Tailored Virtual Reality for Smart Physiotherapy

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Abstract- **Remote sensing and Virtual Reality (VR) are technologies that create new development opportunities in the field of serious games with application in physiotherapy. Thus, during a physiotherapy training session expressed by a game round the remote sensing of user body motion provides measurements that can be used for objective evaluation of physical therapy outcomes. In this work is presented a serious game for physiotherapy characterized by Kinect natural user interface and a set of VR games developed in the Unity3D. To provide patient electronic health record, game remote configuration as well as for data presentation for physiotherapist a mobile application was developed. Additionally, several training results expressed by upper limb, neck and spine angles are included in the paper.**

Keywords**: virtual reality, remote sensing; serious game, physical therapy; mobile application; data analysis**

I. Introduction

The serious game concept is first mentioned by Abt [1] that the games "thought-out educational purpose and are not intended to be played primarily for amusement". Later, Smeddinck et al define the concept of serious game for physical therapy as form of physical exercise as a complement to traditional physical therapies [2] while presenting positive results as a complement for motor rehabilitation, with patients showing improved physical condition, motivation and adherence to the therapy exercises [3], [4].

The advent of the Nintendo Wii™ (Nintendo, Kyoto, Japan) system and later of the Microsoft Kinect™ system with their body controlled type of interaction, allowed using them for studies in physical rehabilitation for different purposes such as: balance control (e.g., [5], [6]), fall risk reduction (e.g., [7], [8]), gait (e.g., [9], [10]), muscle strength (e.g., [11]) and also upper limbs rehabilitation (e.g., [12], [13]).

For upper limbs rehabilitation, the Microsoft Kinect system provides real-time complete body detection features and also is supported by Microsoft with a Software Development Kit (SDK) to access its features programmatically. Furthermore, it can provide comparable data with a 3D motion analysis system, when assessing anatomical landmark position and angular displacement data during commonly performed clinical tests of postural control [14]. Likewise, when analyzing planar motions (within the same axis), the Kinect sensor is as reproducible as a standard marker-based stereo-photogrammetry system [15], it is accurate and can repeatedly measure body joint angles [16]. This makes the Microsoft Kinect sensor a viable and cost-effective solution that could be placed in the user's home for additional training for example. Thus, Virtual Reality Serious Game (VR) that includes this sensor, and has Internet connectivity, would further allow remote exercise session planning and session analysis by the physical therapist.

However, to the best of our knowledge, most of the used physical therapy serious games are pre-built games made for other purposes (e.g., entertainment) and not specifically tailored for physical therapy where both the patient and physical therapist can benefit from the use of the system. Additionally, through tailored game scenarios the motivation of the users can be increased that may lead to sustainable levels of exercise adherence.

In this work we present a system developed which is comprised of a physical rehabilitation serious game for upper limb rehabilitation, where the user and VR scenario is based on Microsoft Kinect. A mobile application was developed for physical therapist side related to training plans setup. The system was developed primarily to allow the tailoring of the exercises according to the patient's preferences and needs. It was also designed to present metrics that characterize the patient outcome. Additional data analysis preliminary results are presented in the paper.

II. System Description

The system was developed using a client server architecture with a remote server for the database storage, a mobile application for the game's parameters setup and presentation of results of the exercise sessions to the physical therapists. The remote server is used by both the mobile application and the physical therapy serious game through a common Application Programming Interface (API) running on an Apache Server (v2.4.7) with PHP v5.5.9.

As shown in Fig. 1, the flow of the user interaction with the system is: (A) the physical therapist creates a new entry for a patient, which includes information regarding name, address, email, birthdate, gender, BMI and a textual description, that will culminate with the generation of a QRCode that the patient will use to login in the game; (B) the physical therapist can then create a new exercise plan for the patient. In a plan, it is possible to define the plan's name, a detailed textual description, the start and end date that the plan will be available for the patient to follow, the type of training (i.e., if exercise will focus on only one of the arms or it will allow both arms to be used), the level of difficulty (i.e., lower angles or higher angles environment), the speed of movement (there are three modes: slow, medium, fast), the quantity of visual elements in the environment (i.e., no elements except the orchard or other elements with animations and sounds with the context of a farm); the duration of the exercise and the minimum points that should be used as a conclusion objective; (C) To start training, the patient may present the QRCode to the Kinect sensor to automatically login and to start the exercise for the imposed daily plan using the serious game installed in the client computer; and (D) After the exercise is complete, the physical therapist can analyze the results of the exercise session using the mobile application and also change the plan.

