- Strategies- teams were successful if they started a game with a set strategy but were able to adapt during the match. It was interesting to see Poland or Ukraine, an experienced and well-drilled team, lose their focus after Croatia or Sweden.
- Goalkeepers-it is fair to say that goalkeepers in this year's European Championship were not very consistent, as excellent performances were followed by inexplicable errors. They not only struggled to boss their penalty area and communicate with their team-mates but also experienced difficulties with shots from long range. Many of these errors led directly to goals.

It was also interesting to note that the best teams conceded very few fouls-if any- around their own penalty area to avoid giving away free kiks in dangerous position.

There were two tactics to gain or regain possession.

a) Teams such as Poland, Portugal, Italy lay in wait in their own half of the pitch before launching quick counter-attacks to catch opponents off guard. Some teams defended too deep, however, which meant that their defenders could be outpaced.

b) Other teams such as Spain, Germany aggressively tried to win the ball back in the opponent's half of the pitch or close to the halfway line at the latest. This tactic prevented opponents from building attacks as they were not given time to construct moves.

Balls played in behind the defence from the centre created a significant number of goals (19) and chances, mainly because the "weaker" teams did not stagger their defence, which meant that they were easier to bypass. Creative wing play was another way to create space and goalscoring opportunities. Teams who used this latter tactic needed good dribblers who were able to get to the goal line before cutting the ball back for advancing team-mates. Congested penalty areas meant that traditional, high crosses were less successful. Long diagonal passes were another option for pulling opposition defences out of position.

Successful teams were also able to switch quickly between defence and attack. Counter-attacks were successful if teams could bypass the midfield quickly and make accurate, well-timed final passes. Teams such as Germany, Spain, the Netherlands were all specialists in this regard. These teams passesd the ball around quickly, trying to take as few passes as possible before taking out the opposition defence. If they lost the ball, they put immediate pressure on the man in possession. By doing so, they hopped to force their opponents into losing possession, which they could then exploit as the opponents would still be on the front foot. It was interesting to note that in the second and third phases of tournament, far more goals were scored on the counter-attack, which was due to the teams being more attack-minded.

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INVERSE DYNAMIC ANALYSIS OF THE HUMAN LOWER LIMBS DURING GAIT

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Abstract

The simulation of musculoskeletal models of the human's body provides critical information about the locomotion mechanism. This information can be used to predict abnormalities and to provide mechanical solution at different levels of human body bio-mechanical structure: muscle system, joint system, bone system etc.

The aim of this paper is to analyze a Multibody system representing the musculoskeletal system of the lower limb in order to determine forces and moments of forces. To achieve this, we have applied an inverse dynamic analysis to an open source kinematic model from OpenSim aiming to calculate the joint's reaction during gait.

Keywords: *biomechanics, inverse dynamics, Multibody System, kinematics, sport, lower limb, gait analyze, OpenSim*

1. INTRODUCTION

Human gait is the action performed by musculoskeletal locomotion system. This action can be defined by an alternate sinuous movement of different kinematic elements resulting bipedal forward propulsion of the human center of mass. The gait action [1] is characterized by differences in limb movement patterns, overall velocity, forces, kinetic and potential energy cycles, and changes in the contact with the surface [3].

The simulations of musculoskeletal models are becoming an important part in analyzing the biomechanics of the human body over a wide range of activities: running, sports, walking, orthostatic position and having an important role in understanding the mechanical principles [6] and determining some possible abnormalities [5].

These simulations have also the role of estimating the parameters that are difficult or impossible to measure in vivo, such as joint and tissue loadings, muscle fiber and/or tendon forces and power generation, and elastic energy storage and return in tendons [4].

2. METHOD

In order to perform this study we have used a model with 7 degrees of freedom, which characterizes the kinematics of the lower limbs of the human body. The proposed model consists of the following kinematic parts: pelvis, femur, tibia, patella, talus, calcaneus, and toe.

In order to estimate the ground reaction in the joints, first we have made an inverse dynamic analysis. The inverse dynamic analyze is a method for determining the forces and moment of forces based on the kinematics (generalized positions, velocities, and accelerations) [2] of a body (fig. 1, 2, 3, 4) and the body's inertial properties [8] (table 1).

