Development and Evaluation of a Motion-Based Exercise Game for Balance Improvement

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Abstract. Over the past years many systems involving exercising through games (exergaming) have been developed by leveraging on new technologies to provide an alternative way for improving physical condition and balance control. Such systems are widely used for improving the physical condition of healthy persons and for rehabilitation. For seniors, exergames provide a new and enjoyable way for increasing physical activity and for improving balance condition and muscle strength to reduce fall risks. However, a matter arising is whether such systems are well designed to suit seniors. In this work the development and evaluation of a new exergame is presented. The development process followed a human centered design approach involving the relevant stakeholders to create an effective system for balance training. The implementation was based on the Microsoft Kinect sensor for motion recognition and the Unity graphics engine for creating a realistic three-dimensional open world. The influence of user diversity on gesture training and recognition is discussed and the proper sample size is determined in order to achieve a high confidence level in gestures recognition. Results of a user evaluation study are reported both on balance improvement and on system usability, by using proper measurement instruments. The results indicate a positive acceptance of the technology and the possibility for balance improvement leading to healthier seniors.

Keywords: Motion-based exercise game · Seniors · Microsoft Kinect · Unity engine · Usability evaluation · Balance improvement · Human centered design · Ambient assisted living

1 Introduction

Exercise games (known as exergames) tend to become a useful home-based tool for improving both seniors' physical and mental health by performing game scenario tasks [1]. Furthermore, there is positive evidence that exercise programs that combine balance training and muscle strengthening and coordination can reduce falls and fall risk in the elderly [2].

During the past years off-the-self gaming consoles like Microsoft Kinect XBOX 360, Sony Playstation Eyetoy and Nintendo Wii have been pervasive. Such systems have introduced a new style of physical interaction based on gestures and full body motions

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and have been used for training balance and improving fitness for healthy elderly [3] as well as for medical purposes as rehabilitation tools [4].

However, the question that arises is whether such gaming systems that are targeted to the general population following a fit-for-all design approach are appropriate for seniors. Usability studies with the participation of seniors have found that popular commercially available games are not necessarily appropriate for seniors due to their complex interface and game structure [5]. Negative feedback when the players frequently fail to perform game tasks because their movements are slower than expected by the game have been also reported [6]. Many exergames are inappropriate for balance training because they are not properly designed for controlled movements of seniors' body centre of gravity [7] and their use can cause injuries [8]. Furthermore, commercial gaming platforms are not flexible enough to provide exergame personalization taking into account the specific needs of an individual and their cost is considerable.

In this work we introduce the design and development of a game tool that combines Microsoft Kinect technology to capture body movements and gestures and Unity graphics engine to create a 3D semi-opengame world. Moreover we present a human centered design approach for the game mechanics and a set of proper design guidelines that take into account the special needs of seniors. The influence of user diversity on gesture training and recognition is discussed and the proper user sample size for the training process is determined in order to achieve a high confidence level for gestures recognition. The aim was to provide a gaming tool that is both enjoyable to use and has a practical impact on improving seniors balance. To assess the usefulness of the tool a pilot study has been performed with the participation of 12 seniors for a period of five weeks using evaluation metrics such as the Berg Balance Score (BBS), the 30 s sit-to-stand test and validated questionaires for assessing usability factors. The qualitative and quantitative analysis of the pilot data shows that the proposed game tool can be used to assist seniors in improving their balance in an enjoyable and engaging manner. The discussion provides an interpretation of the results and supports the conclusions with evidence from the pilot study and generally accepted knowledge. Future work is outlined regarding the new features to be included in the game and the integration of new technologies to support the future versions of the game tool.

2 Literature Review

The development of computer games for assisting the elderly, mostly for memory training, can be traced back in the 1980s [9]. A new era of research and development initiated when the first tracking sensor, Nintendo Wii was introduced. Later on, the development of Kinect technology introduced a new way of exergaming without the need of holding any controller, making Kinect sensor one of the most viable device for exergaming. These exergames are massively used in the field of Ambient Assisted Living (AAL) as a tool to help elderly remain physically and mentally fit through engaging game activities as well as in the rehabilitation process through specially designed balance exercises [10].

Several studies have explored the appropriateness of commercial game consoles for fall prevention of seniors [11]. In particular the suitability of Microsoft Kinect sensor on enhancing physical exercising and performing rehabilitation protocols has been explored by Mousavi Hondori and Khademi [12]. Their review indicates that Kinect is an adequate device for balance exercising and monitoring of the elderly.

A training intervention program was performed in a nursing home based on the Wii Fit balance board to evaluate the effectiveness of exergaming in reducing the risk of falling in patients with history of falls [13]. Sixty seniors above the age of 65 participated in a six weeks program and received balance training using three balance exergames using body motions while standing on the Wii platform. The study indicated that exergaming can have a positive impact both on physical and psychological well-being assessed through relevant scales the training program provided opportunities for social interactions between the participants when the game was played in groups affecting positively the sense of belonging. A similar study using the Wii balance board was reported in [14]. The study used specially designed exergames and the evaluation showed that using a low cost gaming device and a specially tailored application can be a valid method to assist seniors in improving their well-being and balance self-confidence.

Although the use of commercially available games is promising for the balance training of seniors there is a strong evidence that the development of specially designed games in a process involving all major stakeholders (i.e. elderly, caregivers, physiotherapists and developers) can serve more efficiently exercising intervention goals [15].

