Advanced Technologies in Biomechanics Investigations for the Analysis of Human Behaviour in Working Activities

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1. Introduction

The analysis of the human behavior during performing working activities represents at this moment a huge importance domain in obtaining performances and assuring occupational comfort.

Thus the behavioral analyses are oriented towards determinations upon the bipodal posture, normal gait with or without weights carried by the human subject and not last upon the human body motions required for performing different handlings or actions in working activities.

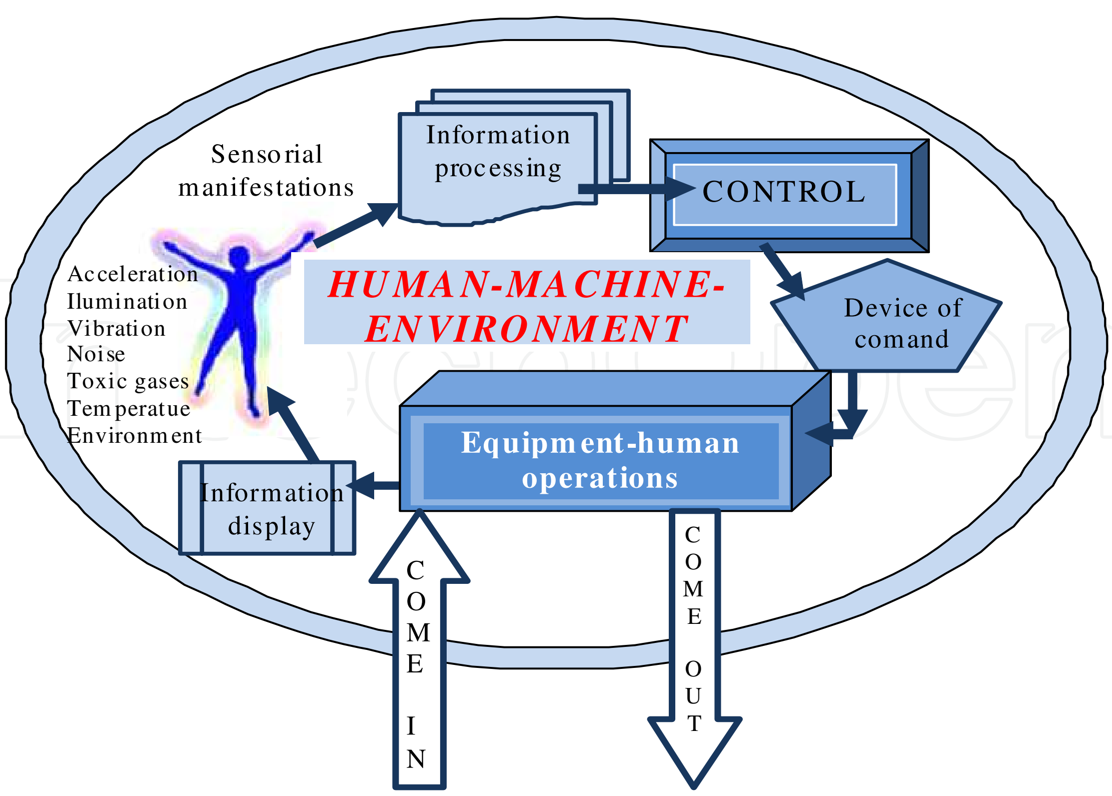


Fig. 1. Structural diagram of the human-machine-environment system

In these behavioral analyses we adopted the concept of human-machine-environment to be used in a unitary way and to be able to consider all the aspects connected to the sources of influence, ways of interaction and obtaining sensorial and decisional responses.
At the same time it is obvious there are three subsystems among which there are interactions, their resultant influencing the quality and quantity of human performed work.
The human subsystem is described by the information receiving and processing functions, decision making and the action function for directly acting upon the machine.
The machine subsystem consists of the following elements: display and signal devices, control devices; between these the machine performs a series of operations.
The environment subsystem influences the system operation by its components given by: noise, temperature, humidity, toxic pollutants, illumination, etc.
In order to reduce the design effort and time we assumed that the working environment is designed and used in virtual conditions, at the same time considering the economical aspects, to eliminate the costs associated with the physical prototypes production, but the workers' safety and work quality remain in the foreground.
For example in 2006, the Bureau of Labor Statistics – BLS in France reported that during production activities occurs the highest number of non-lethal occupational diseases, an average of 6 incidents for 100 workers yearly, so this is why the necessity of virtual modeling occurred, also operation simulation for some equipments especially when the human factor is involved. Digital human models (DHM), possible to be used in such analyses are virtual representations of the human body and allow the products and processes interacting to the human individual, to be virtually "brought" near him, forming together and also with the geometry of the "working cell", a computer designed system, analyzed and optimized by help of the software mechanisms.
A high range of models were developed, their main feature being that the human subjects involved in working activities will be able to choose the postures allowing the human body joints to develop the highest moments and forces, in an optimal self-adjusting manner of the motion and stability mechanisms.