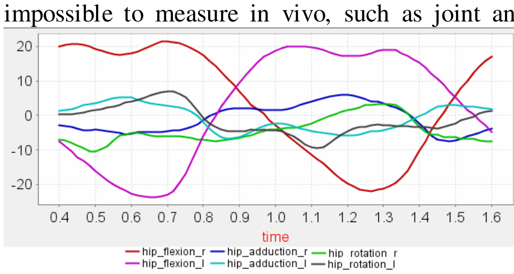

Fig. 1 Hip biomechanics

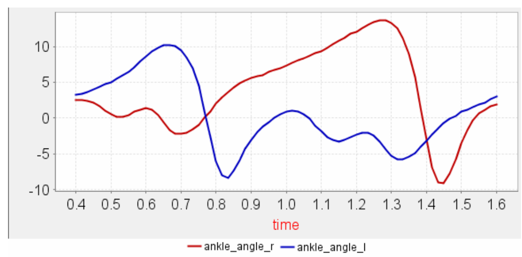

Fig. 2 Ankle biomechanics

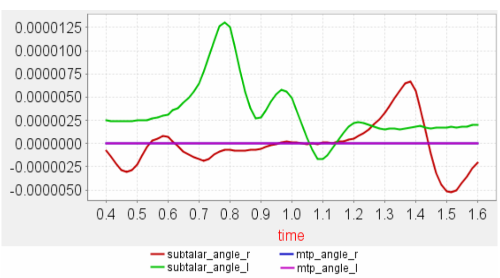

Fig. 3 Foot biomechanics

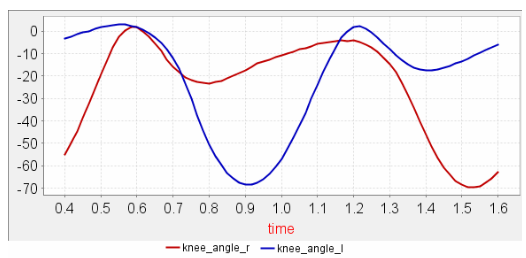

Figure 4 Knee biomechanics

Table 1 Inertial properties

Kinematic element	Mass	Moments of inertia		
		xx	yy	zz
Pelvis	11.777	0.1028	0.0871	0.0579
Femur	93.014	0.1339	0.0351	0.1412
Tibia	37.075	0.0504	0.0051	0.0511
Patella	0.0862	0.00000287	0.00001311	0.00001311
Talus	0.1000	0.0010	0.0010	0.0010
Calcaneus	1.250	0.0014	0.0039	0.0041
Toe	0.2166	0.0001	0.0002	0.0010

In order to calculate the classical equation of motion (1) for a model, we have used the inverse dynamic tool from OpenSim (fig. 5) for a known motion (fig. 1, 2, 3, 4).

The classical equation of motion [10] can be expressed as follows:

$$M(q)\ddot{q} + C(q,\dot{q}) + G(q) = \tau \qquad (1)$$

where:

$q, \dot{q}, \ddot{q} \in R^N$ is the vectors of generalized position, velocities and accelerations;
$M(q) \in R^{NxN}$ is the system mass matrix;
$C(q, \dot{q}) \in R^N$ is the vector of Coriolis and centrifugal forces;
$G(q) \in R^N$ is the vector of gravitational forces;
$\tau \in R^N$ is the vector of generalized forces;
N is the degree of freedom (DOF).

