

## Markerless Assisted Rehabilitation System

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**Abstract.** *The project focuses on the use of modern technology to analyze human movement. This analysis turns out to be useful aid for physicians in rehabilitation of patients with limb injuries. This method is more precise than simple observation of the patient through the organ of sight. The proposed system allows markerless determination of deviations between the selected bones and joints, and as a result do not require specialized and expensive equipment. The implemented application presents instructional animation of the exercises and verify the correctness of its performance in real time. The equipment that meets the requirements of the project is the Microsoft Kinect, which is nowadays widely used in the medical field.*

**Keywords:** *motion capture, computer-aided rehabilitation, augmented reality.*

### 1. Introduction

Currently, medicine is supported by new technologies for more efficient and less invasive surgeries. Existing technologies also create big opportunity in the diagnosis and rehabilitation of injuries and limb posture. A multitude of existing technologies and the ease of adapting them to current needs and available resources

allow their use on a large scale. Experienced doctors perform visual assessment of silhouettes and limbs posture, based on the correct position and the relationship between the data points, which are defined based on the construction of a human skeleton. In order to determine the correct posture and body alignment a criterion of lines can be used: vertical, horizontal, symmetrical angles and symmetry of the body. The silhouette of a patient can also be captured using photography or specialist measuring devices like ISIS (Integrated Shape Investigation System) [1]. The use of modern technology allows for very precise spot of all the irregularities, even the minimal ones that are difficult to observe with the human eye. This brings in the field of rehabilitation great opportunities to create new solutions that are more accurate and user-friendlier than the existing ones and allows greater effectiveness of the performed exercises [2, 3]. The aim of the project is to assist doctors and therapists in their work with patients with bone and joint injuries. These injuries have an impact on reducing the range of motion of the bones and joints as well as reduction in endurance and muscle strength. The proposed system is intended to assist in the accurate determination of the difference between the movement of healthy and injured patient, and decreases this difference by performing a series of specialized rehabilitation exercises. The aim of the project is to implement a system that enables to analyze the movement of human body, tracks the current position of the patient's skeleton and the monitoring criteria that must be fulfilled. Our software is designed to assist patients during self-rehabilitation process at home. This project involves the use of Microsoft's Kinect equipment, which was chosen among other modern technologies, such as the Nintendo Wii or complex motion capture systems.

## **2. Measurement of human movement**

Standard human motion analysis systems are using special markers attached to the skin [4]. The dynamic development of image processing algorithms enables the implementation of the markerless movement measurement systems [5, 6, 7]. Currently used medical devices include: Microsoft Kinect, Motion Capture systems, CyWee Z [8], the Nintendo Wii, equipment for rehabilitating the lower limbs [9] or kinesthetic system for capturing and classifying upper limb movements [10]. The most popular include the first two [11].

Microsoft Kinect was initially used only as entertainment platform with the Microsoft Xbox 360. In time, however, its wide potential on different fields of

application was noted. A characteristic feature of this device is that it does not demand the user to wear or hold any controlling device. The solution introduced by Microsoft, allows a person using Kinect to be a controller itself.

More complex motion capture systems, are mostly based on a set of cameras and markers attached to the person. On their basis the image showing the position of the markers in three-dimensional space is recorded and transferred into destination software. Results, because of its accuracy are often used in computer games and special effects for movies.

### **3. Use of measurement of movements in medicine**

Existing systems in medicine are divided into:

- marker based tracking system
- markerless tracking system
- requiring a controller or other device, which should be worn or held

The principle of using marker based tracking systems relies on the use of a series of cameras located around the actor, who has markers attached to his body. Extracting markers from obtained images depend on the used system is . Currently, we can distinguish: passive and active systems. Passive systems are based on the use of reflective markers that are attached to joints and intermediate locations between them on the actor's body. Movements of actor are recorded by infrared camera catching the light reflected from markers, which is separated from visible light by an optical filter. Threshold algorithm allows to select only bright spots of the recorded image. Active systems use markers which emit their own light. The identification of markers can be approached in several ways. At a given time, light can be emitted by only one marker or each marker emits light with a different intensity which allows to determine the position of specific markers. In both cases, special software allows to combine data from all cameras and place markers in a virtual three-dimensional space. Points are often used to transfer motion of a moving actor to three-dimensional model or skeleton. So that we get accurate movement of the actor on the monitor screen, which is represented in the form of a three-dimensional model.

