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Immersive Rehabilitation Monitoring System Supported with Augmented Reality

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Abstract. Medical rehabilitation treatment is of vital importance to all those who have experienced limb impairments due to unexpected accidents or geriatric dysfunctions. However, due to extensive government savings, the access to regular rehabilitation services is becoming increasingly difficult. This paper presents a low-cost, immersive augmented reality passive medical rehabilitation system exploiting depth-based limb joint tracking, supported with the Microsoft Kinect controller. Depth-based augmented reality solutions, though hardware affordable, suffer from miscellaneous problems. Duality of reference coordinate systems for RGB and depth sensors entails imprecision of limb joint positions measurement, whereas reliable limbs rehabilitation and their motility supervision require precise joints positioning and reliable visual feedback from the system. The present solution proposes the use of visual markers overlaid on the patient's image as an interface layer and two complementary sensors for depth-based spatial limbs tracking. It organizes the visual aspect of the rehabilitation stand, helps to immerse the patients into the rehabilitation process by providing them with a way to follow their achievements, while also monitoring the correctness of exercise performance.

Key words: augmented reality, passive rehabilitation, depth controller.

1. Introduction

Rehabilitation is a complex procedure which aims to restore the patient to full capacity, or at least helps to improve his or her health status. These activities also make it possible to recover the ability to work, earn money, and improve the overall quality of life of individuals with impairments. Rehabilitation as a branch of medicine which emerged in developed societies. It encompasses a broad range of specialties:

- physical rehabilitation,
- social rehabilitation,
- vocational rehabilitation,
- rehabilitation counseling.

The modern model of rehabilitation was developed in Poland in the 1960s. Weiss and Hulek [1, 2] proposed a model which in 1970 was highly praised by the World Health

Organization (WHO) and was indicated as a model for other countries. The primary objective is to meet the essential needs of people and families and enable them to live in conditions appropriate for human dignity. Developers of the Polish rehabilitation model have introduced its principles. Rehabilitation should be universal, fast, comprehensive and continuous. Despite the great evolution of treatment, constantly arriving new knowledge and ideas about how to improve the rehabilitation process, the key assumptions did not change. The basic requirement for the proper conduct of rehabilitation is constant cooperation and consultation between specialists in medical rehabilitation and other fields. Another important principle is active participation of the patient in the rehabilitation process, which requires motivation to pursue a mutually agreed program. A major problem in Poland is the restricted access to specialist care, often requiring a substantial waiting period [3, 4]. The ability to perform exercises at home gives a chance to meet an important condition for fast, comprehensive and continuous rehabilitation.

Engineering sciences are systematically applied to design, develop, adapt, test, evaluate, apply and distribute technological solutions for physiotherapy. Paradoxically, computer games, which are cited as the main cause of posture problems and diseases of the spine [5, 6], may be helpful in injury treatment and rehabilitation. Motion detection devices, such as Kinect, PlayStation Eye, Sega Activator or Wii Remote have become common in the gaming market. Virtual Reality technology connected with the body motion controller can be a useful tool for home rehabilitation. The visual feedback provided by means of augmented reality technology ensures a gamification-based immersion in the rehabilitation process. This paper introduces a system that combines all the rehabilitation model principles and the augmented reality technology into an inexpensive and efficient system.

2. Motion sensing input device – Kinect

Currently, the most popular motion sensing input device is Microsoft Kinect, developed for use with the Xbox 360 gaming platform. The popularity of this device earned it the Guinness World Record for being the “fastest selling consumer electronics device” after selling a total of 8 million units in its first 60 days. The Kinect sensor is a horizontal bar with an RGB camera, depth sensor and multi-array microphone which provide full-body 3D motion capture, facial and voice recognition capabilities for natural user interface using gestures and spoken commands [7]. Microsoft released the Kinect software development kit to allow developers to write applications. The sensors of this device provide the markerless interaction in a virtual reality environment.

A PC-based desktop Virtual Reality system for rehabilitating stroke patients was developed long before the Kinect technology.

