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Development of a system for supervised training at home with Kinect V2

Scherer M.*, Unterbrunner A., Riess B., Kafka P.

University of Applied Sciences Technikum Wien, Höchstädtplatz 6, 1200 Vienna, Austria

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Abstract

Therapy of injured professional and amateur sportsmen can take long periods of time. It is important to promote sustained motivation during long rehabilitation phases. Live feedback and playful applications enhance the compliance of users. For this project the newest version of the Microsoft Kinect sensor (Kinect v2) was used and implemented into a prototype for supervised rehabilitation of injured athletes. A playful approach combined with a proper gamification concept ensures a constant high level of motivation for athletes of all ages recovering from injuries.

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Keywords: Supervised training; Kinect; at home rehabilitation;

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1. Introduction

The demographic change leads to a new composition of age groups. The increase in the proportion of older people precedes in difficulties in supplying essential public services such as health care [1]. Different government health organizations advocate home-based rehabilitation and telemedicine as a tool for the future [2, 3]. Telemedicine and personalized rehabilitation systems, available to elderly people or patients, like injured athletes, and healthcare staff could help to control healthcare expenditure and improve the wellbeing of citizens [1].

Nowadays rehabilitation after sports injuries and accidents is performed predominantly stationary in specialized facilities where the patients are cared by qualified professionals. After discharge from inpatient care patients are left on their own. Further rehabilitation is necessary for an effective recovery process. The execution of continuative therapeutic exercises and the frequency of training cannot be monitored today, due to a lack of feedback through medical and sport engineering experts. Literature shows that rehabilitation at home is a lasting therapy method [4, 5]. Zidén et al. [4] indicates in her study of home rehabilitation after hip fracture that the home rehabilitation program had a long-term effect on independence, balance confidence and physical function. Additionally, the home rehabilitation group regained their independence and balance confidence faster than those who had received a conventional care. Focusing on self-efficacy and exercising daily activities including outdoor walking might have contributed to this results. As a result a quicker re-entry into daily and sports activities was possible. Further, Donohue et al. [5] supports the idea of home rehabilitation after hip surgery and confirms that rehabilitation at home shows greater improvements in functional status and lower extremity compared to a control group.

Several government strategies show that telemedicine and rehabilitation at home will be the future, but the question who pays for additionally medical care is still open [2,3]. This justifies the use of low-cost sensors in this research field. The aim of this project was to implement a low-cost sensor based therapy system for injured sportsmen. A use case would be a knee injured basketball player, who needs to strengthen his upper thigh muscles after a knee operation. The appropriate system was needed to support independent rehabilitation at home. Sensors for the system should be suitable, give feedback in real-time and be cost-efficient.

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* Corresponding author. Tel.: +43-1-3334077-892 .
E-mail address: scherer@technikum-wien.at

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Previous projects focus on the use of video game sensors as useful tools for rehabilitation systems [6, 7, 8]. Microsoft's Kinect [Microsoft Cooperation, Redmond, Washington, USA] provides full-body 3D motion capture and gesture recognition using a RGB camera and infrared depth sensors. This system enables users to control a console without any handhold device. The sensors are based on the time-of-flight principle, thereby 25 anatomical landmarks, like skeleton joints, of one subject are computed. Overall up to six skeleton models can be calculated [9]. The former version of the system generated a coloured point cloud and calculated 20 anatomical landmarks of maximum two subjects [10]. With a resolution of 1920x1080 pixels of the RGB camera and 512x424 pixels of the IR camera the system can measure in a 70 degrees horizontally and 60 degrees vertically field of view, with a maximum frequency of 30 Hz [9]. Diest et al. [11] showed that the first version of the Kinect is a suitable sensor for measuring whole body movement patterns during exergaming. Kinect training systems on the market, do not consider the individuality of each patient. As each patient has individual injuries and complaints a system with personalized feedback is needed.

2. Methods

Since patients start their rehabilitation process in a clinical institution, the consideration was that their individual data should be determined there too. Because of that the application consists of two components, one for the therapist of the clinical institution and the other one for the patient for the usage at home. During the inpatient stay patients are performing predefined exercises under supervision of the therapist, who uses the first component of the application. The applications algorithm saves the patients' reference data, depending on the type of exercise. This can be the patients' maximum and minimum knee angles, as well as his or her complete range of motion. The therapist is able to set a possible amputation level and an exercise which the patient should perform. For now, the patients' data is saved for each exercise in a separate *CSV file. The training plan and the exercises are chosen from the therapist and cannot be changed trough the athletes

At home the patient uses the second component of the application. Each exercise loads the reference data from the *CSV file and adapts the exercise goals according to them. According to the users' state of mind he or she is able to set a difficulty level, which will also impact the goals a little. The individual exercise algorithm compares the current movement data with the recorded reference data and provides as a result live feedback, which shows the correctness of the execution. It was mentioned that the application consists of two components. In fact, it is divided into three components (Core, Therapist, User), however while the User component is used by the patient and the Therapist component is used by the therapist, the Core Component is used by both, as it provides all important data from the Kinect and the user.