Marker based systems are widely used in medicine by companies such as Vicon, Motek Medical, Qualisys or MotionMonitor. Vicon is now a company that

takes up most of the medical market in this area. It is responsible for providing all solutions, ranging from equipment, installation, and finishing on the software. The company's software allows you to read with data from the patient and their rapid analysis is used for medical purposes. Motek Medical constructed the CAREN system that can currently use twenty four cameras working with motion capture system, the moving platform, and the dome, which has a spherical display used for the presentation of games and virtual environment in which the patient is moving. The system allows to treat diseases and injuries such as problems with balance and posture disorders in human mobility problems resulting from disease, bone deformities, limb amputation, neurological and orthopedic problems.

Systems without markers [12, 13, 14, 15] are based on processing algorithms and analysing the contents of the recorded image. The process begins from acquisition of the camera image, which depending from their parameters has a different frame rate of frames per second and a different resolution. There are solutions for this purpose which are using infrared cameras making projection of infrared grid. Infrared sensor makes the acquisition of grid points, which are reflected from the environment and they are returning to him. The intensity of the point depends on the distance from the emitter. The image acquired from camera is processed by algorithms which are performing segmentation.

The image segmentation allows to specify the image regions that have common characteristics. The algorithm divides the image to extract a particular part or parts of the human body and estimate where the joints occur. Segmentation methods can be classified according to the type of information used in its time: point, edge, area, and hybrid. In point segmentation we can distinguished thresholding method (threshold selection based on a histogram, where the resulting image is binary) and clustering method (creating areas on the basis of characteristics that are attributed to the pixels by the use of clustering algorithms). The second group of algorithms are edge methods, which use edge detection algorithms, such as Roberts or Sobel Prewitt. They are based mainly on changes of the luminance in the image. These changes can be caused by varying the depth, surface orientation, material properties and lighting in the scene. Changes in luminance correspond to the edges of the image. The area methods include: area growth, linking areas, the division of areas, split and merge method, watershed segmentation. The final method is hybrid division, combining at least two of the above methods, such as growth areas using a single waveform edge. With the points where the joints are located, we are able to analyze the movement and use them to create graphical representation of the human skeleton.

In terms of application markerless tracking systems can be generally divided into two main groups:

- specially designed games, which by their form intend to improve the condition of the patient while having fun. In comparison to other solutions, they are more friendly and interesting from the point of view of the patient.
- applications based on the performance of specific exercises and repetition. Those solution are less interesting for the patient, but more accurate - you have to perform precise movements, in order to classify current repetition of the exercise as the correct one.

An example of the solutions from the first group using Kinect is a polish software called [16], and from the second group one should mention ReMotion360 software by InfoStrat <sup>1</sup>. Kinect, thanks to its cooperation with the other camera is also able to reflect more accurately the movements made by the patient in each possible pose. These solutions are used by OrganicMotion <sup>2</sup> and iPiSoft <sup>3</sup>.

Systems based on the use of additional controllers or sensors [5] sewn in clothes are usually limited to the study of only parts of the human body. Controllers in each of the systems differ from each other so that the patient is not able to get used to the controller if the system is changed at the time. Systems that require the imposition of a certain item of clothing with sensors are usually less comfortable for the patient. Hence, this type of systems are not particularly user friendly.

Described systems play an important role in medicine. Regardless of its capabilities, they support both diagnostics and rehabilitation part of the treatment to help doctors to make the right decisions. The big advantage of these methods is the lack of invasiveness. A patient can in a quick and painless way get information about his posture, his deformation and lead treatment of acquired injuries. However, these methods are currently used only in the medical centers, so as a result the patient has to commute. There are few systems allowing for rehabilitation in their own home at time of their own choice, where you do not need a physiotherapist and the specialistic software could supervise and correct the actions of the patient.