The early system used some input devices, like a CyberGlove [8], to allow the user to interact with some rehabilitation exercises. However, the equipment was expensive and available only in specialized centres. According to the patients, additional input devices were cumbersome and difficult to use, as additional interface devices (like gamepad, joystick or keyboard) provided little freedom and flexibility. It seems natural to use such a device in the rehabilitation process by creating authoring rehabilitation systems based on markerless interaction in a virtual reality environment [9, 10, 11, 12]. These systems use the Kinect device for assessing the correctness of exercise performance, while also saving the statistics in a form of report, for further professional analysis. The Kinect sensors provide a markerless full-body tracking system on a conventional PC for advancing rehabilitation, training and exercise activities. The skeletal mapping technology of Kinect is capable of tracking four people simultaneously and quantizing their movements directly in real time without encumbering the user with tracking devices or markers. The benefits of implementing this technology in an intelligent rehabilitation system have been observed in different application areas, such as neurological [13] or orthopaedic therapy [14].

Motivation is a very important aspect of the rehabilitation process [15]. The application of video games components (or simply gamification) in rehabilitation settings has the potential to increase patients' motivation and enhance the efficiency of rehabilitation activities.

A serious game [16] or an applied game is a game designed for another purpose than pure entertainment. The application of this type of game to healthcare is an active and rapidly growing area of research [17, 13, 18]. Serious games can be useful tools for balance training of children, as well as for adults with many injuries. The prototype of the game was used in [17] for the rehabilitation of patients with chronic pain of the lower back and neck or for persons with neurological injury [13]. Researchers and JewelMine game developers demonstrated a set of static balance training exercises which encouraged the players to reach out of their base support [18] and a sophisticated post-session analysis tool for dynamic changes during a therapy session.

It has been documented that the sensor devices are easy to cheat and reduce the quality of the movement [19]. Davaasambuu *et al.* [20] explored the potential and limitations of Kinect for rehabilitation purposes. The experiences has shown that the system can recognize gestures with an accuracy of up to 88-92.2%.

The present study focuses on improving depth sensor data interpretation and testing of similar factors in different circumstances. An optimal use of the device may be useful in the design of rehabilitation exercises using Kinect.

3. Method

A passive-type limbs rehabilitation system should work in real time without any noticeable reaction lag. Technically, it should recognize the spatial positions of limb joints and overlay an augmented reality graphical interface layer onto the user image, informing the

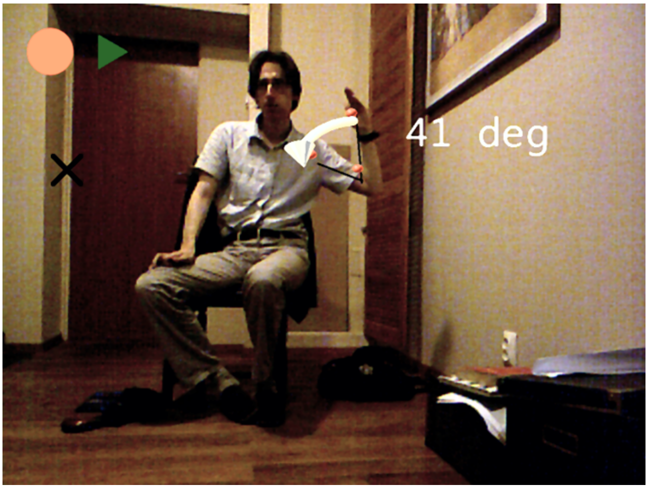


Fig. 1. GUI elements of the augmented reality rehabilitation system. Red circle and green arrow (left-upper corner), operated with the right hand controlled cursor (black cross) enable the user to change the application working mode: movement recording or replay. Left-hand assigned joints markers and skeleton fragments provide the ability to follow exercise advancement (white arrow) and provide the limb angle description.

user about the stage of the exercise. The system's interface, including both the graphical and the technical layer, should be accurate, persuasive and fitted precisely into the image of a real patient.

The functionality of the proposed system was designed and tested for arm rehabilitation but it is not limited to upper limb tracking. The paper concentrates on the rehabilitation of arms and forearms, as hand rehabilitation tackles the most spectacular articulated movement and can justify the wide applicability of the system.