Seitz et al. (2005) and Rothaug (2000) developed a model based on the optimization of the predictive posture, which in its turn is based on the human posture and the information related to the strains and forces developed in the human body's segments. The strains were used in these models as constraints that come closer to the "more natural" aspects of the human biomechanics to improve the visual realism of the posture prediction (Liu, 2003, Zhao et al., 2005). But the aspects of "more natural" regarded as subjective criteria are necessary but not enough for the validation of ergonomic analyses and for solving optimization and efficiency of biomechanical analyses.
Also in the works of Seitz et al. (2005) who calculates with a lot of accuracy the postures in a "plausible" way, there is no comparison between the present posture and the predictive one for the human factor. In a similar way, we find the same modality of approach in Liu (2003) and Zhao et al. (2005) works, who develop models capable of predicting a "natural" form as an opposite situation to the predictive posture but observe that the natural aspect is not enough for a quantity measurement and for the prediction process used for comparison to the present posture of the workers.
Many researches suggested that the working postures should be predictive by optimization of some factors such as potential energy, deviation towards the neutral location of the joint involved by the motion, discomfort and tension. The general approach is to select form a multitude of postures, that are cinematically connected to the constraints, the one that minimizes (or maximizes) an objective function.

For example Marler et al. (2005) suggests three solutions "keys" (the tendency of moving in sequences different body segments, preferably forward with respect to the neutral comfort position, the discomfort of motion near the limits of the joint motion range) that hypothetically are related to the human behavior in the chosen posture.
The human body posture or motion prediction can be completed by the set of information related to motion or stability (Park et al. 2004), and in order to define a precision process, then the fundamental data set should include those characteristics that are similar to those to be modeled, including the forces directions and magnitudes (e.g., Dufour et al., 2001).
Extensive researches conducted in different international centres examined the evolution of the bipedal human gait (Vaughan, 2003), have measured two broad types of gait – the pathological and the normal one (Oberg et al., 1993; Macellari et al., 1999; Perry, 1999 etc.), examined the aging effects (Grieve et al., 1966; Dahlstedt, 1978; Owings et al., 2004; Richardson et al., 2005; DeMott et al., 2007), or investigated the effects of variability in stepping, sliding, going up or down the stairs, jumping or side stepping (Stolze et al., 2000; Danion et al., 2003; Beauchet et al., 2005; Hausdorff, 2005).