A research study performed with elderly in Japan designed and evaluated four exergames developed on the Microsoft Kinect platform with a goal to improve seniors' strength, balance and mobility [16]. The games entailed movements such as grabbing virtual objects using both arms, placing the feet along a straight line, bending knees and hips, crouching and standing on one leg. The users had to perform movements in the context of a game scenario while tasks were becoming more complicated based on the game's level of difficulty. The intervention brought an improvement in daily walking movements as measured by the Berg Balance Scale.

Similar exergames in an AAL environment were examined by Stanmmore et al. [17]. The study focused on whether exergames can be an effective alternative to traditional falls prevention exercise programs for seniors living in sheltered housing. Through a 12-week program which took place in twelve sheltered housing centers, seniors were split into two groups one for standard care and one for standard care including three exergaming sessions per week. The evaluation using the Berg Balance Scale (BBS) showed an increase of 95% in balance due to exergaming.

Studies also are focusing on whether exergaming using consoles can be a helpful tool for patients with chronic diseases. A new exergaming software introduced in [18] called HemoKinect by focusing in patients with hemophilia and evaluating their daily exercise routine using a Kinect V2 sensor. Furthermore, researchers in [19] introduced a three-dimensional exergame based on Kinect sensor for patients with Parkinson's disease. Players interacted with the game using a set of gestures like hitting objects with hands and feet and rotating hip left and right.

The proposed system shares similar goals and embraces the perspective of developing tailored exergames based on a human centered design approach to identify requirements that are closer to the motor and cognitive abilities of seniors. On the sensor technology side, the second version of Microsoft Kinect is used instead of the first one. Besides providing higher resolution, more skeleton joints can be tracked (e.g., thumb joints and hand tip) which allows for identifying more movement combinations. On the game side, further to the basic movements that were used in previous studies, the ability for the user to walk is provided. Moreover, a three-dimensional open world was created using Unity 3D game engine embellished with narrative features through animations, sound and visuals for achieving a more realistic game experience. Although the game requires the use of the Kinect sensor to identify user's movements, there is no dependency on the corresponding game console, thus keeping the cost of the necessary hardware low.

3 Design Methodology

3.1 Human Centered Design

Based on the human centered design (HCD) approach [20] interviews and meetings took place between game designers, seniors and medical experts which allowed for acquiring both qualitative data through brainstorming activities and quantitative data through usability questionnaires to refine the main game characteristics and define the body movements that will be trained throughout the game. Emphasis was given on the motions that were going to be implemented as well as on other game characteristics such as the main game theme. The involvement of seniors under the HCD guidelines from game requirements analysis and design to evaluation was essential in order to adequately capture their preferences and needs.

After every meeting a prototype design was formed using the game ideas exported from the meetings and the mechanisms were evaluated by the users. User feedback on the design and game concepts was analyzed by the users and appropriate changes were implemented. A redesign cycle was followed with refined game rules and interactions before the final prototype development commenced. The iterative user feedback expected to deliver a game tool that will be both useful in terms of balance training and enjoyable in terms of playing experience.

A number of design guidelines for exergames have been gathered by reviewing related research [21] and getting feedback from the elderly people in the HCD process:

- *Body Movements Constraints*: Ageing often leads to both cognitive and physical negative changes, like decline in balance and physical strength. Thus, the game structure must avoid complex movements that may cause injuries. Also, it would be easier for the seniors to deal with only a single task each time.
- *Game Theme*: The theme of the exercise game should be related to real-life activities that are familiar to elderly people. Themes that are associated to natural life such as walking in a forest, picking apples and fishing are more acceptable than artificial settings found in commercial video games.
- *User Interface*: To concentrate on the actual exercise the user interface should be simple and easy to use. All instructions have to be clear and use common language. The interface should have different alternatives for multimedia presentation, such as, text, voice and images. For those who are visually impaired, for example, an audio presentation might be preferable.

- *Provide Instructions*: Learning the game movements before starting the actual game should be provided as a choice to the users. Once those instructions are not required any more, users should have the option to avoid them. Furthermore, it should not be expected that the user will recall the instructions, so every time the user wants to start the game an option to view the instructions should appear.
- *Avoid Small Objects*: It is easier for the elderly to identify large objects rather than small or fast moving.
- *Positive Feedback*: Motivating feedback should be given to encourage play. Constructive feedback should be given to guide and correct exercises. Information and feedback should be given when appropriate, to not disturb the user.
- *Variety of Difficulty Levels*: For users to keep their motivation and continue playing, exergames should include different levels of difficulty. In that way, users will be able to test their skills and try to become better. Also moving to a more difficult level will make users feel that they accomplished something good and the game in fact helps them.

3.2 Game Tool Characteristics

Based on the guidelines mentioned in the previous section a game called "Fruit Collector" was conceptualized. The main purpose of the exergame is to pick up objects that are scattered around the environment and deliver them to appropriate spots. The movements involved in the game design target improvements in balance and walking abilities. Furthermore, other cognitive properties could benefit such as memory, attention and synchronization.

Since the exergame is based on Microsoft Kinect sensor, the game entailed the design of gestures and body movements to interact with the game's environment. Specifically, the game includes the following motions a) Leaning left and right to rotate to the corresponding direction b) on site walking to move forward and c) hand gestures to pick up and drop objects.