Furthermore we have optimized the kinematic model using the Static Optimization Tool provided by OpenSim software. This tool uses the input motion for the unknown generalized forces (e.g., joint torques, joint reaction forces) (fig. 6, 7, 8) ubjected to one of the following muscle activation conditions (2) or (3).

a) Constrained by force – length- velocity properties

$$\sum_{m=1}^{nm} \left[a_m f\left(F_m^0, l_m, v_m\right)\right] r_{m,j} = \tau_j \qquad (2)$$

Or

b) Ideal force generators

$$\sum_{m=1}^{nm} \left(a_m, F_m^0\right) r_{m,j} = \tau_j \qquad (3)$$

Nm is the number of muscles in the model;
a_m is the activation level of muscle *m* at a discrete time step;
F_m^0 is the maximum isometric force;
l_m is the length;
v_m is the velocity;
$f\left(F_m^o, l_m, v_m\right)$ is the force, length, velocity surface;
$r_{m,j}$ is the moment arm about the *j* joint axis;
τ_j is the generalized force acting about the *j* joint axis [9].

3. RESULTS

The ground reaction forces on the hip joint, knee joint, and ankle joint generated during waking are shown in fig. 6, 7 and 8. The inverse dynamic analyze and the static optimization has been applied on a open source model with a input known motion (fig. 5).

Associating the 7 phases (fig. 5) captured during the motion of the kinematic model with the joint reaction data, we were able to observe how the ground reacts to the human gait, in the lower limbs. In order to estimate the ground reaction forces, we have conducted a parallel study between the left and right lower limb. This way we can notice that for a given time the joint reaction components (xyz) are alternating.

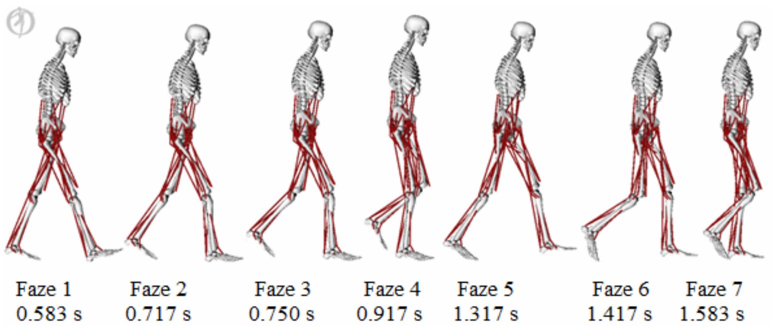

Fig. 5 Gait model phases

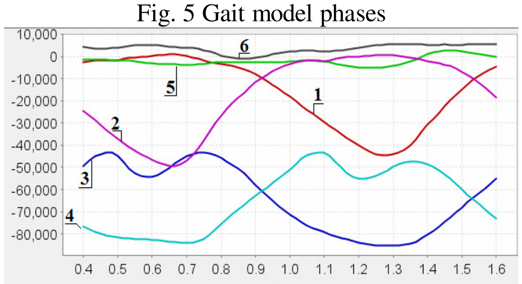

Fig. 6 The hip joint reaction force

In fig.6, the ground reaction forces are as follows:

(1) The X component of the ground reaction force between the hip and the right femur;
(2)The X component of the ground reaction force between the left hip and the left femur;
(3)The Y component of the ground reaction force between the right hip and the right femur;
(4) The Y component of the ground reaction force between the left hip and the left femur;
(5)The Z component of the ground reaction force between the right hip and the right femur;

(6)The Z component of the ground reaction force between the left hip and the left femur.

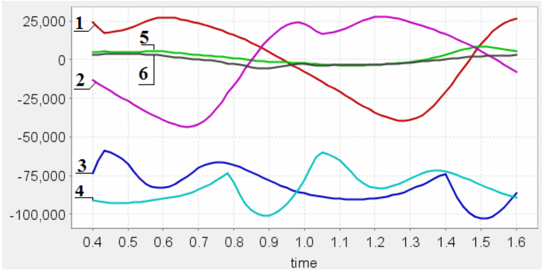

Fig. 7 The knee joint reaction force

In fig.7, the ground reaction forces are as follows:

(1) The X componentof the ground reaction force between the right knee and the right tibia;
(2)The X component of the ground reaction force between the left knee and the left tibia;
(3)The Y component of the ground reaction force between the right knee and the right tibia;
(4) The Y component of the ground reaction force between the left knee and the left tibia;
(5)The Z component of the ground reaction force between the right knee and the right tibia;
(6)The Z component of the ground reaction force between the left knee and the left tibia

