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Therapeutic Motion Analysis of Lower Limbs Using Kinovea

C. H. Guzmán-Valdivia, A. Blanco-Ortega, M.A. Oliver-Salazar, J.L. Carrera-Escobedo

Abstract— Goniometry has been widely used to analyze human motion. The goniometer is a tool to measure the angular change on systems of a single degree of freedom. However, it is inappropriate to detect movements with multiple degrees of freedom. Kinovea is a free software application for the analysis, comparison and evaluation of movement. Generally, used to evaluate the progress of an athlete in training. Many studies in the literature have proposed solutions for measuring combined movements, especially in lower limbs. In this paper, we discuss the possibility to use Kinovea in rehabilitation movements for lower limbs. We used a webcam to record the movement of patient's leg. The detection and analysis was carry out using Kinovea with position markers to measure angular positions of lower limbs. To find the angle of the hip and knee, a mathematical model based on a robot of two degrees of freedom was proposed. The results of position, velocity and acceleration for ankle and knee was presented in a XY plane. In addition, the angular measure of hip and knee was obtained using the inverse kinematics of a 2RR robot.

Index Terms— Goniometry, Image Motion Analysis, Kinovea, Lower Limbs, Patient Rehabilitation.

I. INTRODUCTION

Rehabilitation aims to restore the movement of a extremity after an illness or traumatic incident. Some injuries can cause severe pain and lack of movement to the patient if these are not treat on time [1-2]. When a person needs a rehabilitation program to return to their daily activities, it is better to attend as soon as possible. Goniometry is the technique of measuring angles and aims to assess the position of a joint in space [3]. It can be divided in applications for orthopedics, traumatology and rehabilitation. In rehabilitation, is used to determine the starting point of treatment, assess their progression over time, motivate the patient, establish a prognosis, modify treatment or give an end point.

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César Humberto Guzmán Valdivia, Department of Mechatronics Engineering, University Polytechnic of Zacatecas, Fresnillo, Zacatecas, México.

Andrés Blanco Ortega, Department of Mechatronics Engineering, National Center for Research and Technological Development, Cuernavaca, Morelos, México.

Marco Antonio Oliver Salazar, Department of Mechatronics Engineering, National Center for Research and Technological Development, Cuernavaca, Morelos, México.

José Luís Carrera Escobedo, Department of Mechatronics Engineering, University Polytechnic of Zacatecas, Fresnillo, Zacatecas, México.

The goniometer is the main instrument used in physiotherapy and rehabilitation to measure angles in the musculoskeletal system, see Fig. 1. It is practical, economical, portable and easy to use. Angular measurements using a goniometer in therapeutic treatments are very simple when it comes to a single degree of freedom. However, sometimes it is necessary to measure rapid movements of several degrees of freedom or combined movements, e.g., shoulder, wrist, hip, etc. Table 1 shows a comparison of different body parts and their relation with combined movements.

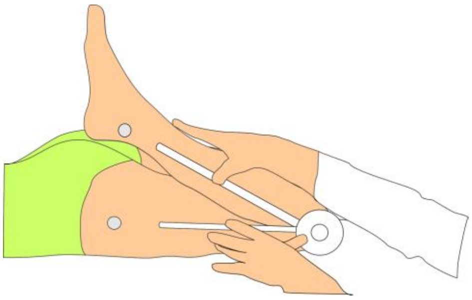

Fig. 1. Physiotherapist measuring knee angle.

Particularly, rehabilitation movements of lower limbs can be divided into hip and knee [4]. The basic movements of hip are flexion/extension and abduction/adduction. The basic movements of knee are flexion/extension. Fig. 2 shows the maximum range of motion (ROM) for hip and knee.