During game design the feedback of the user focus group indicated a topic close to the seniors' interests. Thus, the idea was to create a forest with trees and flowers while in the center of it a small village was placed. As for the collected/scattered objects the decision was to be baskets filled with fruits of different types. Finally, the brainstorming indicated that the places to deliver these baskets should be the houses of the village.

Moreover, different levels of difficulty were added to the game. Namely, there are three levels (easy, normal and advanced) and in each level the player must deliver different number of baskets to complete the game; easy requires only two baskets to be delivered, normal requires four baskets and advanced requires the complete set, meaning eight baskets.

A tutorial was added providing simple instructions on how to perform the body movements and how to play the game. Every time the player starts a new game a message is displayed asking whether the player wants to see the tutorial before proceeding on playing.

The game does not provide any negative feedback to the user because as the design guidelines indicated it is important for the seniors to feel confident while playing the game and creating stress and anxiety has to be avoided. On the contrary, when a basket is delivered a positive message is displayed while an appropriate sound is played. After the design process was completed, the game development was progressed in its final phase as will be described in the next section.

4 Kinect Sensor Programming

Microsoft Kinect is a motion tracking sensor based on a depth camera recording technology for skeletal tracking [22] allowing the user to interact with applications using gestures, movements and voice commands without the need to use any controller. For the developed game tool, the second version of the sensor was used (Fig. 1 left) which is equipped with a richer SDK API, the ability to track more joints to identify hand states (Fig. 1 right) and tools to record the motions. Furthermore, the Kinect SDK provides two machine learning algorithms, AdaBoost and Random Forest which can be trained to identify complicated activities. Such activities are recorded using the Visual Gesture Builder tool.

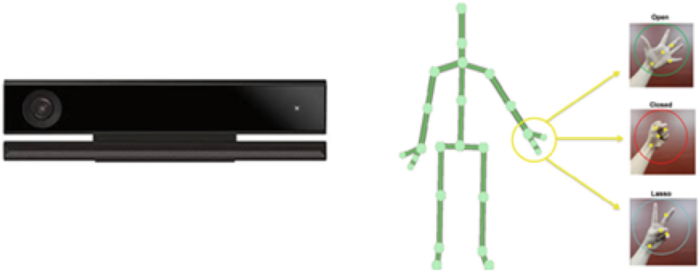


Fig. 1. Left: Kinect Sensor V2, right: Hand states [23].

4.1 Activities Selection and Recording

Besides the motions that already reported above, during the early design stages the game tool included more gestures. Specifically, leaning the head left and right to rotate to the corresponding direction and crouching to move under some obstacles.

Based on the HCD process and interviewing with seniors and domain experts (orthopedics and physiotherapists) the above motions were rejected or modified. Specifically, leaning the head was rejected due to the fact that some seniors had difficulties of a clear view of the game environment while leaning the head, thus this motion was changed to leaning the spine left and right resulting in the same effects. Crouching was also rejected as an interaction motion because of two main reasons. Firstly, the motion was found to be exhaustive and sometimes the reason to quit for many users, and secondly, conflicts occurred with some game scenarios where the user had to crouch and practice on site walking at the same time. As for the on-site walking and the hand gestures no modifications were made.

For game activities recognition a training process was followed by using the recording tool and the machine learning algorithms of the Kinect SDK. For building the activity model the Kinect Studio tool was employed to observe the way the sensor is recording the environment. This tool facilitated also the recording of motions and gestures that were used in the game mechanics. Figure 2 shows, for example, the recording of leaning right and left motions. Such motions are stored in the form of a sequence of frames. A frame is a digitally coded static image represented as a selected number of tracked body parts (i.e. joints). A frame rate of 30 fps (a frame every 0.033 s) was used during activity recording.

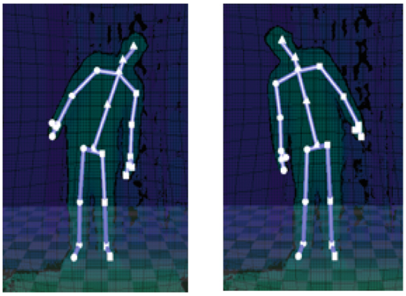


Fig. 2. User leaning right and left.

In order to have more reliable results, the decision was to split the recorded samples into two datasets, one for training and one for validation purposes. In addition, users contributed in recording motions for the training stage did not take part in the final evaluation in order to have more clear results regarding system's ability to identify different users on a variety of motions.

During the training process one issue that required attention was the fact that users cannot execute the movements the same way. Moreover, the body type of each user was an issue that had to be resolved. For instance, some users are taller than others thus, the system would not have been able to identify the gestures and motions if it would have been trained based on a single person.

Furthermore, when it comes to elderly people this issue appears more frequently due to age and physical related issues. Thus, it is expected that the elderly would not perform a specific motion in the same way. For instance, it is expected that seniors would not lean left or right in the same way.

In order to achieve better results regarding the system's ability to identify gestures correctly a group of seniors (male and female) between the age 65 and 70 years with different weight and height characteristics was asked to perform each of the gestures required for game activities. A cycle procedure was followed in order to determine the proper number of users required to train the system to be able to identify the motions with high confidence level. Literature research indicated that the accepted number of people required in situations like this was three in order to cover all body types regarding weight and height. However, after testing that threshold using the live testing option provided by sensor's SDK, it was noticed that system's confidence level was below average. After performing tests with more seniors it was resolved that for the leaning gesture a number of five users is an acceptable limit since the difference in confidence level between 5 and 6 or more users is not significant (Fig. 3).

