The valuable use of Microsoft Kinect™ sensor 3D kinematic in the rehabilitation process in basketball.

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Abstract. Subjects who practice sports either as professionals or amateurs, have a high incidence of knee injuries. There are a few publications that show studies from a kinematic point of view of lateral-structure-knee injuries, including meniscal (meniscal tears or chondral injury), without anterior cruciate ligament rupture. The use of standard motion capture systems for measuring outdoors sport is hard to implement due to many operative reasons. Recently released, the Microsoft Kinect™ is a sensor that was developed to track movements for gaming purposes and has seen an increased use in clinical applications. The fact that this device is a simple and portable tool allows the acquisition of data of sport common movements in the field. The development and testing of a set of protocols for 3D kinematic measurement using the Microsoft Kinect™ system is presented in this paper. The 3D kinematic evaluation algorithms were developed from information available and with the use of Microsoft’s Software Development Kit 1.8 (SDK). Along with this, an algorithm for calculating the lower limb joints angles was implemented. Thirty healthy adult volunteers were measured, using five different recording protocols for sport characteristic gestures which involve high knee injury risk in athletes.

1. Introduction
Knee injuries are very frequent in people who practice sports, either professionally or in an amateur way. 1 in 3,000 people suffer from a knee injury, and of those injuries, 70% is due to the practice of sports. There are a significant number of individuals with this injury [1] particularly in basketball.

Marqueta and Tarrero made an research in the NBA (National Basketball Association) and the ACB (Spanish Basketball Professional League), where they quantified basketball injuries in the various anatomical structures of the body. In both leagues, the incidence of knee injury is in second place, 9.4% and 14.2% respectively in NBA and ACB[2].

The incidence of injury in the external compartment of the knee (osteochondral and / or meniscal injuries) in basketball players is more common than those found in the internal compartment. In recent work, Gumpel raises the possibility that this damage is due to the transmission of loads to the lateral compartment due to the position valgus knee in certain gestures own of game [3].

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It is believed that this chondral injury is caused by a direct trauma to the knee flexed at 40 degrees, predominantly on the medial femoral condyle (including tennis, football and rugby). Injury occurs as chondral disruption by the direct impact with tissue repair and secondary reactive hypertrophic synovium that is located overlying the original injury. In basketball, unlike most sports, the chondral injury occurs most frequently in the external compartment of the knee. It is stated that this event is due to the pronounced position of knee valgus that athletes develop in this sport during every game and every practice session [3] [4]. The logical consequence of this type of damage is a loss of mobility due to the pain and therefore the inability to carry out the activity completely. In the professional basketball field, this is a problem that not only affects the health of the player, but it also presents both an economic and sporting problem to the institution where the athlete belongs.

Even though the injury as a whole as ACL, MCL and medial meniscus is widely known and is assumed to have high incidence, it has been found that the number of lesions in external compartment knee greatly exceeds the internal compartment knee injuries in basketball and other sports [5].

3D kinematic measurements of lower limb and ground reaction force in professional basketball players showed that greater knee valgus moment occurs during a change of direction when both hip flexion and internal knee rotation are incremented [6]. Colby et al. characterized the activation of the hamstrings and quadriceps, also determining the angle of knee flexion by analyzing four gestures: change of direction, jump with and without change of direction, run and stop[1, 7]. Other authors performed a 3D kinematic analysis of the differences in valgus knee between men and women when landing from a platform jump immediately followed by a vertical jump [8, 9].

Studies of Crossley et al. [10] indicate that hip muscle function is compromised in people with anterior knee pain (AKP). They found strong evidence of deficits in hip muscle strength (abduction, external rotation and extension) in patients with AKP compared to healthy people. A measurement of hip muscle function is given by the patterns of activation using electromyography (EMG). A single-leg squat is often an exercise used for clinical evaluation for determining whether the hip muscle function is compromised or not. Nowadays, there is visual analysis of movement patterns used to evaluate lower limb neuromuscular control. Previous studies conducted at gait laboratories using sophisticated equipment have shown movements of the joint in the hip and knee. Consequently, there is a need to develop a more simpler and clinically applicable method for evaluating the performance of one-leg squats and other movements of interest in assessing muscle function. In addition, analysis of the performance of a leg squat is also used to assess rehabilitation after knee injury. A continued development of a method in this field could bring an innovative aspect, which is the quantification of this movement during rehabilitation.

