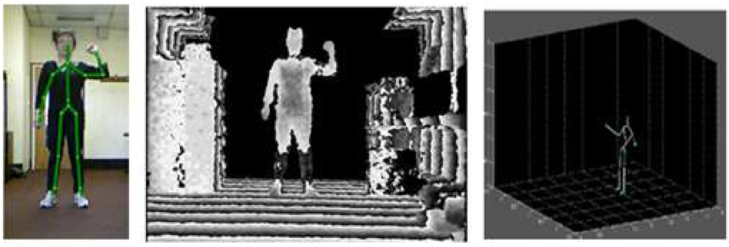

Fig. 1. Analysis of human movements from Kinect RGB, depth and skeleton images.

Microsoft Kinect has been widely used as the state of art motion tracking sensor in gaming. It is portable, easy to set up and allows operation in normal home or clinic settings. It records the body movements of the user in front of it at a speed of 30 frames per second (fps) for depth and colour stream in real-time. Field of view angle of Kinect can achieve 43 degrees vertical and 57 degrees horizontal. The vertical tilt range of the camera is +/- 27 degrees. The Kinect provides skeleton tracking for up to 6 people, of which 2 players can be active. As shown in Fig. 1, the skeleton of a user consists of key body parts presented by 20 anatomical joints with each joint providing a 3 dimensional x, y and z values. Each joint can be described as tracked or inferred. Inferring a joints requires estimating were the joint is likely to be based on the location of the other joints. The accuracy of 3D joint location is centimetre-level which is adequate for rehabilitation games and comparable with marker-based systems

3.2 User play modes

The virtual trainer consists of two modes: physiotherapist mode and patient mode as shown in Fig. 2. In the physiotherapist mode, a physiotherapist can personally perform prescription movements and postures. These movements are recorded and can be played back through a 3D on-screen avatar, so that the physiotherapist can check and edit before storing them in an exercise database. This means in a therapist can record various movements and distribute them to patients according to individual needs. In the patient mode, a patient selects an exercise from the list of exercises. The selected exercise can be played back on a coach avatar. The user can preview the movement, know what to expect and then follow the coach to exercise themself. The user's exercise is captured by Kinect and displayed on the user's avatar during exercise.

Patients should try to copy the movement as accurately as they can, for example to keep in rhythm or pose similarity with the coach avatar. Tolerance is set to allow movements when are sufficiently close to the coach avatar, avoiding frustration. User performance and body postures are analysed. The patient

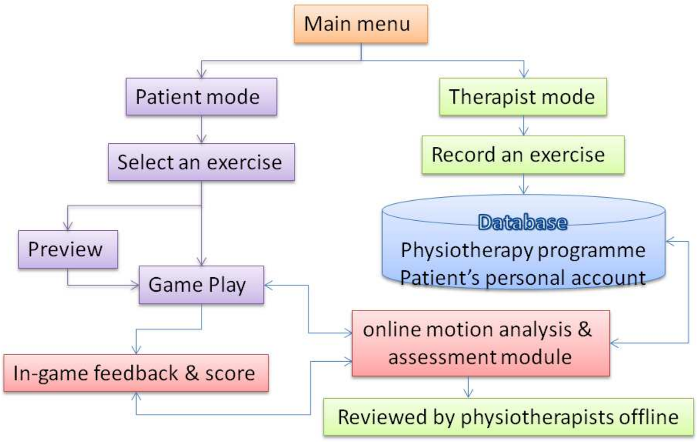

Fig. 2. Virtual trainer Theraplay structure chart

gains a high score by correctly performing and completing the required exercises. Music and songs are used to create entertaining environment and improve user's performance.

3.3 Interface

The interface design of Theraplay is shown in Fig. 3. Screens in each patient and therapist modes contain two avatars. One is linked to the patient/therapist (mirroring their movements in real-time); the other serves as a vessel to replay a pre-recorded movement. To avoid a cluttered screen and distract user attention, the avatar was rendered concisely using 14 joints. The depth image of Kinect is shown in the bottom right corner. It helps the user keep track the field of view and easily adjust the Kinect tilt angle by using "Change Kinect Angle" button provided on the interface.

Users should be able to use Theraplay on their own without requiring another person to assist with game control. However, if the user is out of range of the Kinect, skeletal joint data will be scrambled. To solve this problem, a countdown timer (e.g. 5 seconds) is implemented at the beginning of recording. This allows the user sufficient time to get into position after clicking the button to start Kinect. Meanwhile, Theraplay provides a trimming function that allows removal of any scrambled data at the end of recording before the data are saved.

Checkboxes of limbs was designed in the therapist mode. It allows the therapist to specify any body limb or combination of limbs for assessment. When replaying on the coach avatar, body limbs relevant to the exercise are displayed in blue, distinguishing with the colour used for other body parts.