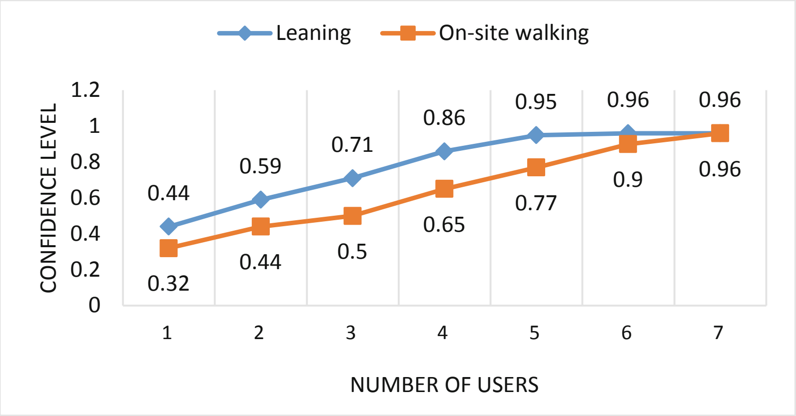


Fig. 3. Average confidence level for each motion in relation to the training user sample.

Regarding the on-site waking motion it turned out to be more a difficult motion for some seniors. Specifically, seniors with less balance control were not able to lift their feet to the same height as others thus requiring more training samples. Therefore, for this type of movement, seven users were found to be the acceptable limit for the training process. Figure 3 shows the confidence level for identifying both gestures in relation to the number of users that participated in the training phase.

4.2 Training Sensor's Algorithm

In order to start the training process, the pre-recorded frame files stored during the recording stage were used. The tuning of the training process entails the selection of several options. These options depend on which parts of the body the sensor will track (upper, lower or both), whether the left and right side of the user's body motion differ and whether the activities are classified as discrete or continuous. A discrete activity is defined as a Boolean entity linked with a confidence value of existence. On the other hand, a continuous activity is associated with a progress value which allows the tool to track its progression optionally via several discrete activities. A continuous activity is more complex, and it is used for motions like dancing or performing certain exercises. The machine learning algorithm that is used for discrete activities is the meta algorithm AdaBoost, whereas for continuous activities the Random Forest algorithm is used. Table 1 shows the selected options for the basic game motions.

As for the walking motion our initial thought was to classify this movement as continuous. A continuous gesture is a combination of two or more discrete gestures and in order to track its progress it has to be split into stages. The user has to pass with success each of these stages for the whole gesture to be successful. In order to split the

Table 1. Options for training gestures [23].

Option	Leaning	Walking
Rely on joints in the lower body	False	True
Rely on hand states	False	False
Right and left side are different	True	True
Discrete/Continuous	Discrete	Discrete

gesture, we use "Tags" to mark the exact timestamp where the user begins to execute the appropriate motion. Figure 4 shows the walking motion split into 5 stages where the pink line indicates the whole gesture and the gray dots are the stages as shown in Table 2.

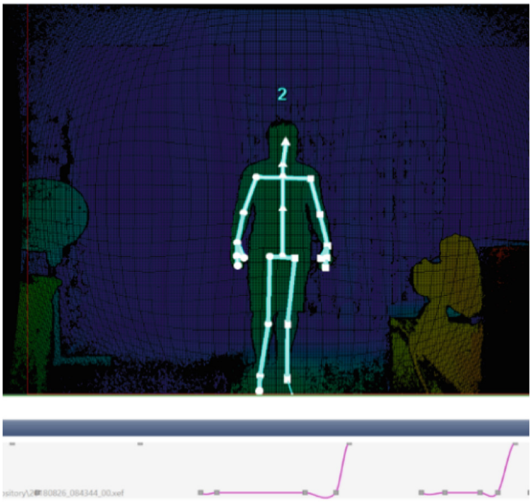


Fig. 4. Continuous gesture tags.

Table 2. Tags for walking gesture.

Stage number	Description
1	User begins to lift left/right foot
2	User begins to lower the raised foot
3	User begins to lift the other foot
4	User begins to lower the raised foot
5	Both feet are on the ground and the gesture is completed

After testing the above scenario, cases were noticed where the system could not recognize the gesture correctly. Specifically, after the end of stage 2 and just before the start of stage 3, the user has both legs on the ground the same as at the end of the gesture which resulted some times in a conflict state, where the system would falsely consider that the motion was completed after stage 2 and right before stage 3. The result of this was for the player to stop moving from time to time which had a negative effect on the overall game experience. Thus, it was decided to reject this approach and classify this motion as discrete and use the same training technique as for the leaning gesture.

The AdaBoost algorithm was used to train the recognition model for leaning and walking motions. After importing the recorded files, the timestamps where the user was performing the corresponding motion were marked. Figure 5 shows the lean left and walking motions performed by a user while the blue lines represent the exact timestamp of that motion.