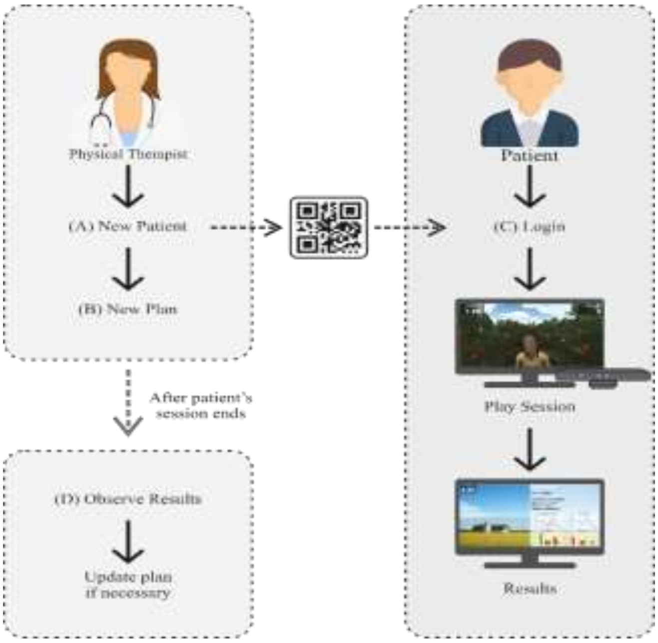


Fig.2 Flow of interaction with the mobile application (physical therapist) and the Kinect Serious Game (patient)

The patient VR tailored environment interaction was carried out using Microsoft Kinect sensor [17]–[19] that is mainly characterized by a depth sensor that consists of an infrared laser projector and a monochromatic CMOS sensor. It can track 2 active users for skeletal tracking with 20 joints per user.

The Kinect Serious Game Platform is characterized by two software module the Tailored VR serious game for user training and the Physio APP for settings and data analysis visualization.

A. Tailored VR serious game software module

The development of the tailored VR serious game was carried out using Unity3D and using C# scripts. The 3D models and sounds used to create the virtual environments were either purchased in the Unity's Asset Store or found online with a permissive license allowing its use in research. For accessing the Kinect sensor, the Kinect with MsSDK v1.8.1 package from the Asset Store was used. This package is based on the official SDK from Microsoft.

According with Fig.1 the patient may present the provided QRcode to the Kinect sensor camera. As soon as the Kinect detects the QRCode the patient details are presented on the screen followed by Objectives screen. In this screen, the objective of the particular game session is presented in accordance to the configurations made by the physical therapist made by Physio APP. Two types of training session are considered: fixed time duration session and minimum point session. During the session the game objective is to catch fruits associated with angles that might be reached by left hand, right hand or both hands during the game based training session. In case "Low angles" setting considered by physiotherapist the fruits to harvest are raspberries while for "High angles" the fruits to harvest are apples (Fig.2).

a)

b)

Fig.3 Game screen for both the lower angles level (a) and higher angles level (b)

The serious game screens presented above underline the avatar personalization (gender based) of the game according user's registration. On the top right corner, the current score (*pontos*) is presented and is updated automatically when the patient picks a fruit. When the countdown ends, the avatar will start to move in a straight line, according to the movement speed defined. The patients should move their arms, with the movement being detected by the Kinect and reproduced in the avatar. The fruits have a collision box that surrounds them in shape and the avatar's hands have collision boxes in a similar fashion. When the avatar hand enters in contact with a fruit, that fruit is “picked”. That means that the score is updated according to the color of the fruit (50 points for green and 100 points for red) and the fruit disappears. Since the Kinect also detects positional changes (moving left or right for example) on the movement of the patient, a zone where the patient can move and pick fruits was defined. Tailored scenario was considered. Thus, more or less visual elements (e.g., birds flying when the participant approaches the tree/bush they are on; bunnies, cats, dogs running, horses, cows; goats and pigs) are considered as part of environment. All the visual elements were accompanied by corresponding auditory elements to increase the immersion level of the patient to the defined context.

When the participant reaches the required points (e.g. 1000 points) or the countdown timer reaches zero in the case of training by points. The results screen with graphical information regarding the score achieved, the number of fruits (red and green) picked, per hand and by the angles made by arms to catch the fruits. Additionally, the hand motion progress of the patient in the last 5 sessions (number of harvested fruits and final score) is also displayed.