The purpose of the augmented reality system was to measure the spatial angle between the user's arm and forearm during the forearm's movements – bending an arm at the elbow, as well as measure positions and, consequently, the movement of limbs joints: wrist, elbow and shoulder. Additionally, the system should precisely overlay graphical markers onto limb joints image positions (Fig. 1).

Moreover, spare hand controlled interface was introduced to let the patient navigate through available options. The left hand is equipped with joints markers (balls and lines of skeleton) which enable joint angle description. The angle value is additionally printed in an upper-right corner of the display. The right hand controls a cursor (the black cross in Fig. 1) and allows the user to adequately switch on the recording or replay the recorded exercises. Descriptive textual information and the active elements of the interface require further usability design. However, they reveal the most important interface functionality.

By using Default Microsoft Kinect SDK skeleton joints tracking, it is possible to determine the positions of limb joints in two modes: 2D and 3D. In the 2D mode, the joint positions are mapped to the RGB image, and their coordinates are represented in pixels. The coordinate system origin is situated in a left upper corner of the screen. In the 3D mode, the positions of joints are measured in the real-world coordinate system, associated with the RGB camera sensor, and their coordinates are expressed in meters. Therefore, in the context of the 3D controller based joints tracking, two additional coordinate systems should be taken into consideration. As Microsoft Kinect is based on two independent sensors, namely depth and RGB, the process of 3D joint positioning must combine two different types of data acquired from two independent sensors. It requires adequate calibration and actualization of RGB and depth sensors measurements. Fortunately, the 3D mode internally correlates these two separate coordinate systems (depth and RGB) but in the context of computer games, which the Kinect technology was originally designed for, pure skeletal movement is more important than absolute skeleton joints determination. The process of rehabilitation requires a very precise joints positioning capability and the default controller software development kit does not fulfil this requirements at a satisfactory level.

Effective control of rehabilitation exercises is based predominantly on precise spatial joints positioning. For the 3D joint position measurement, two reference coordinate systems are used. The first one is the 3D Cartesian system, associated with the RGB camera, while the second one is associated with depth controller. Every joint is at the particular distance (depth – z) from the camera plane and (x, y) coordinates are in the plane, orthogonal to sensor view direction (Fig. 3). As the planar (x, y) joints position are determined mainly with their position in the RGB image, their distance from the camera is quantized with a separate depth sensor. The depth sensor's position not only differs from the position of the camera but also the depth resolution is limited to 11 bits range variable and camera resolution is 1024×768 pixels in the image size. Thus, the positioning of joints is based on two independent sensors with limited resolution. Their cooperation requires inner calibration. Thus, the final position of joints is calibrated in relation to the RGB camera coordinate system and retrieved in metric units.

Verification of the retrieved spatial joints positions can be performed by means of virtual objects imposition into the real image of the user. Possible distance (given in pixels) between image position of a virtual object and patient corresponding joint (which can be noticed by the observer) can be interpreted as a measurement error. Additionally, the angle between two neighbouring limbs (i.e. arm and forearm) can be compared with the angle of the corresponding bones of the joints based skeleton.

Fig. 2. Kinnect 2D and 3D mode joints positioning accuracy comparison. Red balls represent joints in the 3D mode, black crosses mark the corresponding joints in the 2D mode and green circles describe actual joints positions (wrist, elbow, shoulder).

Virtual object rendering should be performed according to Kinect controller perspective projection view volume. According to the Kinect's specification, the horizontal and vertical field of view angles are equal to 57° and 43° respectively. The angles determine unambiguously the virtual camera aspect ratio.

Unfortunately, 2D coordinates of joints do not reflect their actual angular interrelations. The actual angle between the arm and the forearm differs from the angle between the corresponding 2D (projected) joints markers. On the other hand, the positions of the joints in a 3D setting can not be imposed correctly either onto joints, visible in the RGB image, or onto the joints positions, measured in the 2D mode (Fig. 2).