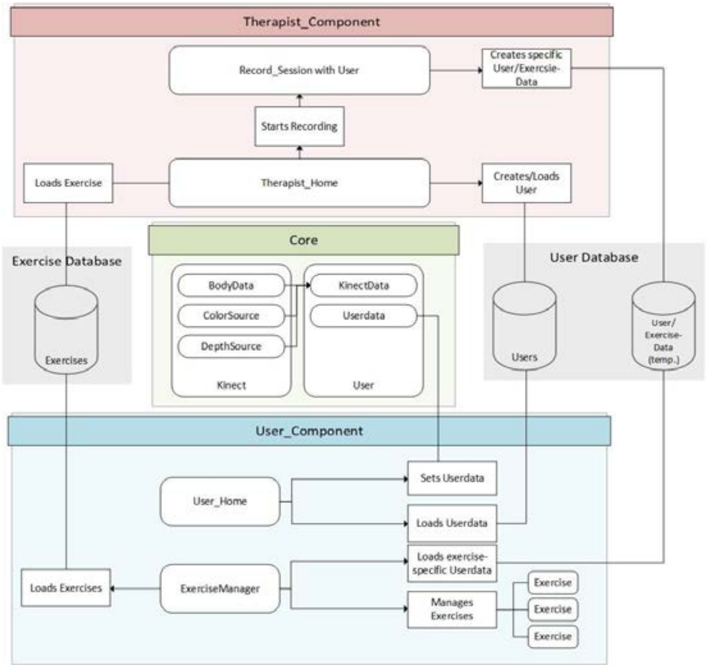


Fig.1 Flow Chart of the Software Architecture. In the upper part the therapist sets the exercise and creates or loads the user which will perform it (red). In the record session the exercise-specific user data will be created. In the lower part the user sets his todays' well-being. Afterwards he performs his training scheme, which was set by the therapist (blue). The core component (green) in the middle consists of the data provided by the Kinect and the user. It is used for both other components (therapist and user).

Exercises are defined as various tasks which the patient needs to overcome in order to master an exercise. He or she needs to achieve certain angles and/or joints positions in a certain order and for a certain period of time. To calculate an angle, the algorithm chooses three joint positions, provided by the Kinect SDK, whereby one operates as the center point. Two vectors are calculated by subtraction and the scalar product (1) provides the desired angle between them.

$$\varphi = \cos^{-1}\left(\frac{\vec{u} \circ \vec{v}}{|\vec{u}| \cdot |\vec{v}|}\right) \tag{1}$$

As an example serves a basketball player with an injured knee, who does a squat under therapeutic supervision. The application measures his possible knee angle range, which is between 88 (stretched) and 50 (bent) and the application saves this data. Afterwards the patient does this, and other exercises, at home. He sets the difficulty level medium which decreases the maximum angle und increases the minimum level by 7 degrees. The application adjusts the new goal settings and as a result the player has to overcome the range between 81 (88 – 7) and 57 (50 + 7) degrees in order to master the task of a squat. He gets live feedback about the progress he made and the important joints turn green in color if a required angle is reached.

It is worth noting that additional angles are also calculated to reduce potential sources of errors and which are not affected by the difficulty level. In case of a squat shoulders and hips angles are compared as well. They only have to be within his recorded angles. Because of that the patient is not able to bend his knee for example in a lying position to cope with a task.

3. Results

The implemented software consists of two parts: a therapist-mode, where different parameters can be selected and a user-mode for workout. The sequence of the program consisted of several steps. At first the reference had to be created. Therefore the therapist starts his version of the program. Afterwards the name of the patient is entered and the recording time for the reference and the exercise is chosen. The therapist can make further settings if the patient is an amputee. After clicking the start button on the home screen the program switches to the reference recording screen.
When the patient is tracked by the Kinect v2 green points representing his joints appear on his body (Fig 2.) and the defined recording time elapses (Fig 2. (b)). This is the sign to do the reference exercise while being supervised by the therapist. When the time is elapsed the program creates a reference file and stores it before it returns to the home screen. In this project stage for each exercise an own reference file is needed.