B. *Smart Physio APP software module*

Referring the mobile application (Smart Physio APP), it was developed using the cross platform Xamarin, which allows to create applications that work on the Android, iOS and UWP (Universal Windows Platform) platforms. The Smart Physio APP is to be used by the physical therapist. The implemented APP is characterized by the following screens 1) Login; 2) Patients list; 3) Plans list; 4) Session details; 5) Progress details; 6) Create new patient; and 7) Create new plan (Fig 3).

Fig.3 Screen from the mobile application: Session information (left) and Progress information (right)

In the Login screen (1), besides introducing the login credentials, the user can also change the presentation language of the rest of the application. When a valid login is made, the Patients list screen (2) is presented. The list can be filtered and if the physical therapist decides to remove a patient from showing up on the list, this patient will be marked on the database as disabled and will not be presented to the user. At the same time when selecting a patient the plans list screen (3) for that patient is presented with details including the plans that are defined. The physiotherapist can create a new plan. Regarding the exercise sessions details (4) (image on the left on Fig. 2), the screen has on top a summary of the plan and a picker (dropdown control) to select a session. A session is represented by the date and time that it occurred. When a user selects a session it is presented graphical data regarding: the amount of points the patient made considering also the arm usage (left arm or right arm). A chart representing the variation of the angles of the left and right shoulder, elbow and also the spine and neck angle, in the moment that each fruit was caught has been implemented on the mobile application. The progress on hand motor capabilities a screen of APP (image on the right on Fig. 3) presents the user progress of the patient throughout the last 5 sessions. Currently the progress of the number of fruits picked by color and the points achieved in the session are presented.

III. System Test

The system was tested in laboratory with a big screen (Samsung 78’’ TV, model UE75F8000SL) to induce a semi-immersive experience on users while performing the exercise. Users were placed 2 m away from the Kinect sensor and 2.30 m from the TV, inside a 45cm side square, drawn on the floor. For testing of the system a sample of users was considered. Thus students (N= 33; 18 Females, 15 Males) were accept to play the serious game. More than half the participants had interacted before with a system based on Kinect. (51.5%).

The experience are focused to extract information about hand motion. Thus, when the patient picked a fruit, the following information are retrieved: color of the fruit picked, its angle on the tree/bush, and the posture angles of the elbows (le – left elbow, re – right elbow), shoulders (ls-left shoulder , rs-right shoulder), of neck (n-neck angle) and spine (s-angle). Considering the joint coordinates provided by Kinect SDK the angles associated with posture and upper limb motion (**Error! Reference source not found.**) were calculated [20][21].

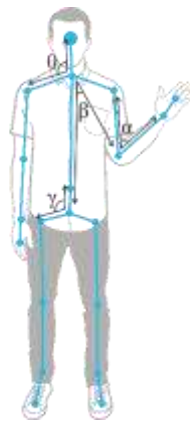


Fig. 4 – Angles recorded when picking a fruit: elbow angle (α=left elbow), shoulder angle (β=ls), neck angle (θ=n) and spine angle (γ=s).

IV. RESULTS AND DISCUSSIONS

Several game sessions of 1 min were performed and the values of the angles associated with body motion during the training was stored in the database for off-line data processing and data analysis.

In Table 1 are presented the values of the measured posture angles and the statistics for two female and two male volunteers. Values of minimum, maximum, average and standard deviation are calculated for whole the training session, where the physical training objective focused on upper limb rehabilitation that is translated on fruit pickup on the player side.

Table1– Body posture angles metrics (met) during the fruits harvesting game performed with the left hand by four volunteers (two female volunteers F1 and F2; and two male volunteers M1 and M2, met-metrics)

V	**met**	**le**	**ls**	**re**	**rs**	**n**	**s**
F1	min	151	104	146	30	96	114
	max	179	155	179	147	141	139
	av	168	120.5	171	109.1	119	126.9
	std	5.4	9.37	7.58	29.58	9.28	5.31
F2	min	119	73	120	43	108	115
	max	155	125	170	140	132	139
	av	138	97.95	143.5	107.5	122.2	122.6
	std	10.3	17.67	14.39	21.12	5.9	5.87
M1	min	121	56	121	33	111	123
	max	177	122	179	122	140	131
	av	165.3	106.7	164.5	83.77	23	125.2
	std	11.12	11.58	14.04	20	6.29	1.91
M2	min	113	57	115	22	122	123
	max	175	126	159	87	138	30
	av	154.3	90.64	143	44.96	131.5	125.6
	std	17.63	18.93	12.61	21.98	4.14	1.47

As it can be observed in the above table, during the training session the users performed the left arm and right arm motion activity that will affect the posture angles. Based on the measured body angle metrics it is possible to evaluate the posture and the stability of the volunteers as a training outcome. Using a set of thresholds for low level of stability the accidents during the training sessions can be avoided based on previous alarm generation.