In practice, there are disparities between these coordinate systems. In particular, the accuracy of 3D joint tracking (from the RGB image point of view) is lower than in the 2D mode, i.e. 3D joints retrieved positions imposed on the RGB image are usually misplaced in reference to corresponding actual joints positions. On the other hand, 2D joints positions do not provide sufficient information to determine the 3D angle between the arm and the forearm. That is why the proposed system uses both 3D and 2D joint tracking data. The former are used for the measurement of the angle, whereas the latter – for the visualization purposes. Dedicated part of the tests is concentrated on the coordinate systems compatibility.

Two Kinect controllers were also introduced to improve the precision of 3D measurements. Nominally, the precision of Kinect does not exceed 2 cm (1 cm in depth and 0.3 cm in the image plane), but it reaches such a precision if no occlusions or challenging limbs movements are performed (i.e. hand movements in a plane orthogonal to sensor view direction). Both Kinect devices positions and orientations should differ as to obtain

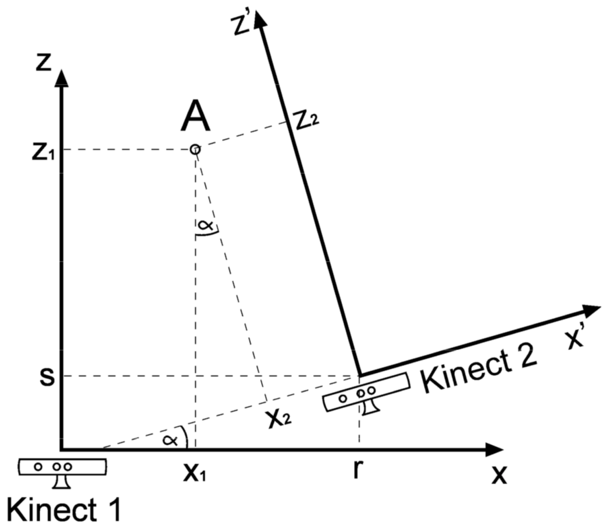


Fig. 3. Relative Kinect transformations for measurement enhancement.

different view perspective. The second Kinect can remain at the same level (y coordinate) but it should be translated in the horizontal plane ($[r, s]$ vector in xz plane) and rotated around the vertical axis (angle α in Fig. 3).

Next, the joints' coordinates recorded by the second sensor (Kinect 2 in Fig. 3) should be transformed into the coordinate system of the first sensor (Kinect 1 in Fig. 3) in order to increase the precision of measurements. This can be performed according to

$$\begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \\ 1 \end{bmatrix} = \begin{bmatrix} -\cos\alpha & 0 & -\sin\alpha & r \\ 0 & 1 & 0 & 0 \\ -\sin\alpha & 0 & \cos\alpha & s \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \\ 1 \end{bmatrix} \tag{1}$$

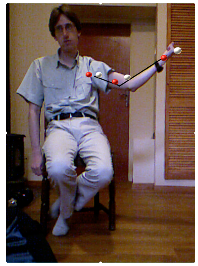
The coordinates obtained from the two controllers, after unification into the first controller coordinate system, were averaged. The role of the second controller was to improve the results of joints depth evaluation. Their usage was validated by appropriate tests.

4. Tests and discussion of results

During the tests, two groups of system measurement contexts have been verified. In the first one, the verified values were the relative positions of actual joints in the RGB image,

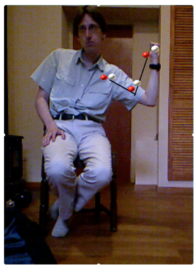

(**1**) Perpendicular 180°

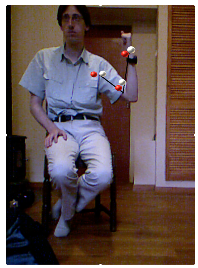

(**2**) Inclined 180°


(**3**) Perpendicular 135°


(**4**) Inclined 135°


(**5**) Perpendicular 90°


(**6**) Inclined 90°


(**7**) Perpendicular 45°

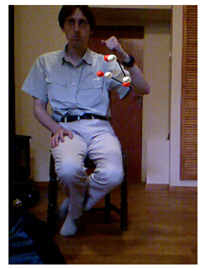

(**8**) Inclined 45°

Fig. 4. The four arm poses considered during the tests, perpendicular and inclined to the Kinect controller view direction. Red dots mark one sensor 3D mode joints positions, white dots mark two sensors 3D mode retrieved joints positions and black lines along user limbs mark Kinnect 2D mode arm skeleton. Numbers of poses will be used in Tabs. 1, 3 and 4.