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<sup>1</sup><http://www.infostrat.com/solutions/Remotion360>

<sup>2</sup><http://www.organicmotion.com>

<sup>3</sup><http://ipisoft.com>

## 4. Hardware equipment

We assume, it is crucial in this type of applications, that the solution could be available for a wide range of users. It is necessary to select available and popular device. The device, which meets this requirements is the Microsoft Kinect. It has a range of equipment, compared to similar devices for a relatively low price.



Figure 1. Microsoft Kinect Controller

Kinect is the sensor connected to a small base with a motorized pivot. The device features an RGB camera, depth sensor and multi-array microphone. The depth sensor consists of an infrared projector combined with a monochrome CMOS sensor. Infrared ray is projected from the device and a sensor reads the reflected ray form surfaces. Rays package allows the reconstruction of the surrounding environment in 3D. Calibration of depth sensors to accommodate existing objects in its visual field is made automatically. Kinect uses 3 different sizes of speckles for 3 different regions of distances (0.8 – 1.2 m, (1.2 – 2.0 m, 2.0 – 3.5 m)

The device is also equipped with multi-array microphone. This system allows to audio-locate the user in the room.

Microsoft's joint tracking algorithm identifies joint positions by processing a depth image.

SDK (Software Development Kit) provides to the user Skeleton API that allows easy manipulation and tracking the human skeleton. In order for a skeleton to become active, camera must be able to see the user from head to foot. The virtual skeleton is made up of 20 joints (Fig.2). Kinect is able to detect four persons, but only for two, can create all possible joints. For the purpose of rehabilitation and diagnostics, only one skeleton identification seems sufficient.

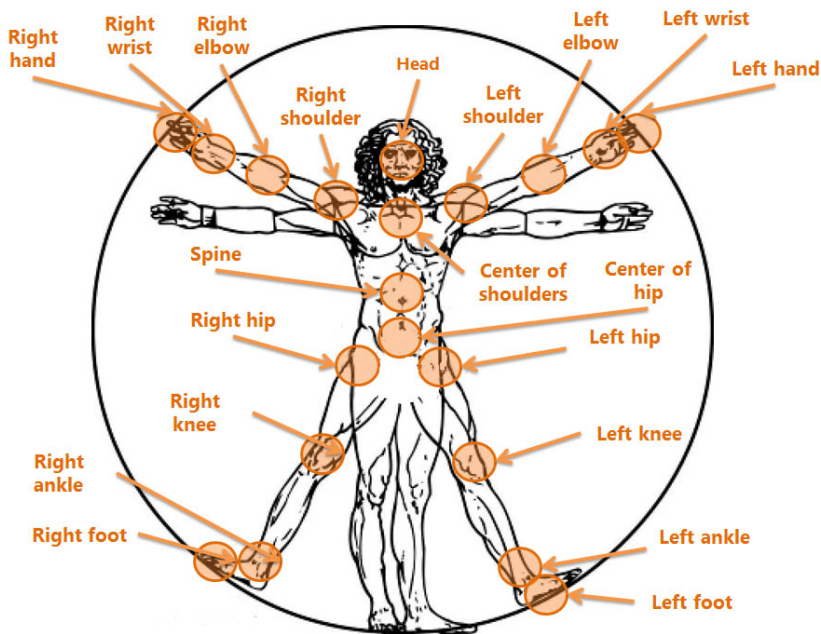


Figure 2. The 20 Joints in the Kinects virtual skeleton [17]

## 5. Design and development system for supporting rehabilitation

Our goal is to develop and optimize the system to assist the monitoring of rehabilitation process. Rehabilitation has many specialties including: remediation of impairments and disabilities, promotion of mobility or functional ability. In our solution, we focus on injuries that limit abilities to move of the patient.

The developed system will enable effective physiotherapy of diagnosed injuries on the basis of a treatment plan of exercises. In the physical therapy process it is very important that the goals of the treatment plan are met. There are two different factors of physical disability. First is the range of motion, second is a strength and muscular endurance.