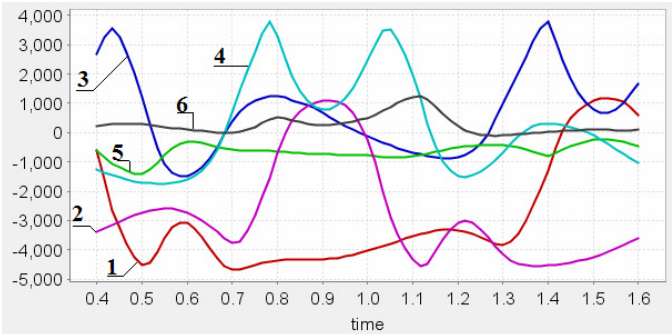

Fig. 8 The ankle joint reaction force

In fig.8, the ground reaction forces are as follows:

(1) The X component of the ground reaction force between the ankle knee and the right talus;
(2)The X component of the ground reaction force between the ankle knee and the left talus;
(3)The Y component of the ground reaction force between the ankle knee and the right talus;
(4) The Y component of the ground reaction force between the ankle knee and the left talus;
(5)The Z component of the ground reaction force between the ankle knee and the right talus;
(6)The Z component of the ground reaction force between the ankle knee and the left talus.

4. CONCLUSION

The musculoskeletal models simulation of the body, based on numerical data collected from video captured system, are able to provide critical information that can't be measured in vivo (joint and tissue loading, muscle fibre and/or tendon force and power generation, and elastic energy storage and return in tendons) about the human body dynamics.

In this paper we have emphasized a method for determining these characteristics using an open source program computer software and using a model of the human gait.

Acknowledgments

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KINEMATIC ANALYSIS OF THE LOWER LIMB DURING GAIT

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Abstract
The aim of this paper is to describe the relationship between acceleration and position of the kinematic elements of lower limb model during gait. The linear kinematic analysis of the human lower limb during gait has been studied using an open source kinematic model from OpenSim.
Keywords: *gait, kinematic analysis, acceleration, position, lower limb*

1. INTRODUCTION

The human gait can be defined theoretical by an alternate sinuous movement of different kinematic elements of the locomotors system. Injuries or abnormalities of the locomotion system can cause gait asymmetry. Human gait performed by a healthy subject is nearby symmetrical with insignificant deviation [4].

The effects of this deviation can be caused by differences in gait phases, stance time and swing time [5], differences in ground reaction [1], [2] and differences in the range of motion [6], [7].

Therefore for estimating this deviation researchers have used musculoskeletal models of the human's body based on numerical data from motion captured systems [3], in order to calculate position, trajectories, velocities, accelerations, and data which are impossible to measure in vivo, such as: muscle fiber power generation and tendon force, joint loadings, elastic energy storage and return in tendons, etc.

2. METHODS

In order to conduct the kinematic analyze we have used an open source kinematic model provided by OpenSim, which represents the human lower limb. This model comprises the following kinematic elements: pelvis, femur, tibia, fibula, talus, calcaneus, and toe bone.

The inertial properties and the masses of the kinematic elements are listed in table 1. The following joints connect the elements of the bio-mechanical structure:

- The hip joint is a ball and socket joint with 3 degrees of freedom:

1. A flexion with a range of 90^0 (fig. 1.d)/extension with a range of -20^0 (fig. 1.c), in the sagittal plane (xoy);
2. An adduction with a range of 10^0 (fig. 1.b)/abduction with a range of -40^0 (fig. 1.a), in the frontal plane (yoz);
3. An internal rotation with a range of 40^0(fig. 1.f) and external rotation with a range of -40^0 (fig. 1.e), in the transversal plane (xoz);

- The knee joint is a hinge joint with 1 degree of freedom: extension (fig. 1.g)/flexion (fig. 1.h), in the sagittal plane (xoy);
- The ankle joint is modeled as a revolute joint between the tibia and the talus, and is has 1 degree of freedom: dorsi-flexion (fig. 1.i) and plantar flexion (fig. 1.j), in the sagittal plane (xoy).