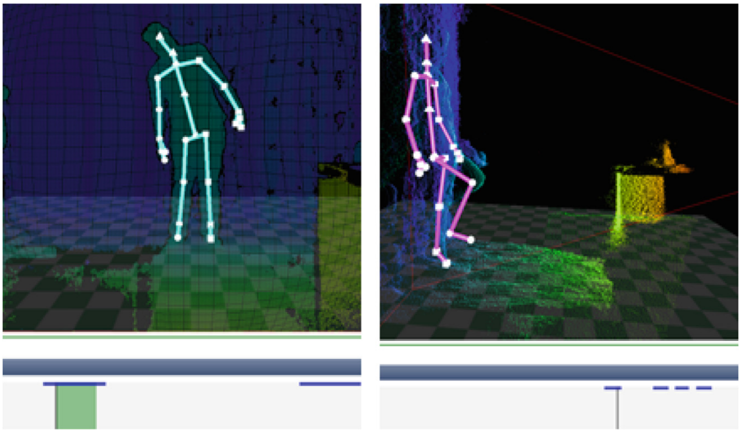
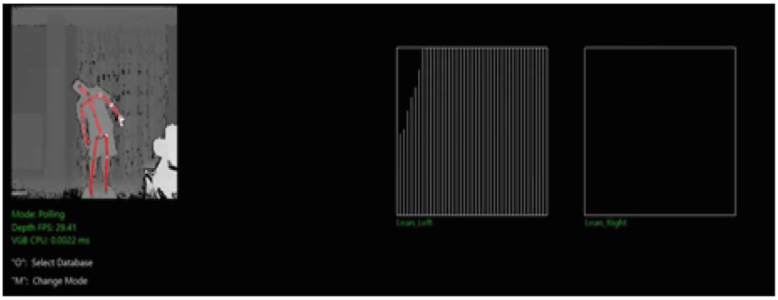


Fig. 5. Training AdaBoost algorithm.

A validation of the trained activity recognition model was performed in order to ensure that the game tool identifies correctly the user's activities. For this purpose, the live testing option was used. Figure 6 shows the tool representation of a senior performing the leaning left motion. The white lines that are passing through the corresponding windows indicate the level of confidence for the gesture.

5 Game Scenery Development

The proposed game tool offers a more realistic game experience than other similar games reported in the literature by playing in a three-dimensional open world. Also, the user is not only limited in executing the game mechanics to complete each level but is also able to explore this game world by executing the same motions described earlier. In this section the steps taken to create the 3D game world are described based on the Unity cross platform game engine.



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Mode: Polling
Depth FPS: 29.41
VGB CPU: 0.0022 ms

"O": Select Database
"M": Change Mode
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Fig. 6. Validation of leaning left.

The game concept included the creation of a small village inside a forest. Firstly, the terrain on which all the game would take place was created. The terrain's main color is green embellished with some trees and flowers in order to create the forest. At the center of the forest some houses were placed to create the village. Figure 7 illustrates the final view of the village and its textures.

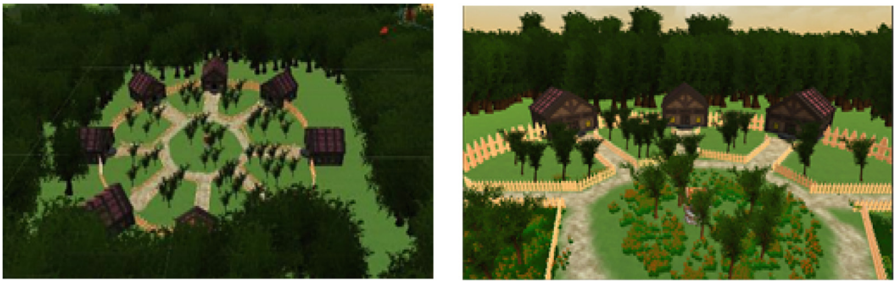

Fig. 7. Game's terrain [23]. (Color figure online)

The game scenery included a number of game objects. Two assets were used to create the baskets and the fruits respectively and by combining these two, one composite game object was created, the basket filled with fruits (Fig. 8). In addition, colors were added to the baskets so that the player can identify them easily. Furthermore, colliders implemented on every game object making the player unable to pass through trees or houses making the game more realistic.

The game also takes advantage of the Unity's particle systems by implementing effects such as explosions or indicators that help the player move forward in the game and improve the whole game experience. Following the HCD design guidelines, indicators were provided in the form of colorful lightning indicators in order for the player to know where to place each basket. Furthermore, these indicators were used in a way of a bonus provider for the player. In particular, if a basket's color was matched to the indicator's the player received double points (Fig. 9). Therefore, players had a motivation to place each basket in the same color spot and so the gaming time could be increased resulting in more user training.

Fig. 8. Baskets filled with fruits. (Color figure online)

Fig. 9. Lighting indicators. (Color figure online)

An important step was to create the avatar that would be controlled by the user. Unity provides the prefab "First Person character" which has all the utilities needed to complete this task. Furthermore, a target in front of the avatar was added (Fig. 10). The purpose of this was to provide an indication to the player on when the basket could be picked up. Thus, when the avatar is close to the basket the target becomes green otherwise the target remains white.

Fig. 10. Target in front of player. (Color figure online)

As for the last step, details that would show the user information about the time and the scoring as well as motivated messages and sounds, which were played when the player completed a task, were added.

5.1 Integration of Kinect with Unity

Microsoft provides a library with various scripts in order to combine Unity projects with the Kinect sensor. The game tool is a combination of scripts from this library, customized scripts created, and C# code added in order to retrieve data from the activities stored during the training stage and to interact with the game.

The flow of control starts with the “Body Source Manager” script which is responsible for activating and deactivating the sensor and tracking the user. This script was customized so that the on-line data from the user’s activities are received and processed. Processing is done by the “Activity Detector” script.