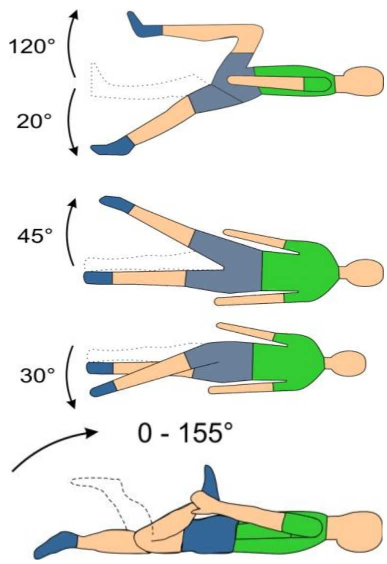

Fig. 2. Basic movements of hip and knee and range of motion

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Table 1. Simple and combined movements of the human body

Body Part	DoF	Movements	
Shoulder	5	Abduction/Flexion/Extension/Internal Rotation/External Rotation	Combined
Elbow	2	Flexion/Extension	Simple
Forearm	2	Pronation/Supination	Simple
Wrist	4	Flexion/Extension/Abduction/Adduction	Combined
Hip	6	Flexion/Extension/Abduction/Adduction/Internal Rotation/External Rotation	Combined
Knee	2	Flexion/Extension	Simple
Ankle/foot	4	Dorsiflexion/Plantarflexion/Inversion/Eversion	Combined
Lumbar Spine	2	Flexion/Extension	Simple

Many investigations have demonstrated the use of new devices to measure angular position of an extremity of the human body. The lower limbs are the most common part of the body who needs measurement and evaluation due to disabilities. The traditional measurement system consist of one acceleration sensor fixed to the patient's leg [5-8]. This kind of method needs a computer, electronic boards and some knowledge in data acquisition. The disadvantage is the difficulty to obtain angular measures from the leg without a reference system. In another study the measurement of movements using the Wii Remote with infrared (IR) sensors was demonstrated [9]. The system consists of a table, a glove and IR LEDs. This kind of system uses a XY table to set an origin. The movement is registered through the reflection of IR LEDS and it is capture with the IR camera of the Wii Remote.

In a similar contribution, Spencer used the Wii Remote's accelerometer to measure the combined movements of the wrist [10]. The system consists of a glove attached to the patient's hand and is capable of measuring flexion/extension and abduction/adduction of the wrist. Later, a haptic joystick was proposed by Celik to improve the quality of measurements for therapeutic robots [11]. The study was compared with clinical measurements and robotic movements. Another studies using control techniques have been proposed to analyze, generate and detect movement [12-16]. Basically, this kind of systems needs hardware to acquire electrical signals and later implement a control law. Loconsole used a webcam to detect the human arm motion [17]. The experiment places a sit person in a chair to detect the movements. Finally, Shin developed a training system with real-time measurements for lower limbs [18]. The system consists of two sensors fixed in the leg with a graphical user interface (GUI).

Examples of analog [19] and digital goniometers [20] are very common in market. Generally, measurement systems for physiotherapy require expensive devices. An ideal measuring system is one that can be easy to use without the need to utilize sensors attached to the body and cheap.

Kinovea is a free software application for the analysis, comparison and evaluation of sports and training, especially suitable for physical education teachers and coaches [21]. Some advantages of this program are: observation, measurement, comparison of videos, etc. Table 2 shows a comparison between actual systems for the detection and motion analysis and Kinovea. The main advantage of Kinovea is the easy of use and the analysis without use physical sensors. In addition, it is free and can be used for measurements in a rehabilitation process. The aim of this paper is to evaluate the performance of Kinovea for detection and analysis of movement focused on lower limbs rehabilitation. The paper is structured as follows: Section II shows the methods and materials used for this experiment. Section III shows the results. Section IV discusses the results. Finally, Section V presents the conclusions and future work.

II. METHODS AND MATERIALS

Fig. 4 shows a detailed block diagram of the proposed method. The first step is to set the webcam and the person whom will be on a bed. Second step, using Kinovea application is possible record the moves of the leg and save them. Once the video has been recorded, now it is time to add tracking markers for the analysis of movement, as described in section II.A.