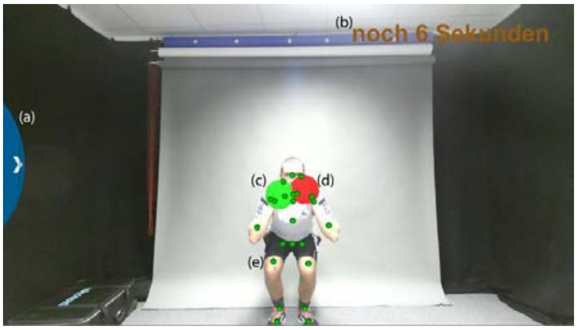
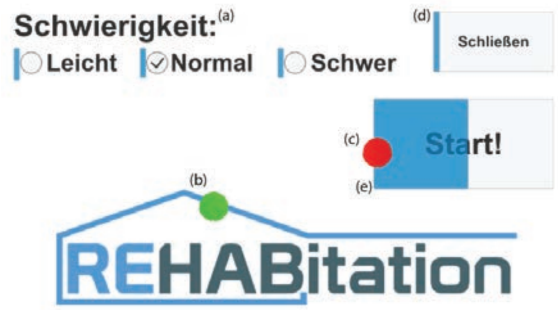


Fig. 2. Reference recording screen with patient in end position. (a) button to return to the home screen; (b) remaining time for the recording; (c) controller of the left hand; (d) controller of the right hand; (e) green points representing the joints.

For the training at home the patient uses his or her version of the program where it is not possible to create a reference file. When the patient starts the program the home screen appears where difficulty (Fig. 3 (a)) is chosen. Afterwards the exercise can be started (Fig. 3 (e)). Two controllers (Fig. 3 (b) & (c)) are implemented to give the patient the opportunity to control the program without a mouse or a keyboard. The green point represents on every screen the left hand, while the red point represents the right hand. The patient has to move one of his two hands to the element he wants to activate and hold it there for two seconds. A blue progress bar shows how long the hand has to be held on the selected element. Only after selecting a level of difficulty it is possible to start the exercise (Fig. 3 (c)).



Schwierigkeit: ○ Leicht ☑ Normal ○ Schwer

Fig. 3. Home screen of the patient version to perform an exercise (2). (a) level of difficulty selection; (b) controller of the left hand; (c) controller of the right hand; (d) button to return to the home screen; (e) button to start the exercise.

Before the exercise starts two safety warnings have to be accepted. The first safety warning (Fig. 4) requested the patient to stay alone in front of the Kinect, while the second safety warning requested to empty the space from dangerous obstacles.

Stellen Sie sich alleine direkt vor die Kinect!

Fig. 4. Screen with the first safety warning. (a) button to return to the home screen; (b) controller of the left hand; (c) controller of the right hand; (d) button to accept the warning.

After accepting the second safety warning the exercise screen appears. On this screen the patient can see the name of the exercise and the number of correct repetitions related to the total amount of repetitions required. The background of the exercise name is red when the patient has to occupy the start position to enable the detection of the whole body (Fig. 5 (b)).

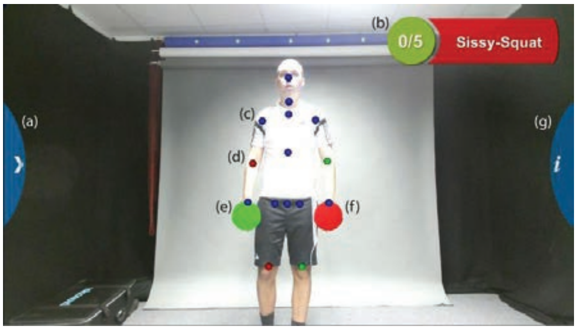


Fig. 5. Exercise screen with untracked patient. (a) button to return to the home screen; (b) number of successful repetitions related to the required amount of repetitions and name of the exercise; (c) blue points representing the joints; (d) points of the elbows and knees showing if the angle of the joint is in the required range; (e) controller of the left hand; (f) controller of the right hand; (g) button to show a video of the exercise.

When the patient stands in the correct start position the background of the exercise name changes into green to show that the program is able to detect the patient's body and the workout can start (Fig. 6 (b)). If the patient is not sure how the exercise has to be done, a tutorial video can be started by moving one of the controllers to the information button (Fig. 5(g)). When the information button is held long enough, the video starts on the bottom right corner of the screen (Fig 6 (h)). If the video was too small, it can be maximized by pressing the symbol in the top left corner of the video, causing the video to expand in the center of the screen.