Our sample exercise is based on the second factor. This is a very important part of physical therapy but rarely found in existing solutions. This exercise (Fig 3) is part of the third phase of the rehabilitation. It concerns shoulder injury and

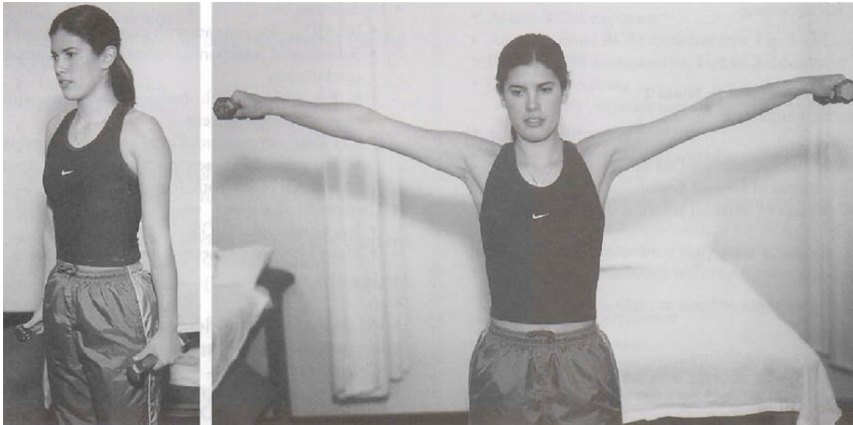


Figure 3. TRehabilitation exercise after shoulder injury [18]

supports stretching the shoulder muscles [19].

The project focused on the implementation of a single exercise. The system should determine and correct the accuracy of the patient's activities. In addition to information about the current progresses, he will be informed about irregularities in his attitude (Fig 4).

The project is easily expanded by adding more exercises and more functionalities. Modularity of the program allows to add in the future additional virtual skeleton and more sensors.

The main class of the project is `Game1.cs`. This area contains variables and parameters for the other classes. The constructor method `Initialize` method are called once at startup. It is used to load some variables and initializations needed by the XNA framework like streams from RGB and Depth camera, as well as virtual skeletons. Working-class components are also responsible for the activity. `KinectSet.cs` class is responsible for connecting to the Microsoft Kinect device and configuration settings of the sensor relative to the surrounding area. The main class `KinectSet.cs` is declared as a service for other classes which have access to it. Applications must indicate skeleton data at initialization and must enable to track it. Skeleton is tracked, when its position is given with all the Joints. The position from the Kinect SDK is scaled to be used in a World captured by the camera. This gives the ability to view real-time images captured by the camera with skeleton animation for guidelines exercises. The skeleton is only made from two types of