Table 2. Comparison between devices in literature and Kinovea for movement analysis

Features	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	Kinovea
Sensors	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N
Hardware	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N
Software	Y	Y	Y	Y	N	N	Y	N	N	N	N	Y	Y	Y	N	Y	Y
One DoF	Y	N	N	N	N	N	N	Y	N	N	N	N	N	N	Y	Y	N
Multiple DoF	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	Y

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Control law	N	N	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	N	N	N	N
Easy of use	N	N	N	N	Y	Y	Y	N	N	N	N	N	N	Y	Y	Y	Y

The video can be manipulated to obtain measures and angular positions of the leg. Furthermore, it can be possible export the data to a spreadsheet with the results of motion analysis. The angles of hip and knee can be obtained using a robot model of two degrees of freedom. In this particular case, an inverse kinematic analysis was proposed to find the angles, as described in Section II.B.

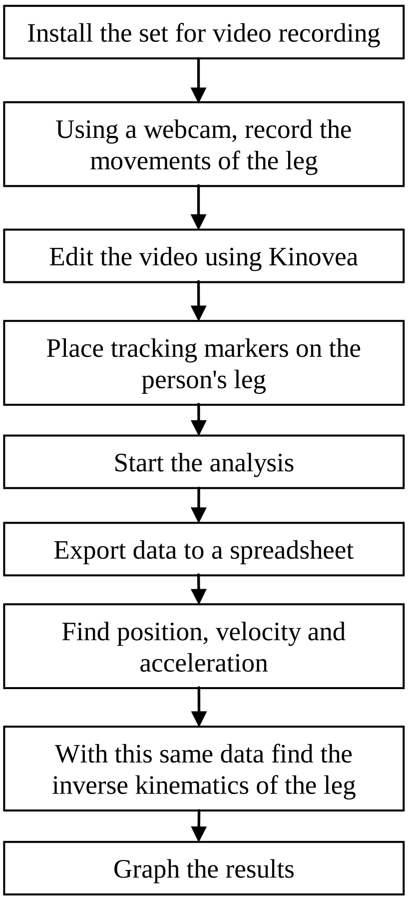

Fig. 4. Block diagram of the solution.

A. *Detection and Measurement of Movement of Lower Limbs*

For this experiment, is necessary to have a computer and a webcam to record the movement of the patient. Fig. 5 shows a sketch of the positioning of the camera, the patient and the physiotherapist.

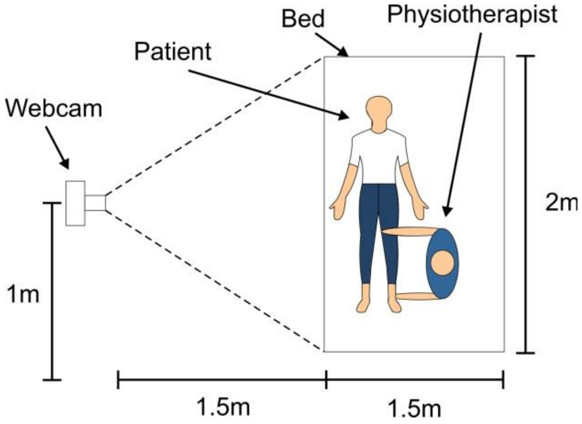

Fig. 5. Positioning of the webcam and the patient.

Detection and tracking of movements is achieved by the insertion of tracking markers, see Fig. 6. The detection process starts when the user places the tracking marker, later, the coordinate system is detected and it is possible to start with the analysis.