We have attempted to use hand gestures (e.g. pushing and waving) to begin or stop data recording or gameplay. The results from testing were unsatisfying. This is because the command gestures may not be always detected properly. When

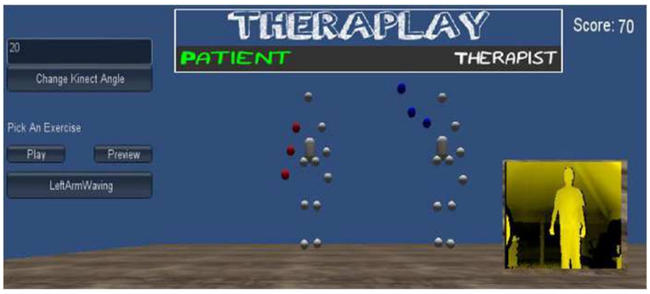

Fig. 3. Theraplay interface. The arm of coach avatar (right) is in blue, indicating relevant body part to the exercise. The arm of user's avatar (left) is in red, indicating incorrect movements. This turns to green when correct.

performing exercises including gestures similar to those command gestures, the game will work inappropriately. People with cognitive or physical difficulties could find it even more difficult and frustrating to use gestures to control the game.

3.4 Feedback

Due to the varying ability from patient to patient, a successful game requires the ability to adapt to users' motor skill level [10]. The challenge and feeling of self-improvement is what motivates the patient to continue exercising. The user will need to be prompted when they are doing something wrong, but also given the correct indication to allow them to fix or improve their movement so that they will benefit from playing the game. This feature also means that as a patient improves, they do not outgrow the usefulness of the game as it will adapt to their improvements, providing an ever-increasing challenge.

In Theraplay, a in-game score is provided on screen. This will increase continuously while the patient's movement is within the acceptable range of accuracy as the coach avatar replays the movement. The score can then be used as a reference point to show how well the patient did compared with their previous performance. An important feature of Theraplay is direct visual feedback on user's movement presented on user's avatar during exercise. The patient will not have to check the score as the only means of telling how well they performed. Different colours of the joints on the user avatar are used to indicate satisfaction to the player's movement. For example, green indicates good mimic inside of the accepted range, while red indicates that the patient is performing the movement incorrectly with the coach.

Joint data of the player are calculated and compared with the coach avatar to assess the quality of the exercise in terms of posture and rhythm. Tolerance on joint angles and timing is used to setup the acceptable range. We have developed machine learning based action recognition method to automatically identify if an exercise is performed correctly [9]. The average recognition accuracy can achieve 90% on 10 testing exercises.

3.5 System development architecture

Unity3D is a cross platform (e.g. Windows, Mac OS, Xbox and mobile) and powerful game engine that comes complete with an intuitive set of tools to create interactive 3D content. There are thousands of ready-made assets available and a vast knowledge sharing community. It is an ideal game engine allowing quick production of prototyping games for feasibility and concept proof.

Unity does not natively provide connectivity for the Kinect. Accessing the Kinect in Unity3D can be achieved using OpenNI/NITE or third-party plugin Zigfu. OpenNI/NITE requires both the OpenNI framework to be installed as well as the Primesense NITE middleware for integration of the Kinect into Unity. However, this framework and its installation could be deemed too complicated to our targeted user group. In our game design, we chose Microsoft SDK driver and used Zigfu to connect the Kinect into Unity. The developed game is standalone, it runs on Windows machine with Microsoft Kinect SDK installed. The architecture of the virtual trainer development is shown in Fig. 4

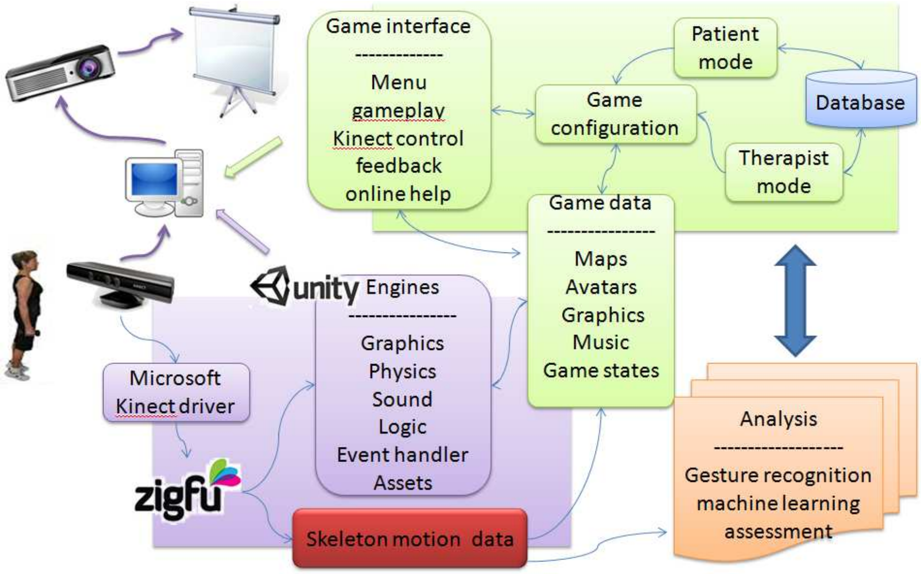

Fig. 4. Architecture of the Kinect-based virtual trainer development.