pointed by a user, the positions of joints detected by the Kinect device in the 2D mode, and the virtually imposed joints detected by Kinect in the 3D mode according to the reconstructed view volume. In the second context the verification involved comparing actual angles between the arm and the forearm, measured physically, with the angles determined using Kinect SDK 3D mode joints tracking data. The experiments were repeated for 1 and 2 Kinect controllers working simultaneously.

The tests were performed on a set of four arm poses. Each pose was considered for two different relations to the Kinect controller view direction: perpendicular and inclined (Fig. 4). These four poses represented four different angles between the arm and the forearm (180°, 135°, 90°, 45°). The relative angles of the bones of hand limbs were assured by a specially constructed frame fixed to the arm and the forearm so as to eliminate possible angle changes during the experiments. Arm fixed frame was progressively adjusted and a series of experiments were performed for each pose.

For each of these poses, the controller was able to retrieve recognized skeleton joints.

Tab. 1. Average errors (in pixels) between real (perceived by the user) and measured (in the image plane) joint positions for 1 and 2 sensors in Kinnect 3D mode and Kinnect 2D mode. Numbers of poses according to Fig. 4.

No. of pose	Joint	Average error in distance [pixels] for 1 sensor in 3D mode	Average error in distance [pixels] for 2 sensors in 3D mode	Average error in distance [pixels] for 1 sensor in 2D mode
7.	wrist	40.8	15.7	10.4
5.	wrist	30.9	18.0	6.0
3.	wrist	60.9	28.7	12.5
1.	wrist	46.9	32.8	20.0
7.	elbow	49.2	46.4	24.4
5.	elbow	50.1	43.4	12.2
3.	elbow	55.9	39.6	2 5.5
1.	elbow	48.1	31.1	26.2
7.	shoulder	31.0	10.8	7.4
5.	shoulder	29.8	9.2	7.7
3.	shoulder	25.3	14.8	8.0
1.	shoulder	35.3	19.7	16.4
8.	wrist	31.3	42.6	11.0
6.	wrist	30.8	15.0	6.0
4.	wrist	49.3	24.1	22.8
2.	wrist	26.9	15.2	14.3
8.	elbow	40.8	35.1	19.5
6.	elbow	46.3	42.1	17.9
4.	elbow	52.0	27.7	18.3
2.	elbow	57.3	36.9	11.4
8.	shoulder	30.6	14.6	8.6
6.	shoulder	28.0	8.9	5.8
4.	shoulder	31.5	9.2	7.1
2.	shoulder	41.9	25.7	20.1

The positions of joints derived using the device's algorithm differ from those perceptually marked in the image (see Fig. 4). Set of distance errors representing joints positions misplacement, perceptually marked in the image, and joints positions retrieved from the Kinect SDK 2D and 3D modes are illustrated in Tab. 1. The evaluation of Kinnect 3D mode joints' positions was additionally tested with two simultaneously working controllers. The results are also presented in Tab. 1.

Tab. 2. Averaged results of errors (expressed in pixels) for different Kinect modes and considered joints: wrist, elbow, shoulder.

Joint	Average error [pixels] for 1 sensor in 3D mode	Average error [pixels] for 2 sensors in 3D mode	Average error [pixels] for 1 sensor in 2D mode
wrist	39.7	24.0	12.9
elbow	50.0	37.8	19.4
shoulder	31.7	14.1	10.2
all	40.5	25.3	14.1

Averaged results of errors in distance, expressed in pixels for individual joints are summed up in Tab. 2.