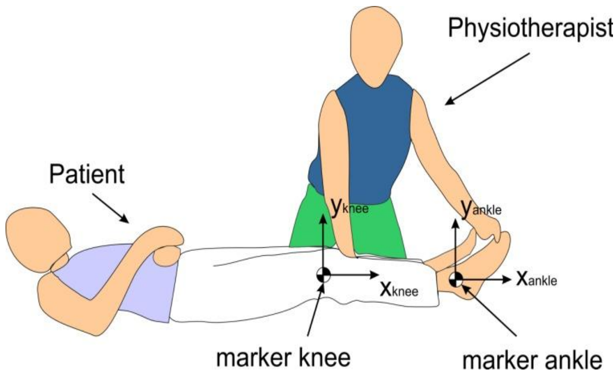

Fig. 6. Inserting tracking markers in Kinovea.

B. *Analysis of Leg Movement*

Kinematics describes the spatial movement of the robot and the end effector according to the positions of each joint [22]. Fig. 7 shows the geometric representation of the 2RR robot. In this particular study, the leg was modeled as a robotic system of two degrees of freedom.

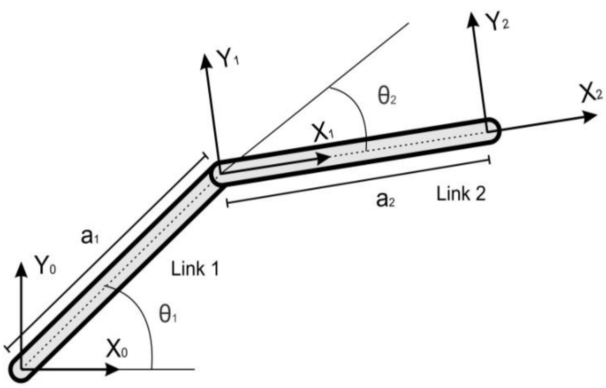

Fig. 7. 2RR Robot.

Table 3 presents the geometric parameters of the robot according to the Denavit-Hartenberg convention [23]. In this table, *i* represents the number of the joint, a_i represents the distance along the axis x_i, α_i refers to the angle between the axes z_i and z_{i+1}, d_i represents the distance between the axes and finally θ_i represents angle to the axis x_i and x_{i+1}.

Table 3.- Geometric parameters of the leg

i	a_i	α_i	d_i	θ_i
1	a_2	0	0	θ_1
2	a_3	0	0	θ_2

The direct kinematics allows calculate the position and orientation of the leg based on their joint angles [23]. To find the direct kinematics is necessary to calculate the homogeneous transformation matrix $^{i-1}T_i$ of each joint using (1).

$$^{i-1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

To obtain the direct kinematics for the leg is necessary to multiply the following matrices in the following order:

$$^0T_4 = {}^0T_1\, {}^1T_2\, {}^2T_3\, {}^3T_4 \quad (2)$$

Thus the direct kinematics of the robot is:

$$Px = a_1 C\theta_2 + a_2 C(\theta_2 + \theta_3) \quad (3)$$

$$Py = a_1 S\theta_2 + a_2 S(\theta_2 + \theta_3) \quad (4)$$

On the other hand, the inverse kinematics can determine the joint movements to bring the end effector to a desired Cartesian position [23]. The solution of inverse kinematics is essential to control the end-effector trajectories. Using (3) and (4) and after several algebraic manipulations the inverse kinematics of the robot is:

$$\theta_3 = Acos\left(\frac{{P_x}^2 + {P_y}^2 - a_2^2 - a_3^2}{2a_2a_3}\right) \quad (5)$$

$$\theta_2 = Atan\left(\frac{P_y}{{P_x}^2}\right) - Atan\left(\frac{\sqrt{{P_x}^2 + {P_y}^2 + a_2^2 - a_3^2 C_3^2}}{a_2 + a_3 C_3}\right) \quad (6)$$

For more details about the inverse kinematics of the robot see [24].

III. RESULTS AND DISCUSSION

A. Detecting the position of the leg

The Kinovea detection system can only start if the program knows the measures of the lower limbs. For this reason is necessary to measure the distance between each limb of the patient. Fig. 8 shows a picture with the measurement of the leg. The distance between the hip and knee is 0.5m and from knee to ankle is 0.45m.