Activity Detector receives the output from the “Body Source Manager” script and evaluates it based on the activities included in the AdaBoost’s training files. A local database contains all the user’s activities required to interact with the game. If the user is performing one of the stored activities a message is sent to “Kinect Manager” script. Kinect Manager receives data indicating if the user is performing a known activity. Specifically, it evaluates the detection confidence and if this is above a defined threshold, it allows the activity to be performed inside the game. For example, if the user is leaning right and the detection confidence is above 60% then the game avatar is rotating to the right.

6 Pilot Study

The evaluation of the game tool took place at the Elderly Protection Center in the city of Ptolemaida, Greece. A group of twelve healthy seniors with an age between 61 and 85 years participated in the evaluation study ($n = 12$, 6 male and 6 females, $\text{mean} = 73 \pm 6.3$ years). Once informed consent was obtained the seniors were asked to play the game twice per week for a period of five weeks. In every session each senior was playing the game on all different levels for 25–35 min. The evaluation was organized into four stages and during the whole process a physiotherapist was present for domain-specific support and a researcher for administration and technical support. There were no dropouts.

6.1 Introduction Stage

Firstly, an overview of the technology as well as of the game was given (Fig. 11). The participants received information about the research goals and the scheduled tasks. They were informed about the Kinect device and its applications. From the beginning the seniors showed a great interest in the exergames concept and the supporting technology although they had no relevant experience in the past.

6.2 Physical Condition Assessment

Before the seniors start playing the game, their physical condition was evaluated in order to have a baseline. For this purpose, two widely accepted tests were used: The Berg Balance Scale (BBS) [24] and the 30 s Sit to Stand Test (30SST). The BBS test takes about 15 min and consists of fourteen exercises in order to examine and evaluate

Fig. 11. Seniors learning about the evaluation process [23].

balance control. Examples of the test challenges include (Fig. 12): standing for two minutes, standing unsupported with one foot in front, standing in one leg, picking up an object from standing position and moving from sit down to standup. Based on the participants' performance for each exercise a grade between 0 and 4 is given. The total score determines the balance condition as follows: a score below 20 indicates poor balance, a score between 21 and 40 indicates fair balance and a score over 40 is considered good. The average BBS score was 49.8 (SD ± 0.9) which indicates a good baseline balance for the study sample.

Fig. 12. Seniors during BBS exercises.

The 30SST is a simple exercise to assess the muscle strength of the participants. The senior is asked to sit in a chair and stand up as many times as possible in 30 s without any help. Table 3 provides the 30SST scores per participant for the baseline stage. The average score was 13 (SD ± 1.7). The overall outcome of the baseline physical condition assessment was that all participants had relatively high scores and therefore there was no high risk of falling during the game.

Table 3. Statistics of BBS and 30SST [23].

Metric	Pre	Post	Diff	p-value
BBS	49.8 (±0.9)	50.3 (±0.8)	0.5	0.007
30SST	13 (±1.7)	13.4 (±1.2)	0.4	0.05

6.3 Exergaming

During this stage the seniors played the game starting with the easy level and continued to the next one up to the advanced level (Fig. 13). While playing various parameters were recorded like the playing time, the collected points and whether the participant completed the level or stopped and quit. In the initial sessions, while all the participants completed the first and second level, many of them had to stop prematurely the advanced level due to tiredness. After some sessions however they were able to complete all game levels. It is worth mentioning that during this stage there were requests by more seniors of the Elderly Center to play the game. They had the opportunity to play sometimes the game, but their statistics were not recorded because they didn't participate in the study from the beginning.

6.4 Post-exergame Physical Condition Assessment

After the end of the five weeks period the participants repeated the two balance tests to evaluate the effect of exergaming in their performance. Table 3 summarize the results by comparing the baseline and post exergaming scores. The average BBS score after exergaming was improved to 50.3 (SD ± 0.8) (50% of the participants experienced an improvement in their balance) while the average 30SST score was slightly improved to 13.4 (SD ± 1.2). Given the good scores from the baseline stage and the limited timeframe of the study the overall balance improvements attained were considered positive.

6.5 Results

The quantitative and qualitative data collected during the study were analyzed to identify the impact of the proposed exergame.

Statistical analysis using Wilcoxon signed-ranks test (due to non-normality of the data) for paired samples and a level of significance ($a = 0.05$) was applied to compare the BBS and 30SST scores between pre and post exergaming. The results shown in Table 3 indicate that the BBS score improvement between the pre and post exergaming periods is statistically significant ($p < 0.05$), whereas the 30SST score improvement is

Fig. 13. Seniors playing the game [23].

statistically marginally significant (p = 0.05). The walking and leaning motions included in the exergame design could explain the improvements as these movements contribute in maintaining both motor and balance function.

The performance statistics exported by the system indicated an improvement on the game completion time per level throughout the timeframe of the study. In particular, for the easy level the average completion time for all participants was reduced from 358 to 254 s (29.1%), for the normal level from 540 to 485 s (10.2%) and for the advanced level from 1000 to 917 s (8.3%). Figure 14 illustrates the progress of the average game completion time throughout the study for the three game levels.

Another indicator of participant's interest towards the game is given in Fig. 15 which shows the number of the baskets the players delivered in the advanced level. In the first two weeks due to physical tiredness the average baskets delivered was less than the threshold to complete the level. However, from week 3 until the end of the study all the participants were able to complete the advanced level.