The Microsoft Kinect® sensor has been used to record movement in recent years. Specifically, Stone et al. conducted an analysis of the gesture of the jump from a platform on the ground and a jump back up. The results indicate that the skeletal model Kinect® Microsoft has acceptable accuracy for use as a tool to identify the risk of ACL injury [11].

From this analysis, it is possible to establish that knee injuries may be caused by the transmission of loads to the lateral compartment due to the position of valgus knee in certain own gestures of basketball game. Even though there have been some studies done, the causes have not yet been determined as well as the ability to generate optimal strategies for the prevention and rehabilitation of this traumatologic pathology. It is therefore presented in this work the proposal for the development of a system of registration and testing protocol for measuring kinematic 3D using the Microsoft Kinect®, a simple and portable tool for field use. This tool was used to record and analyze some common movements made during basketball practice, which served to develop a system that uses the data output of Microsoft Kinect® sensor system. The algorithms needed for the 3D kinematic assessment were calculated, while also obtaining the relationship between global and local coordinate systems using additionally the Software Development Kit (SDK) additionally which is available for free.
2. Material and Methods

2.1. Implementation of the registration system

In this presentation, the implementation of a system of capturing motion without markers (MMCS-Markerless Motion Capture System) is based on the Microsoft Kinect® sensor for Xbox 360. This is a portable and easy to assemble system, capable of acquiring and storing 3D kinematic data records in different scenarios for subsequent statistical analysis. This developed system is used to evaluate several representative sporting gestures and protocols.

2.1.1. Hardware: In this development we worked with Microsoft Kinect® sensor, device developed by PrimeSense® [9] and distributed by Microsoft [12] for the Xbox 360 console, and since June 2011, available for PC. It has a VGA color camera 640 × 480 (CMOS) with Bayer color filter, an infrared camera 640 × 480 (CMOS), an infrared laser projector, microphone Multi Array, a motor to adjust the tilt angle of the device and a accelerometer for sensing the spatial orientation (figure 1) [13].

![Figure 1](image-url)

**Figure 1.** Features of Microsoft Kinect® sensor. (a) - (b) image sensor. (c) - (f) outline of vision and depth ranges. (d) the MMCS global coordinate system. (e) image of points infrared laser pattern projected and captured by the sensor [13].

The sensor can capture RGB images and depth at different resolutions at a maximum rate of 30 frames per second (CPS) depending on the desired resolution. The vision cameras range, both RGB and depth, has a horizontal angle of 57.5 ° and a vertical angle of 43.5 ° with the possibility of displacement of 27 ° down to 27 ° upward through motor possessing tilt (figure 1a.) [13].

This device combines infrared structured light laser and computer vision algorithms to obtain a depth chart from a single image. The entire process consists on projecting infrared laser pseudorandom points pattern at the scene (Figure 1e.). The infrared sensor then captures an image obtained thereof and then, through a deformation process, it estimates how far away objects are located in the scene. All this is done at the hardware level and a depth chart is obtained from grayscale of 16 bits, with a maximum resolution of 640 x 480, where each pixel encodes the distance between the object and the sensor in millimeters. From the 16 bits of each pixel, 13 of these contain distance information, giving a resolution of 1 mm in depth for optimal sensor range (800-4000 [mm]), this is shown in Figure 1f [14].