Using the same procedure to measure distances between limbs is possible to measure positions respective to a origin. Fig. 9 shows the insertion of four lines to measure the distance on each limb. The first one is from hip to knee (0.5m), the second one is from knee to ankle (0.45m), the third one is from ankle to origin (0.4m) and the last one is from origin to hip (0.9m). In a similar way, it is possible to measure the angular position of the limbs. Fig. 10 shows the angular measurement of hip and knee. In this result, the hip reached 120° degrees in flexion and knee reached 110° in flexion.

Fig. 11 shows the insertion of tracking markers for the detection and analysis of the lower limbs movements.

Fig. 8. Measurement of the leg.

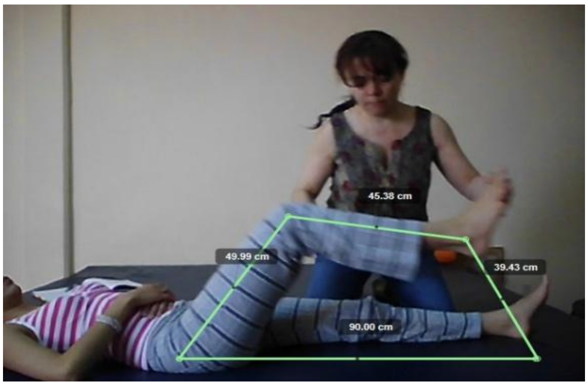

Fig. 9. Measured relative to a reference point.

Fig. 10. Measurement of each limb.

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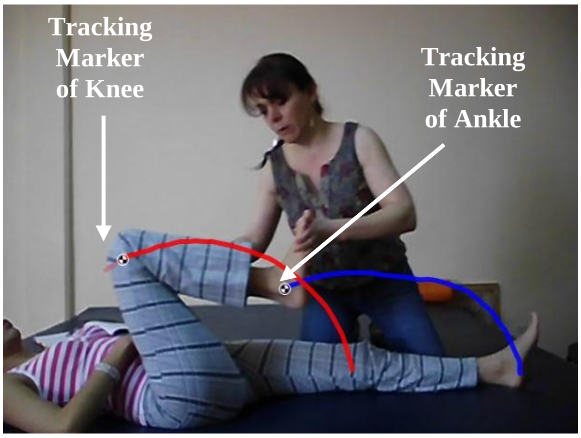

Fig. 11. Tracking markers.

B. Analyzing the position of the leg

This section presents the results of the application of Kinovea focused on rehabilitation movements for lower limbs. Some therapeutic movements of displacement and velocity needs a complete analysis for the physiotherapist. The displacement and velocity of the lower limbs using tracking markers was obtained. Fig. 12 shows the tracking of the ankle motion. The movements are presented in a XY plane. The displacement for the ankle in the X axe ranges from 0 to -0.62 m. Similarly, the displacement for the ankle in the Y axe ranges from 0 to 0.2 m. The total time of the motion capture was 1.25 seconds.