6.6 Usability Assessment

In order to determine the system's usability, short duration interviews and meetings were conducted with both seniors and medical experts in order to assess whether the system had a positive impact and to identify the future features that need to be implemented. The interview with the seniors showed that 100% of the participants found the exergame to be enjoyable, 80% thought that the movements were not complicated but easy to

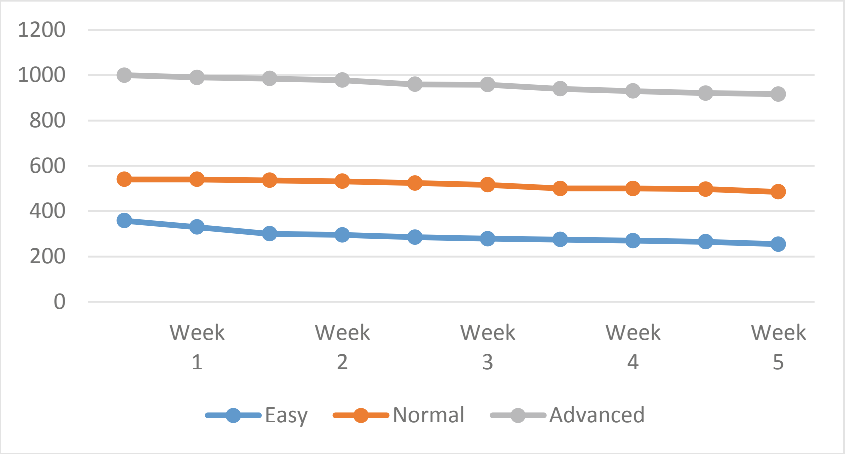

Fig. 14. Average game completion time.

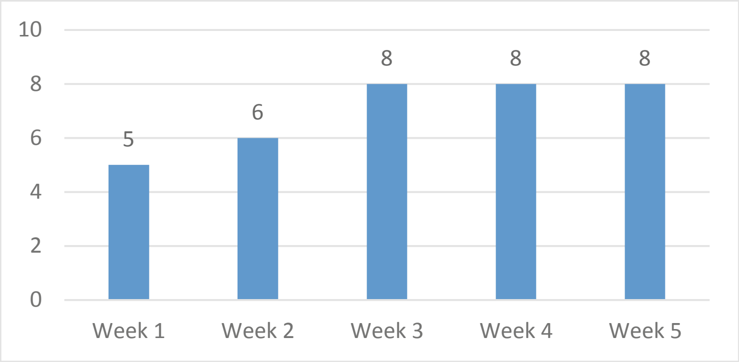

Fig. 15. Baskets delivered in advanced level [23].

remember and 90% of them expressed their expectation to use the exergame after the study.

Positive comments were provided for the game theme and the extensionality of the 3D textures as well as the seamless navigation of the game through the player avatar. Positive comments also provided that their confidence on the technology increased due to their experience with the game tool. The interview with the expert gave the feedback that the use of the game not only helped the seniors to improve their physical state but contributed to the improvement of their psychological and emotional state as they were happy when playing the game and throughout the duration of the study there was a positive feeling and anticipation towards the planned activities.

Besides the semi-structured interviews, users were asked to fill out a questionnaire in order to better investigate and evaluate the degree of which the users were satisfied by the system. The questionnaire was based on the constructs of the Unified Theory of Acceptance and Use of Technology (UTAUT) model [25] as summarized in Table 4. For each of the construct two questions were drafted (see Table 5) with rated response from 1 to 5 with 1 being strongly disagree and 5 being strongly agree.

Table 4. UTAUT constructs used in the study.

Construct	Description
Performance Expectancy (PE)	The degree to which the individuals believe that the use of the technologies will result in performance gains
Effort Expectancy (EE)	The ease of use of the technologies
Social Influence (SI)	The extent to which the individuals believe that others should use the technologies
Facilitating Conditions (FC)	The perceived extent to which the organizational and technical infrastructure required for the support of the technologies exist
Behavioral Intention (BI)	The degree to which the individuals have the intention to use the technology in the future

Table 5. Question items for each category.

Construct	Item Code	Item
Performance Expectancy (PE)	PE1	The system would improve seniors physical condition
	PE2	The system would reduce fall risk
Effort Expectancy (EE)	EE1	The system is easy to use
	EE2	I would need the support of an expert to use this system
Social Influence (SI)	SI1	I think most people will learn to use this system quickly
	SI2	I think most people will enjoy playing this game
Facilitating Conditions (FC)	FC1	I have the necessary resources to use this system
	FC2	I have the necessary knowledge to use this system
Behavioral Intention (BI)	BI1	I intend to use this system in the near future
	BI2	I felt very confident using the system

After collecting the responses to the questionnaire from the seniors we have calculated the Cronbach's Alpha score for each of the categories in order to determine the reliability degree. Table 6 shows the results for each of the model's construct, which is higher than 0.70 which makes the questionnaire that was formed valid and reliable [26].

Table 6. Cronbach's Alpha of the measurement constructs and items.

Category	Cronbach's Alpha	Number of Items
Performance Expectancy (PE)	.802	2
Effort Expectancy (EE)	.787	2
Social Influence (SI)	.797	2
Facilitating Conditions (FC)	.756	2
Behavioral Intention (BI)	.757	2

Descriptive statistics analysis (Table 7) reveals that for the performance expectancy the majority (41.6%) strongly agrees that the system would help seniors improve their physical condition. As for reducing the risk of falling, seniors simply agree that the system could help towards this goal.