2.1.2. Software: The development of the 3D kinematic system uses Microsoft Kinect® SDK (SDK - Software Development Kit) with its drivers, tools, native APIs (Application Programming Interface)
and code available APIs for the development of Windows applications based on Kinect. This SDK has extensive technical documentation and open code samples optimized for the exploration and experimentation of the main features offered by the sensor. One of its highlights is the pipeline offered by the Natural User Interface-API (NUI - API) for recognition and automatic tracking of people in real time (Skeleton Tracking), which gives applications the ability to record and interact with those present in the field of view of the sensor.

This process is accomplished through classification algorithms (randomized decision forest) trained to quickly and accurately predict the 3D positions of the joints of the body from a depth image without using time information (Figure 2a.). Once the "runtime core" has determined body parts and the more likely skeleton is chosen, then the space data for each local coordinate system of the skeleton are generated (Figure 2b.). By not using time information for each picture, it can achieve detection of up to 6 people in the scene (Figure 2c.), with the possibility of active capture of two people selected [13].

![Input and Output of algorithm Randomized Decision Forest for recognizing people](image1.png)

**Figure 2.a.** Input and Output of algorithm Randomized Decision Forest for recognizing people [14]. **b.** 3D kinematic model used by the Microsoft Kinect SDK. **c.** Skeleton Tracking.

Thus through this API the spatial position of the markers 20 (joints) can be obtained, as well as the spatial orientation, relative to the sensor, of the segments of the skeleton (Bones) to a maximum frequency of 30 Hz.

The C# language oriented objects and integrated development environment (IDE) Microsoft Visual Studio 2012 Express are used for the development of the acquisition software, processing and recording. This set up provides great advantages in the integration of libraries and components provided by the SDK when developing applications based on the Microsoft Windows Kinect® sensor as well as extensive documentation and code samples.

A program using MatLab® was used to process the recorded data of the position and orientation of segments. This can also do the graphical presentation and evaluate parameters of interest of the different registers that allow evaluating the proposed tool. An algorithm for calculating the angles of the joints of the lower limb was implemented. The angles of the joints of the lower limbs in the three anatomical planes for each recorded frame were obtained from the guidelines regarding the origin of coordinates provided by the SDK (Figure 1d.). Local segment coordinate systems are defined to evaluate the angles in each of the joints, as shown in Figure 3a [15].
Joint axis is defined to evaluate each articulation, 

\[ I_{\text{joint}} = \frac{k_{\text{proximal}} \times j_{\text{distal}}}{|k_{\text{proximal}} \times j_{\text{distal}}|} \]  

(1)

linking two segments: proximal and distal. For example, for knee joint, the versor \((i_{\text{proximal}})\) corresponds to the versor \((i_{\text{thigh}})\) and the versor \((k_{\text{distal}})\) to the versor \((k_{\text{leg}})\) and similarly for each joint [15].

Likewise, the axes of rotation of joints are defined as: flexion-extension occurring with respect to the medial-lateral proximal segment \((k_{\text{proximal}})\), internal-external rotation axis occurs relative to the longitudinal axis of the distal segment \((i_{\text{distal}})\) and the abduction-adduction is defined relative to the floating axis perpendicular to the axis of flexion-extension and internal-external rotation \((I_{\text{Joint}})\), see figure 3-b [15]. The anatomical joint angles are obtained.

\[ a_{\text{joint}} = \sin^{-1}[I_{\text{joint}} \cdot i_{\text{proximal}}] = \text{flexion angle (+)/extension (−)} \]  

(2)

\[ \beta_{\text{joint}} = \sin^{-1}[k_{\text{proximal}} \cdot i_{\text{distal}}] = \text{abduction angle(+)/adduction(−)} \]  

(3)

\[ \gamma_{\text{joint}} = \sin^{-1}[I_{\text{joint}} \cdot k_{\text{distal}}] = \text{internal rotation angle(+)/external(−)} \]  

(4)

2.2. Participants

The study was conducted through the registration of 30 participants (11 women and 19 men) who gave their informed consent; the average age is 25.53 ± 4.13 years, 27 right-dominant, 3 left-dominant, without knee injuries and 22 of the participants practiced amateur sports of some form. The average height is 1.73 ± 0.10 [m], and the weight is 73.62 ± 14.76 [kg].