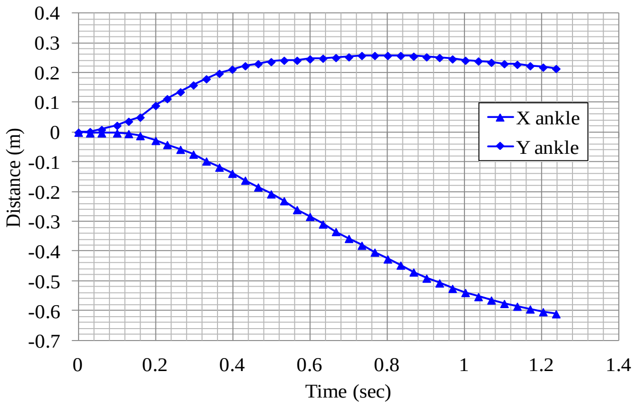

Fig. 12. Ankle displacement with respect to the XY plane

Using the same methodology, Fig. 13 shows the tracking of the knee motion. The movements are also presented in a XY plane. The displacement for the knee in the X axe ranges from 0 to -0.6 m. The displacement for the knee in the Y axe ranges from 0 to 0.3 m. With this results is possible calculate the workspace and the maximum limit of the movement for this particular therapy. As it is mentioned before, this type of analysis is fast and simple to perform, i.e., for an inexperienced user should not take more than 10 minutes to do this, because Kinovea is very intuitive.

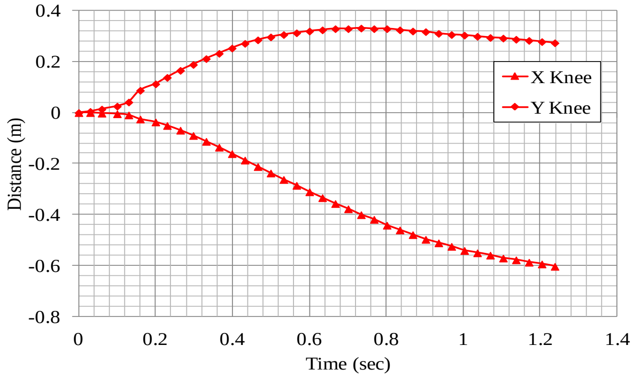

Fig. 13. Knee displacement with respect to the XY plane

Fig. 14 shows a comparison between the movement performed by the therapist in Fig. 11 and the analysis obtained using Kinovea. This two graphs shows that there is an excellent trajectory tracking. Furthermore, the knee and ankle motion can be expressed in the same graph for easy of appreciation of the results.

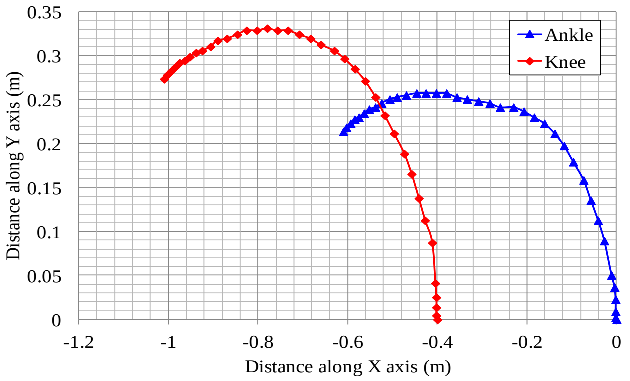

Fig. 14. Leg movement induced by the physiotherapist

Using the previous results of position obtained in Figs. 12 and 13 is possible to know the velocity of the leg. It is important to measure the maximum velocity of each therapy to assess the progress of the patient. This kind of results are handy in the design process of a new therapeutic robot. In this particular experiment, the subject was a healthy patient but with real movements. In general, some movements in rehabilitation are very fast to perform.

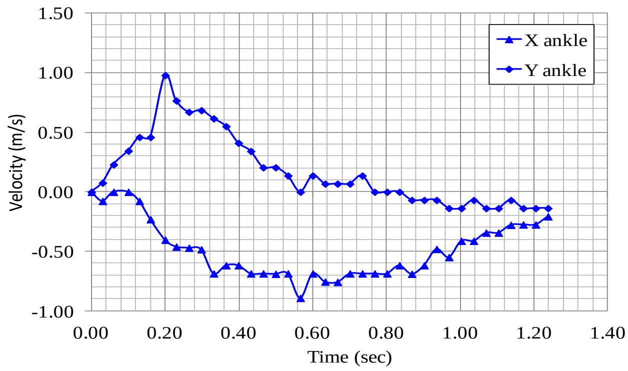

Fig. 15. Ankle speed with respect to the XY plane

That is why, the therapies have to controlled movements for avoid a damage the patient. Figs. 15 and 16 shows the velocity

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analysis of the knee and ankle. According to the measurements performed in Kinovea the maximum speed reached by the physiotherapist was 1 m / s applied to the limbs. On the other hand, we analyzed the behavior of the acceleration of the system. Figs. 18 and 19 shows the behavior of acceleration. This type of analysis can be compared with systems using acceleration sensors to detect movement of the lower limbs.