Correlations between the body posture angles and the values of angles associated with the position of the fruits in the trees can be extracted. Thus, for future implementation the imposed range of fruits' angles might assure the user stability during the entire training session.

Referring to the balance of the body during the training session values of neck and spine angles are remotely measured. For a training session performed by a male volunteer the evolution of spine and neck angle are presented in Fig. 5.

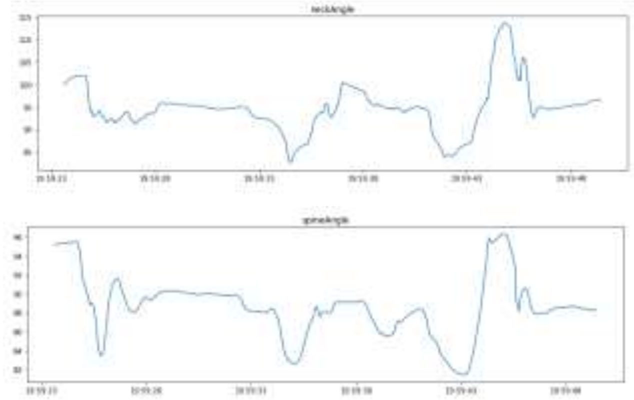
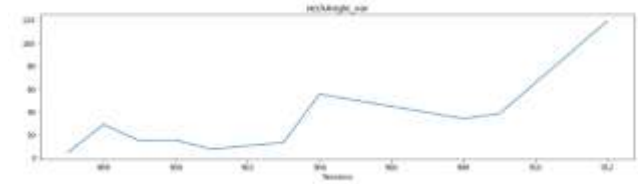


Fig. 5 – The evolution in time of neck and spine angles during the serious game session as metrics of user balance estimation

To evaluate the capabilities regarding the balance several training session were considered and the statistics values obtained for successive training session are calculated. Thus, in Fig. 6 are presented the evolution of the variance and maximum of neck and spine angles during the six successive training sessions.



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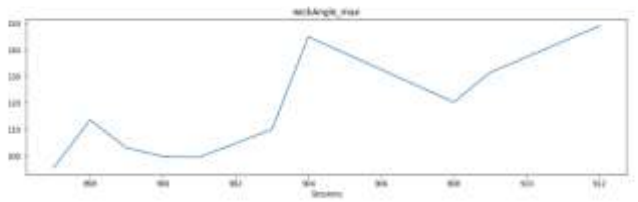

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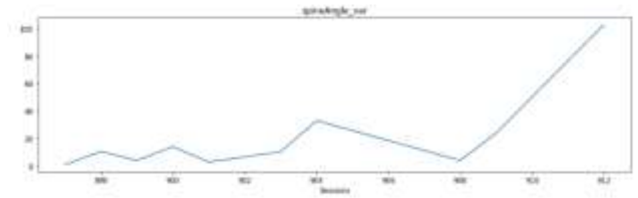

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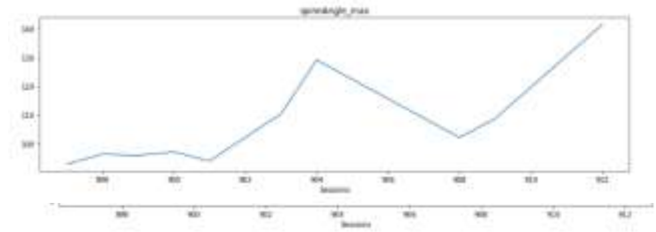
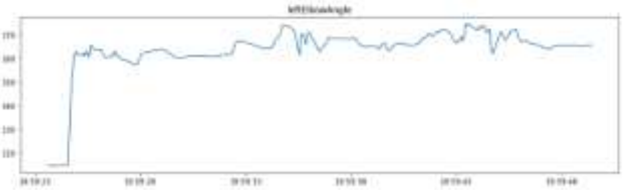


d)

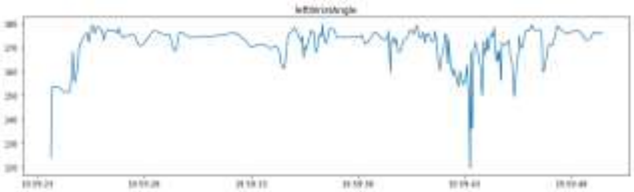
Fig. 6 – Neck and spine angle metrics (max and variance) for a sequence of six serious game training session performed by a volunteer

Taking into account the balance requirement the big variation of the spine and neck angles during successive session might highlight the reduced balance and accident potential.