The experiments have shown that average planar distances between joints retrieved in Kinect SDK 2D mode and those marked by user are about 13 pixels for wrist, 11 pixels for shoulder and about 19 pixels for elbow positioning. The final average error in 2D mode joints positioning is about 14 pixels. Moreover, the results of tests have shown a considerable discrepancy between actual joints positions and their coordinates retrieved by the 3D mode controller. The errors in distance for one controller have reached, on average, 40 pixels in the case of wrist positioning, 50 pixels for the elbow and a misplacement of about 32 pixels in the position of the shoulder joint.

An average error in pixels for one controller based 3D mode positioning is about 40 pixels. The introduction of the second Kinect controller provided an improvement of the results. Joints tracking precision has increased at minimum 25%. The average wrist positioning error has fallen down to 24 pixels, the elbow error has reached about 38 pixels and the shoulder positioning displacement was about 14 pixels. On the average, the results provided by two controllers were almost 38% better than those obtained with only one controller.

A separate part of the experiments was devoted to the measurement of angle between limbs. A set of predefined hand poses (Tab. 4) with an arranged angle between arm and forearm was presented separately to the system equipped with one and two controllers. Corresponding angles of actual limbs bending (measured during physical exercise) and results retrieved with Kinect (3D mode based skeleton) were compared.

The experiments on angles comparison have shown that the values of the angle do not differ much either for 1 or for 2 controllers and their relation to the actual limb bending is quite acceptable. Nevertheless, the support of the second controller has improved the angle measurement almost by 30%, from 5.9° error in the case of one controller down to 4.2° error for two controllers.

Tab. 3. The angles (in degrees) of real hand poses and their corresponding 3D mode measurements for 1 and 2 controllers. Numbers of poses according to Fig. 4.

No. of pose	Actual limbs angle [deg]	Angle measured with 1 controller in 3D mode	Angle measured with 2 controllers in 3D mode
1.	180	176	178
1.	180	174	178
1.	180	179	170
2.	180	169	172
2.	180	173	177
2.	180	175	176
3.	135	141	136
3.	135	141	67
3.	135	132	70
4.	135	152	130
4.	135	122	131
4.	135	141	140
5.	90	92	84
5.	90	87	90
5.	90	87	82.8
6.	90	86	84.4
6.	90	93	87.2
6.	90	92,5	87,6
7.	45	48	43
7.	45	49	46
7.	45	50	49
8.	45	54	47
8.	45	53	50
8.	45	53	54

Summing up the experiments, it should be noticed that the accuracy of measurement of joint positioning (both 2D and 3D) differs for separate joints and depends on the user's position. The types of joints measured were: wrist, elbow and shoulder. These joints were necessary to determine the angle between the arm and the forearm. As it has appeared, the shoulder was detected the most accurately, much better than the wrist and the elbow.

The second factor influencing the precision of measurements is user relative position and orientation to the controller. The errors were smaller in the case of limbs moving

Tab. 4. Averaged results of errors (in degrees) for different limb poses. Numbers of poses according to Fig. 4.

No. of pose	Angle [deg]	Average error for 1 controller [deg]	Average error for 2 controllers [deg]
1.	180	3.7	4.7
2.	180	8	5
3.	135	5	1.5
4.	135	12	4.7
5.	90	2.7	4.4
6.	90	3.2	5.2
7.	45	4	2.5
8.	45	8.3	6
Average		5.9	4.2

in the plane orthogonal to the sensor view direction, and sometimes doubled, when the joints were collinear with themselves and with the sensor (they occluded themselves).

5. Conclusions

The presented solution was tested in terms of visual consistency and user satisfaction. During bare one-sensor based system experiments, imperfections reaching 60 pixels were recorded. However, for two sensors, the precision of wrist visual location reached a 40% localization improvement rate and the wrist was localized about 55% better. The system received positive feedback from the users who appreciated its functionality and provided valuable improvement suggestions, which will be considered in further research.