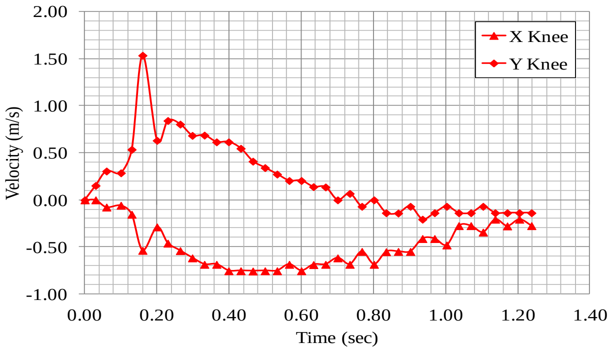

Fig. 16. Knee speed with respect to the XY plane

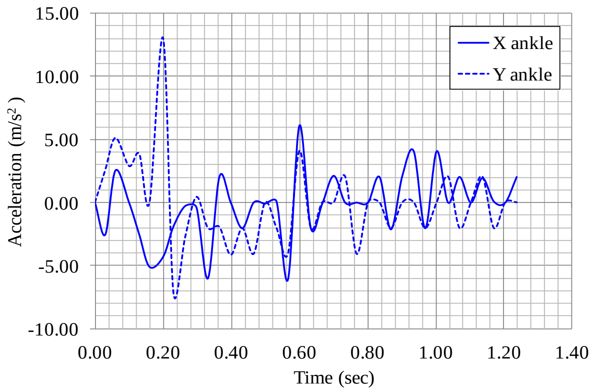

Fig. 17. Acceleration of the ankle with respect to the XY plane

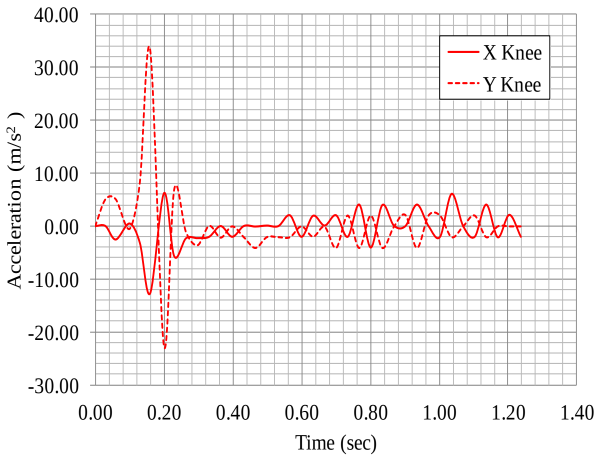

Fig.18. A Acceleration of the knee with respect to the XY plane

The practical application of this research can be used for detection and trajectory planning of robots with various degrees of freedom for lower limbs rehabilitation. For example this kind of results can be used in [25]. Using the coordinates generated in Figs. 12 and 13 is possible to find the movements for a robot. The equations (6) and (7) can calculate the angular position of the hip and knee. Fig. 18 shows the results of the inverse kinematics of the leg. Where θ1 correspond to hip angle that goes from 0° to 90° and θ2 correspond to knee angle that goes from 0° to -130°