Table 7. Descriptive statistics analysis of the measurement constructs and items.

Category	1	2	3	4	5
PE1	0%	0%	16.6%	33.3%	41.6%
PE2	0%	0%	50%	25%	25%
EE1	0%	0%	25%	33.3%	41.6%
EE2	0%	0%	33.3%	50%	16.6%
SI1	0%	0%	33.3%	25%	41.6%
SI2	0%	0%	33.3%	25%	41.6%
FC1	58.3%	16.6%	25%	0%	0%
FC2	50%	33.3%	16.6%	0%	0%
BI1	0%	0%	25%	33.3%	41.6%
BI2	0%	41.6%	25%	25%	8.33%

Furthermore, data from the effort expectancy category show that seniors didn't find the system hard to use but only after they got the appropriate instructions from an expert since they didn't have the knowledge to use the system from the beginning.

As for the social influence, seniors believe that others would benefit from using the game and enjoy such systems which was also reflected during the sessions where some elderly outside the study group showed interest in playing the game. Also, even though the majority of the users do not have the appropriate equipment to use the system, seniors showed a positive attitude towards acquiring the equipment in order to be able to use the system in the near future.

Finally, seniors were asked to fill out the system usability scale (SUS) questionnaire. SUS is a 10-item questionnaire with five response options from strongly disagree to strongly agree [27]. The participant's grades for each item were processed so that the original scores of 0–40 are converted to 0–100. Except from three seniors who rated the exergame tool as acceptable (scores 75–78) all the other scores were above 80. The average SUS score was 84.3 out of 100, suggesting a high user acceptance [28].

7 Discussion

The research conducted and described in this paper argued and provided evidence that exergames for seniors, if properly designed, can be an enjoyable tool for balance training leading to improvements in physical health conditions.

Data analysis from the evaluation study showed that seniors consider such systems can be reliable and used as an alternative mean for improving their physical condition through daily exercise. Also, they believe that the system complexity is low, the exergame is easy to understand on its mechanics and doesn't require much effort to use. Furthermore, users found the required gestures of the game easy to perform and expressed a positive intention to use the designed system in the future and were willing to recommend it to other seniors.

The system achieved a SUS score of 84.3 which means that the interaction mechanisms of the developed system have a good to excellent usability. Also, the post-exergaming physical evaluation of the seniors through BBS and 30SST tests showed a significant improvement according to literature measures compared to the baseline physical assessment. Despite the small sample size, the findings are considered relevant as there are similar levels of improvement to other studies found in the literature [29, 30].

In line with other studies, seniors due to the lack of knowledge for the new technologies often show a hesitation in interacting with it [31, 32]. Despite that, seniors show a positive attitude towards learning to use such systems. Choosing an appropriate game theme as well as providing positive feedback during the game proved to be the main reason for seniors to stay motivated and thus keep progressing in the game.

While other studies focus on developing a two-dimensional world, the development of a three-dimensional open world makes such system more realistic and thus more attractive to use by the elderly. Also, such a world provides motivation to keep playing as it provides the opportunity to explore the game world without being limited in a single place.

From a technological scope, Microsoft Kinect sensor proved to be a reliable device in correctly identifying motions and gestures under any game scenario and providing useful feedback to the user. Thus, low cost commercial sensor devices can be a viable tool for alternative daily exercise. Given the low cost of the sensor device and its portability the tool can be deployed and used in settings ranging from homes to facility centers supporting the elderly.

Limitations of the current study are acknowledged. The limited number of participants and the short evaluation timeframe prevent the justification of more sound results. Achieving substantial balance improvements in elderly requires playing the games over 3 times per week for at least 3 months [29]. In comparison, the duration of this study was 5 weeks with 2 game sessions per week.

8 Conclusion and Future Work

In this work a system that aims to improve seniors' physical condition and balance control through exergaming has been developed using a human centered design approach. A three-dimension world was developed allowing the user to explore various sceneries and not being confined by just completing a level. The evaluation study showed a high usability score and a positive acceptance of the system by the users providing a new and enjoyable way of performing exercises.

Work in progress includes the addition of more game features such as a multiplayer option where players can either work together to complete the game level faster or against each other. Furthermore, the implementation of daily missions (such as "Deliver two baskets under x min") would increase challenges for more demanding users. Figure 16 shows an early development stage of the multiplayer game scenario where the pink colorized object indicates the second player. Our goal is to implement a 3D avatar for each player. In the current scenario the two players work against each other to complete the level.

Fig. 16. Early stage of a multiplayer version of the exergames. (Color figure online)

Future plans include the integration of newer technologies like Virtual Reality (VR) in the game mechanics. Furthermore, since VR technology besides requiring an appropriate mask employs also controllers to move the player, designing a scheme that combines other sensors like the Azure Kinect will enable to track the user's gestures without the need of holding extra controllers.

Furthermore, a cognitive assessment dimension is planned to be incorporated with automatic game adaption based on user's characteristics and progression using machine learning techniques which will perform classification of the collected game data. For instance, the new implementation aims to remove the fixed difficulty levels. The aim is to have a system that will adjust its difficulty based on the results from the user's data analysis giving the player extra motivation in playing the game and thus resulting in more training.

Finally, an evaluation study with a larger sample of seniors, including a control group, and for a longer period of time would provide a more sound justification of the present results.

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