Referring the hand abilities to perform arm movements the elbow and wrist angles are remotely measured with Kinect. Results for one serious game training session performed by a volunteer are presented in Fig. 7.



a)



b)

Fig. 7– Elbow and wrist angles evolution for a serious game training session performed by a volunteer

The imposed position in the trees provide physical training challenge through the imposed angles. Thus for 3 min session the number of harvested fruits and corresponded angles are presented in Fig. 8 for female users and Fig. 9 for male users.

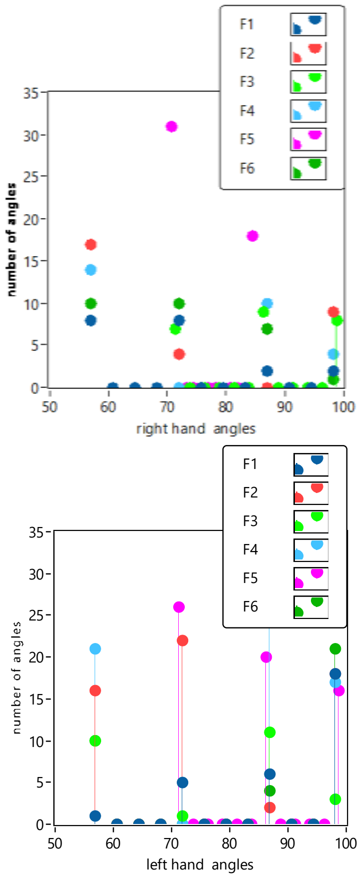


Fig. 9– The number of successful fruits pick-up actions (number of reached angles) according with the fruits disposal in the trees for female serious game user: top - – right hand; bottom-- right hand.

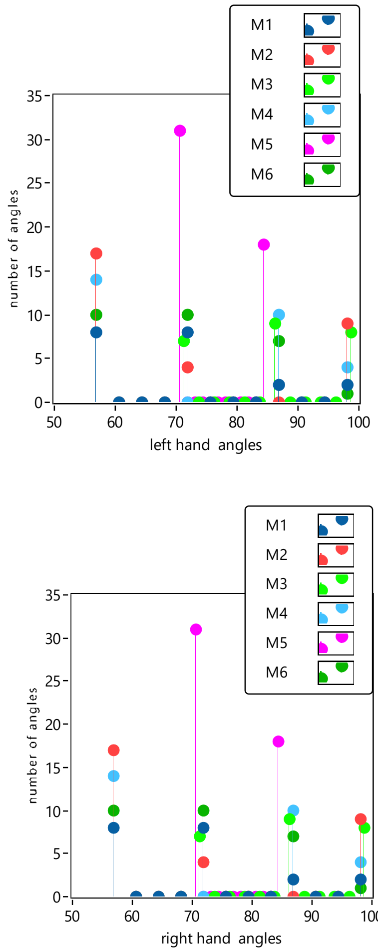


Fig. 9– The number of successful fruits pick-up actions (number of reached angles) according with the fruits disposal in the trees for male serious game user: top - – right hand; bottom-- right hand.

As it can be observed in Fig. 8 and Fig.9, the highest values and the lowest values of the reached angles by right and the left hand during the serious game are between 70° to 90°. It can be also observed the relation between the hand usage and the number of successful actions (number of reached angles). The right hand's corresponds to higher performance by comparison with the left hand regarding the amplitudes of reached angles during the serious games session. No significant differences were observed considering the data obtained for male and female for serious game sessions.. The next tests will focus on stroke patients that will perform upper limb rehabilitation plan based on fruits harvesting serious game. The usability tests will be also performed.

V. CONCLUSION

A serious game based on virtual reality and Kinect natural user interface for physical therapy area, namely for upper limb rehabilitation was designed and implemented. The tailored virtual reality provides improvement of the quality of motor rehabilitation by better engaging of the patients in their training plan. A mobile application was developed to help therapists with the selection of appropriate training plans and to visualize the metrics values associated with the performed training. The game personalization was considered, thus simplified and complex serious game scenarios characterized by low values angles and high values angles to be performed by the users but also motivate them was considered.

A real-time data collection of all the body segments positions was carried out and are prepared for future data analysis to allow the physical therapist to have a better understanding of the movements that the patient makes during the training using serious game for smart physiotherapy.

Taking into account the necessity to develop models of rehabilitation data science techniques will be applied on the stored data and new tests will be performed with real patients in physiotherapy clinics.

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