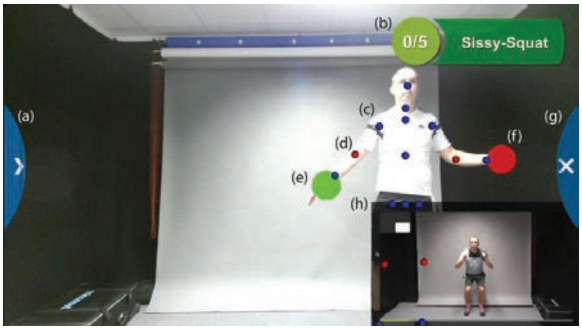


Fig. 6. Exercise screen with video of the exercise. (a) button to return to the home screen; (b) number of successful repetitions related to the required amount of repetitions and name of the exercise; (c) blue points representing the joints; (d) points of the elbows and knees showing if the angle of the joint is in the required range; (e) controller of the left hand; (f) controller of the right hand; (g) button to show a video of the exercise; (h) video of the exercise with option to maximize it in the top left corner.

When the Kinect v2 tracks the whole body the patient can start to move. When the patient reached the end position of the exercise an acoustic signal sounds. If the patient moves back to the start position and all the joint angles are correct the program counts the repetition and an acoustic signal sounds. If a single joint angle of the repetition is not correct (Fig. 7.), the point of this joint changes red (Fig 7 (d)) and the system does not count the repetition.

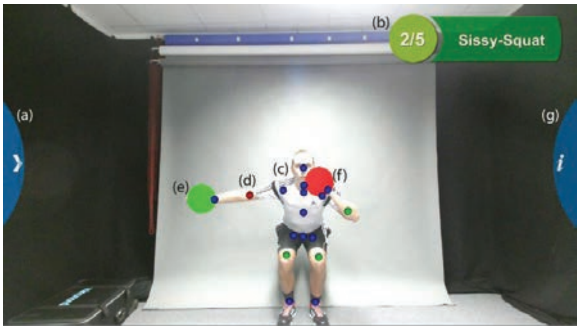


Fig. 7. Exercise screen with patient performing a false repetition. (a) button to return to the home screen; (b) number of successful repetitions related to the required amount of repetitions and name of the exercise; (c) blue points representing the joints; (d) points of the elbows and knees showing if the angle of the joint is in the required range; (e) controller of the left hand; (f) controller of the right hand; (g) button to show a video of the exercise.

This sequence is repeated until the defined amount of repetitions is reached. Afterwards feedback that the exercise is finished is shown on the screen and the athlete can start with the next exercise.

4. Discussion

Long-term sport injuries can lack the confidence and motivation of athletes. High compliance during the therapy can lead to a quicker return to training and as a result a rapid re-entry into competition. In order to increase the patient‘s compliance, the exercises of the Kinect-based prototype system were implemented as games or similar to games with different levels of difficulty. This enables the patient to recognize his or her rehabilitation progress more easily during the training at home. Depending on the type of game, the patient is able to compare his or her game data (e.g. time, points, length, etc.) during the rehabilitation process. The playful approach combined with a proper gamification concept ensures a constant high level of motivation for all types of patients. In the next steps of the project the gamification part will be expended. A virtual sports coach and a virtual user avatar are possibilities for further improvements. The exercises should have a more game-like approach or should be completely hidden inside a game. Moreover, the user could have the chance to unlock certain achievements, which in addition could be linked to vouchers of fitness centers and sporting venues.

The correct execution of an exercise is one of the most important aspects during training. The therapy system can assure the correctness of the training by giving live feedback to the user on the screen. It is contemplated to proof this statement and the usability in a clinical trial. Due to the individual references files the system aims athletes of all ages recovering from injuries. Beside the gamification part the implementation of additionally exercises in cooperation with sport coaches and therapists will be conducted.

5. Conclusion

Appropriate sensors are needed to support independent rehabilitation at home and to monitor the therapy process of athletes. Microsoft's Kinect provides full-body 3D motion capture and gesture recognition using a RGB camera and infrared depth sensors, due to its size and its usability the Kinect can be recommended as an adequate sensor in the rehabilitation sector. The framework and structure of the user-specific therapy program is completed and preliminary data show that the physiological and pathological motions can be differentiated. This statement has to be proven with clinical trials, as soon as the system is fully developed. Improvements in the gamification and the quantity of exercises has to be made beforehand. Thereafter a classification as medical or fitness device can be conducted.

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