2.3. Experimental set

Participants performed five different tasks, the first consisted on static position and the remaining four were pre-set movements. In the following sections the movements registered with software developed in this work and using the Microsoft Kinect that was described below. Three repetitions of each gesture were registered.

2.3.1. Standup posture: In the first record the subject is positioned in the capture area of the Microsoft Kinect. The acquisition volume was marked with white tape on the floor. Each participant was instructed to remain in a natural upright position for a few seconds while the recording was made.
2.3.2. *Free throw with jump*: 2.3.3. The participant was positioned in the acquisition volume of the Microsoft Kinect and makes a free throw of basket. participant was instructed to perform the exercise of jump and shot to hoops without race. The collection of data began with the participant standing and ended when returning to the start position.

2.3.3. *Free throw with jump and run*: In each record the participant must begin the movement outside the acquisition volume of Microsoft Kinect. The participant performed a race in the longitudinal direction of the axis of acquisition by 3-5 steps as fast as possible. When reaching the acquisition volume, the participant must stop abruptly and make the jump and shoot hoops, then cushion his fall and return to a standing position.

2.3.4. *Jump from a 30 cm high platform*: In this study, a platform of 30 cm high was used. The participant was positioned standing up on the platform in the center of the acquisition volume marked on the ground. The participant must do a running jump "Squat Jump". The record was made starting from the standing position on the platform by placing the legs at an equal distance shoulder-width, and then the participant had to make a leap moving his arms to get impulse. At the moment of falling over the front of the platform, he had to cushion his fall and return to the upright position. The recording of data was taken during the complete gesture.

2.3.5. *Single-Leg Squat*: The participant was at the acquisition volume and performed a squat supported on a lower limb meanwhile other limb remained straight forward, with the arms folded across the chest and hands resting on opposite shoulders. In the exercise, the participant performed squats lowering down as much as possible, doing five repetitions while keeping a balance and performing each squat every two seconds in a controlled manner. The movement on both lower limbs was captured with the developed system.

3. Results
This initial work presents the results and initial analysis of the data recorded by several tasks used in rehabilitation and sports are presented, which allow us to appreciate the value of the registration tool Microsoft Kinect® in its applicability to this type of field studies and in rehabilitation.

A static postural analysis of patients is important, considering the fact that it provides many clinical data that are useful for designing an effective treatment. This study evaluated the tendency to varus or valgus knee in a static standing posture and the differences between men and women. The varus-valgus angle average was obtained in a standing posture of the left and right knees of all participants. An analysis of these results shows that the use of this measurement system reveals that participants in a static position have a tendency to varus angle at knee. The average valgus-varus in men and women are presented in Table 1.

Table 1 presents the average population showing a slight varus angle at knee for both genders, showing a higher incidence in men. Dispersion occurs in small angular values, which is due to the variability between participants, thus it presents values close to the standard deviation values. It is believed that this men-women difference is because women have a physiologically wider pelvis, and therefore a greater Q angle compared to men. In other studies, it has been found that this difference is 2-4 degrees [16, 17] therefore expected to possess less varus angle. These results are consistent with those presented in Table 1.

| Left Knee                      | Right Knee                      |
|-------------------------------|---------------------------------|
| **Mean**                      | **Standard Deviation**          |
| varus (-)/valgus (+) in women | -1,60 ± 2,16                    |
| varus (-)/valgus (+) in men   | -2,98 ± 2,46                    |
Figure 4 shows, as an example, knee and hip angles of one of the records of a participant who did a free throw with jump that is usually performed during a basketball game. The peak knee flexion can be seen during the impulse and the landing after the free throw and also the asymmetry of the movement that is characteristic of each player. The participant can do advances with one leg or with the other, put one leg in front of the other or put both legs together to jump or tilt either side. To perform a first preliminary assessment, the peaks varus-valgus angle were calculated during impulse and landing phases. In order to evaluate these phases (impulse and landing), the knee rotation was used. This is because when the knee is extended there is no rotation due to a blockage at this joint (see Figure 45). Since a more detailed analysis of the gesture is not the aim of this study, results and preliminary assessments are presented only for illustrative purposes.