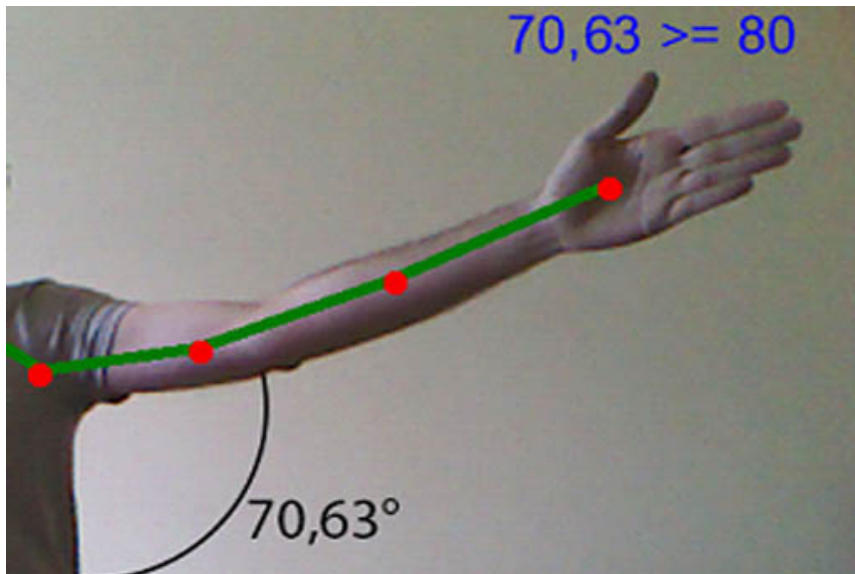


Figure 4. The application interface

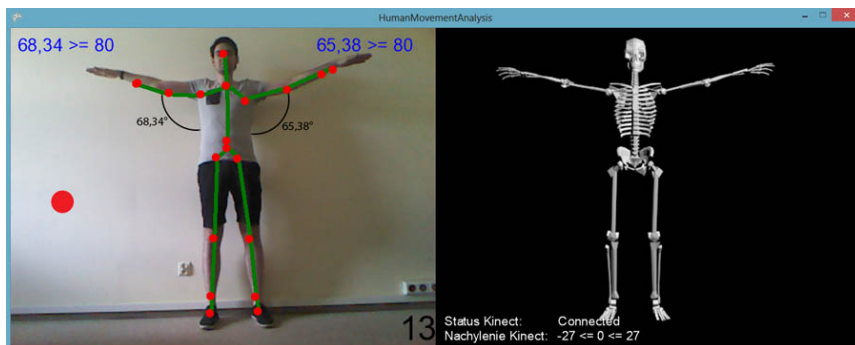


Figure 5. Demonstration exercise, which has been implemented

shape, spheres representing skeletal joints, and cylinders for the limbs connecting the joints.

Exercise for limb requires the correct analysis of three joints and two connecting bones. This exercise requires the calculation of the rotation range of the limbs (Fig 6). The rotation should be carried out around the vector, which is normal to the

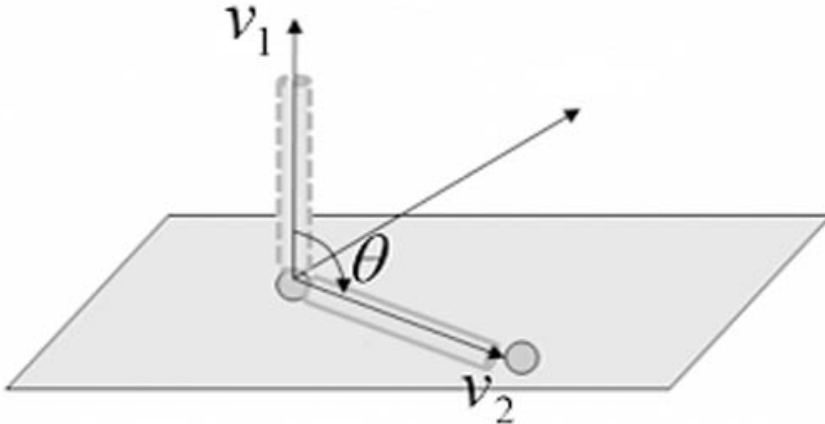


Figure 6. Rotating a Limb

plane defined by the two vectors and is known as their cross product. The tangent function calculates the angle:

$$\operatorname{tg}(\theta) = \frac{V_1 \times V_2}{V_1 \bullet V_2} \quad (1)$$

The application has the following features:

- measures the angle between the selected joints,
- allows for easy implementations of new exercises,
- allows for the correct configuration of the device to the ambient conditions,
- displays the camera image, which is applied to the skeleton recognized by the Kinect with additional information,
- counts the number of correctly performed exercises,
- instructed by the description and animation how to properly perform an exercise session,
- the user get feedback information if his attitude is not correct or the way of the exercise is inconsistent or inaccurate with the target's course.

Physical therapy can be provided only by qualified physical therapists or by physical therapist assistants working under the supervision of a physical therapist. That is why the user interface and the whole environment was established on the basis of tests and work with an expert (Physical therapists).

This performed project has a number of important factors that distinguish it from existing solutions:

- low equipment operating costs,
- the user do not need special costumes or several markers,
- all exercises can be done in a small space,
- system of the correction of exercise give possibilities to monitor current progress while practicing at home.

## **6. Conclusions**

This developed interdisciplinary project combines medicine and computer science. Exercises are more user-friendly and allow to save time while making sure the patient perform them correctly. The system can be used both in health service under the supervision of a physiotherapist as well as alone at home. Rehabilitation of the patient at home is very comfortable, provided that the system is able to replace the therapist, at least in the main part. The activities are monitored while taking as much as possible the correctness of their execution. The patient at home can also do the exercises at any time. Against the background of existing solutions, our system is not expensive, and analyzes and controls the patient movement in real-time. The structure of the program also allows for easy implementation of future exercises, so that the system can grow along with the increasing demand for the next exercise. Unlike to others, our solution allows to synchronize animation and implementation of exercises.

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