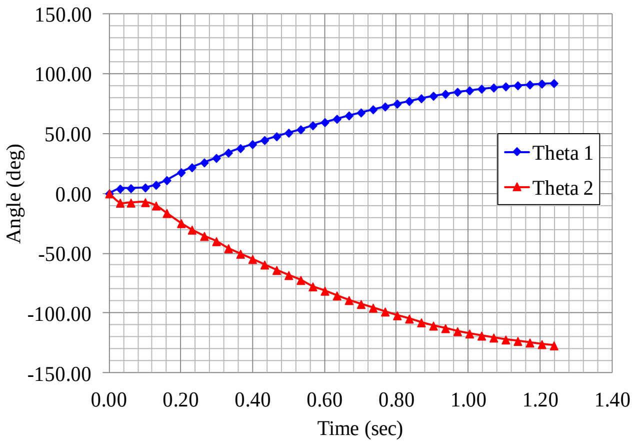

Fig. 18. Angular movements of hip and knee

IV. CONCLUSION AND FUTURE WORK

In this paper, a therapeutic motion analysis for the lower limbs rehabilitation using Kinovea was presented. The motion analysis was performed mainly using computational tools instead of traditional sensors and special hardware. The position, velocity and acceleration in a rehabilitation for lower limbs was obtained through a new proposed method. The evaluation of the software and the test performed focused in the rehabilitation of lower limbs. For this particular study a healthy patient was proposed, but this work is not limited to make the same experiments for the upper limbs and the inclusion of a patient with stroke.

The main purpose in rehabilitation robotics is simply to facilitate the application of techniques for the physiotherapist, we do not intend to replace the experience and knowledge of the experts. The advantages demonstrated in this article can be an starting point to analyze fast systems of multiple degrees of freedom for rehabilitation purposes. Exist different systems for gait training that can need a continuous analysis of the patient for assess the progress in a passive rehabilitation program.

Finally, this kind of systems have several advantages the principal is their cost. The motion detection using Kinovea allows evaluate the rehabilitation progress of the patient for achieve the best recovery. For the improvement of this work is necessary the implementation of the generated trajectories in a prototype to evaluate the motion. In addition, a comparison of the results obtained in this study with a prototype can be carried out as future works.

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César Humberto Guzmán Valdivia, was born in Fresnillo, Zacatecas, México in the year of 1986. He received B.Sc. degree in Mechatronics Engineer from the University Polytechnic of Zacatecas (UPZ), México in 2007. He received M.Sc. degree in Mechatronics Engineering with specialization in Robotics and Process Automation from National Center for Research and Technological Development (CENIDET), México in 2010. Currently, he is a student in the PhD program in Mechatronics Engineering Sciences at the National Center for Research and Technological Development in México.

Andrés Blanco Ortega, was born in Taxco, Guerrero, México in the year of 1971. He received B.Sc. degree in Electromechanical Engineer from Zacatepec Institute of Technology, México in 1995. He received M.Sc. degree in Mechanical Engineering with specialization in design from National Center for Research and Technological Development, México in 2001 and PhD degree in Electrical Engineering from Center for Research and Advanced Studies IPN, México in 2005. Currently, he is a professor in the Department of Mechatronics Engineering, CENIDET.

Marco Antonio Oliver Salazar, received B.Sc. degree in Systems Engineer Electrical and Electronics from Universidad Anahuac, México in 1983. He received M.Sc. degree in Control and Information Technology from University of Manchester Institute of Science and Technology (UMIST), UK in 1989 and a PhD in Control by the Department of Automatic Control and Systems Engineering, University of Sheffield, UK in 1994. Currently, he is a professor in the Department of Mechatronics Engineering, CENIDET.

José Luís Carrera Escobedo, was born in Fresnillo, Zacatecas, México in the year of 1981. He received B.Sc. degree in Mechanical Engineer from the Faculty of Mechanical Engineering at the Autonomous University of Zacatecas, México in 2003. He received M.Sc. degree in Mechanical Engineering from University FIMEE Guanajuato in 2006 and a Ph.D. in Mechanical Engineering from the Medici of the University of Guanajuato in 2011. Currently, he is a professor in the Department of Mechatronics Engineering, UPZ.