Figure 4. Knee and hip angle of one of the records of a free throw with jump in basketball.

Table 2 shows the average and standard deviation of varus-valgus knees peak values during the impulse and landing phases. It can also be observed the time difference between the occurrence of the flexion peak and the maximum angle of knee valgus-varus.

To make a quantitative analysis of valgus-varus motion in all records, we divided the qualified participants into the ones that did an internal rotation of the knee during a basketball shot and the others who did an external one, knowing that the two movements are linked and that the participants inherently make one of the two rotations when shooting. Peak angles of each record are shown in Figure 5: impulse and landing phases, and the rotation of the knee (internal or external). The distinction between internal or external rotation is made to distinguish whether the knee had-made a varus or valgus correlated movement. The external compartment knee injury is associated with valgus motion, then higher valgus angle amplitude, higher the risk of injury. It is expected that a further continuation of this study can bring a more complete analysis of this gesture.
Table 2. Varus-valgus knee average and standard deviation of angle peak values in a single throw.

|                          | Varus-valgus peak angle of impulse phase with knee internal rotation (°) | Varus-valgus peak angle of impulse phase with knee external rotation (°) | Varus-valgus peak angle of landing phase with knee internal rotation (°) | Varus-valgus peak angle of landing phase with knee external rotation (°) |
|--------------------------|--------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Mean                     | -6.99                                                                    | 3.82                                                                      | -8.90                                                                    | 2.76                                                                     |
| Standard Deviation       | 4.17                                                                     | 3.06                                                                      | 6.61                                                                     | 6.23                                                                     |

Figure 5. Peak angles of varus-valgus knees in impulse and landing phase in free throw with jump in basketball, separated by the type of knee rotation (internal or external).

Free throw with jump and run from a participant is shown in Figure 6 as an example. The flexion-extension angles, varus-valgus and internal-external rotation of the knee and hip of each lower limb were plotted. The flexion peaks corresponding to the impulse and landing phases can be seen. In addition, all participants that performed a jump from a platform and five repetitions of the single leg squat were evaluated, in both instances three sets of each record. For length purposes, these data are not presented in this study, but the quality of measuring 3D kinematics is the same as shown in Figure 6.
4. Discussion and Conclusions
The system developed in this work is a simple, portable tool designed to on-field appliance, using Microsoft Kinect® to record and analyze some common movements in sports and rehabilitation. 3D kinematics algorithms from data available using the Software Development Kit (SDK) were developed. Records of the position and orientation of segments were used in a program using MatLab®. This program allows the processing of data, make graphical presentation and evaluate parameters of interest of the different registers, which in turn show the effectiveness of the proposed tool. It also provides visual feedback when using its software during rehabilitation, which serves to assess the treatment progress and can be used as feedback to the patient.

In order to show the usefulness of the proposed system, measurements of 30 participants of 5 different protocol of records used in sports training and rehabilitation were made. Relevant results showing the capture quality and a preliminary analysis of the obtained results in a standing posture and free throw with jump tasks were done. Due to the limited length of this study, only a record of free throw with jump and run is presented, with the omission of registers of jump from a platform of 30 cm high and registers of single leg squat. However, it is emphasized that the quality of the measurements made with Microsoft Kinect® for the five types of records used as a first test of the device allow proper quantification of movement. Also, a future study using this proposed tool could show a comparison of simultaneous captures of Microsoft Kinect® with commercial equipment available in our laboratory. In this context, a comparison can be made between the two systems, and then the Microsoft Kinect® can be definitely validated for on-field. In summary, the use of the Microsoft Kinect® for field use is of better value in instances when the use of a commercial laboratory is not effective due to several operational reasons.

5. References
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