It should be noted that large differences between RGB image joint positions and joints detected in 3D may not be damaging to the rehabilitation system. The 2D joints tracking can be used for visualization purposes, since the 2D mode joints positions differences were significantly smaller than those obtained for the 3D mode. On the other hand, as it is not possible to evaluate the angle in the 3D space on the basis of 2D joints positions, the 3D mode should be also incorporated into the rehabilitation system to improve its diagnostic functionality. The joints detection in 3D mode can be used for joint positioning and skeleton angle evaluation. It must be emphasized that within the 3D measurement mode supported with two controllers, the results regarding both joint positions and the corresponding limb angles measurements errors were acceptable form the rehabilitation point of view.

Currently, the work on further development of the system is being continued under the supervision of the Physiotherapy and Rehabilitation Division of the Medical University of Łódź, with medical tests planned in the forthcoming future.

References

[1] Dega W., *Ortopedia i rehabilitacja.* PZWL, Warszawa, 1983.

[2] Weiss M., *Rehabilitacja – zagadnienia wybrane.* In R. B. W. Brühl, editor, *Vademecum lekarza ogólnego*, PZWL, 1974.

[3] Rodrigues R., Huber M., Lamura G. (eds.), *Facts and figures on healthy ageing and long-term care.* European Centre for Social Welfare Policy and Research, Vienna, 2012.

[4] Sagan A., Panteli D., *Health systems in transition.* World Health Organization, 2012.

[5] Białokoz-Kalinowska J., *Zagrożenia zdrowotne wynikające z nieracjonalnego korzystania z komputera przez dzieci i młodzież.* Dziecko i media elektroniczne, Białystok, 2005.

[6] Griffiths M. Technological addictions. *Clinical Psychology Forum*, 76:14-19, 1995.

[7] Totilo S., *Natal recognizes 31 body parts, uses tenth of Xbox 360.* Computing Resources Kotaku, Gawker Media, 2010.

[8] Jack D., Boian R. et al. A virtual reality-based exercise program for stroke rehabilitation. In *Proc. 4th Int. ACM Conf. Assistive Technologies, ser. Assets '00*, New York, USA, 2000.

[9] Labelle K. *Evaluation of kinect joint tracking for clinical and in-home stroke rehabilitation tools.* Ph.D. dissertation, Undergraduate Program in Computer Science Notre Dame, Indiana, 2011.

[10] Chaves M. Development and evaluation of a Kinect based motor rehabilitation game. In *SBC – Proc. SBGames*, 2012.

[11] Chang C.-Y., Lange B. et al. Towards pervasive physical rehabilitation using Microsoft Kinect. In *Proc. 6th Int. Conf. Pervasive Computing Technologies for Healthcare*, San Diego, CA, May 2012.

[12] Lange B. B., Rizzo S. Markerless full body tracking: Depth-sensing technology within virtual environments. In *Interservice/Industry Training, Simulation, and Education Conference*, 2011.

[13] Lange B., Chang C.-Y. et al.Development and evaluation of low cost game-based balance rehabilitation tool using the Microsoft Kinect sensor. In *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, 2011.

[14] Chang Y.-J., Chen S.-F., Huang J.-D. A kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. *Research in Developmental Disabilities*, 32(6):2566-2570, 2011.

[15] Barry J. R., Malinovsky M. R., *Client motivation for rehabilitation: A review.* Rehabilitation Research Monograph Series, University of Florida, 1970.

[16] Arvers I. Serious games. *Digitalarti Mag*, 4:24-25, 2009.

[17] Schönauer C., Pintaric T., and Kaufmann H. Full body interaction for serious games in motor rehabilitation. In *Proc. 2nd Augmented Human International Conference, ser. AH '11*, New York, NY, USA: ACM, 2011.

[18] Lange B., Koenig S. et al. Interactive game-based rehabilitation using the Microsoft Kinect. In *Virtual Reality Short Papers and Posters (VRW 2012)*, IEEE, 2012.

[19] Hondori H.M., Khademi M., A review on technical and clinical impact of Microsoft Kinect on physical therapy and rehabilitation. *Journal of Medical Engineering*, 2014:846514. `doi:10.1155/2014/846514`, 2014.

[20] Davaasambuu B. E., Chiang C.-C. A Microsoft Kinect based virtual rehabilitation system. In *Proc. 5th Int. Conf. FITAT 2012*, 2012.