4 Evaluation and testing

A range of excises at different difficulty levels have been recorded for testing. These include: 1) static posture matching, 2) simple uni-limb movements, 3) simple multi-limb movements and coordination, 4) complex uni-limb movements, such as changing route, speed matching, and combined postures, 5) complex multi-limb coordination, symmetry and asymmetry.

The prototype and recorded excises were evaluated by 15 volunteers of age from 18 to 65. Some of the subjects were specialists in physiotherapy and computing in addition to the general user population. Therapists were able to provide suggestions about the system therapeutic's effect and functionality requirements in clinic settings. Computer specialists could give their opinion on more technical aspects, for example code optimisation, system design and robustness of posture assessment to individual variations. General users evaluated usability and system applicability, including system setup, interface, control, visual clarity and feedback.

We first explained and demonstrated the functions of the prototype system to the users undertaking testing. Then the user was required to explore every function and try out by him/herself. At the end they were required to complete a survey consisting of eleven questions. These questions can be split among three major aspects:

Therapeutic domain: 1) Do you feel the application was beneficial to your therapy? 2) Do you feel the display of movements on the virtual therapist helped you to correctly perform the movements? 3) Did you think the assessment was appropriate? 4) Do you think such system can be an alternative to face-to-face clinic-based interventions?

Welfare: 5) Did you feel that it is easy to setup the system including the Kinect? 6) Did you feel comfortable during the playing experience? 7) Did you find that it is easy to use and understand? 8) Would the imitation game improve your motivation to perform the exercises?

Engagement value: 9) Did you think visual display of player's movements and indication of correct/incorrect postures helped your engagement? 10)Did you feel challenged? 11)Did it feel fun?

Each question was scored into 5 levels from strongly agree (100%)to strongly disagree (0%). The results of evaluation from 15 subjects is shown in Fig.5. At the end of questionnaire, open text space was provided for suggestion on e.g. how you think the system could be improved. Main suggestions centred on adding variation in gameplay to increase fun and user adherence. Many users also think the assessment criteria could be relaxed, allowing variation when individuals take an exercise in a slightly different way.

5 Discussion

Active participation in rehabilitation programs increases the benefit and effectiveness of therapy [2]. In the current proof of concept design, the program fulfills

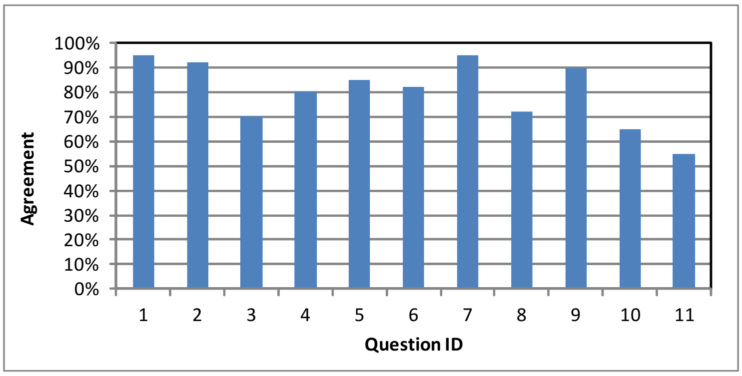

Fig. 5. Ratings of each question agreement in the evaluation questionnaire.

a similar role in therapy as a virtual trainer. Patients are required to mimic the designed exercises. Although visual feedback and scoring on movement accuracy etc. show promise in helping patient's engagement in short term, long-term patients motivation in rehabilitative context needs to be addressed. Preliminary studies on understanding motivational requirements in doing rehabilitative exercises show many factors that can influence on the patients level of motivation, such as social functioning, patient-therapist relationship, goal-setting, environment, meaningful rehabilitative tasks, recreational activities, positive feedback and music.

The prototype tool takes an imitation-based approach to monitor user performance. We have successfully developed real-time posture and movement assessment techniques that underpin the fundamentals of scoring. This provides a robust underlying framework to further develop the prototype into a fully-fledged game. In order to achieve this end, we envisage the inclusion of motivation-driven game context, contents and gameplay.

6 Conclusion

The imitation-based virtual trainer [1] could provide an assistive tool as an alternative to traditional face-to-face clinic-based interventions, reducing the need for clinic visits. We proposed the use of Kinect technology, enabling full body movements to become the gameplay input and to be analysed quantitatively for feedback. Such techniques underpin the development of complex exergames that encourage patients' engagement with their physiotherapy regimes. We have found that helping users feel motivated and engaged through motivational, recreational activities was crucial to the success of using such technology. Developing motivation-driven functional games with appealing gameplay would be a major focus to improve the current design.

Machine intelligence will be further explored for quantitative assessment on the similarity and variation of postures and kinematics. Abnormal and risky movements (e.g. risk of fall) could also be a focus of detection, so as to automatically generate risk alerts. Novel methods need to be investigated to interpret high volume data inputs from the sensor, and also possibly inputs from cognitive assessment and medical conditions. By mapping these onto patient profiles, low volume summary can be created for the supervising therapist. Such machine intelligence would be novel and advance to many general exercise/sports games.

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