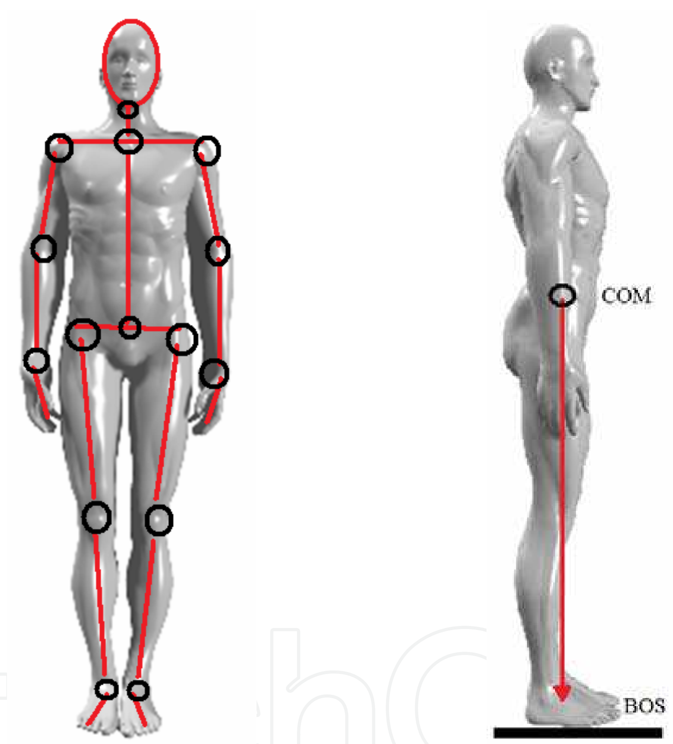


Fig. 2. Human body structure

The analyses of the postures and muscles activity set (Breniere & Do, 1981; Breniere & Do, 1986; Winter, 1995), gait cycles or stability characterization (Nissan et al., 1990; Breniere et al., 1991), were analyzed, studied and conceptualized (Winter 1995), in order to obtain multiple information for the management of ergonomic posture issues, for lucrative activity and way of life (Sparrow et al., 2005).
Thus we define the vertical-bipedal position of the human body as a mutual relationship between all the body segments and its vertical orientation as being determined by the gravitational field, the segments shape and size. In order to sample and configure the modular structure of the morpho-functional elements and for defining the bio-behavioral performances, the international anthropometric databases are to be accessed.

The anthropometric databases are created by the national and international agencies respecting the same acquisition, analysis, storing and creating principles of an interactive configuration for representative samples of population from different parts of the world. The variables of the human body are divided in standard modules and are defined by a unique anthropometric dimensional parameter.
The average anthropometric dimension which is selected – percentile 50 – allows the estimation of the standard deviation with respect to the other percentiles.
Because the human body is a multi segment architecture joined by links with different actions, this aspect may determine the occurrence of a certain postural instability which is controlled by the human organism in its whole by *feed-back* type reactions.
For the general definition of the postural stability of the human body we use a unitary parameter named **centre of mass (COM)** whose positions and displacements about the basis of support are recorded along different durations, in controlled environmental conditions, correlated by using several biomechanical investigation technologies (video, mechanical, electromagnetic, optical or mechatronic).
In static postures such as standing, sitting or laying, the human body and its segments are aligned and maintained in a certain position unlike the dynamic posture when these are in relative motion one about the other and the entire body about the environment. In this respect the study of a certain posture includes the kinetic and kinematical analyses for all the human body segments.
Especially in the static analyses, it is important to identify the **base of support (BOS)** defined as the area between the heels line in the back and the line of the sole tips in the front. This quantity may determine certain stability manifestations when the human body is subjected to some stimuli (audio, light, vibrations, shocks, temperature, etc.).
Even if the base of support is small and the centre of mass is higher on the human body, maintaining the stability in static postures requires a low quantity of energy consumption and only for keeping the muscle contraction.
Also the bones, joints and ligaments are systems capable to assure the necessary torques, the energy quantity being used to counteract gravitation and body's positions change induced by the circulatory and digestive system.
An important aspect in the action and maintaining postural stability is represented by its control, be it static or dynamic, manifested by the ability of the human subject to maintain the balance between the external forces and the organism response to their effect.
The feature of maintaining balance is "taught" by the **central nervous system** (CNS) using information captured from the sensorial system, passive biomechanic elements and from muscles.
Also CNS should be capable of detecting and predicting the future instability of the organism in bipodal posture and must react to all input signals by responses at the system output in the form of balance maintaining reactions of the human body. For this, the entire body with the component segments must present a **range of motions** (ROM) which corresponds with the kinematical and kinetic requirements and also is capable to respond fast by applying the necessary forces and velocities.
The postural stability as well as the initial orientation of the human body position may be altered if the inputs or outputs of the system are distorted, absent or incomplete, forcing thus the CNS to respond suitably by indicating a compromise of the action.
In case of organism normal operation, CNS selects the necessary muscles and joints combination to accomplish the stability or motion requirements of the human body. The

external forces that may intervene upon the human body system are: the forces of inertia and the forces of reaction, while the internal ones are developed by muscular activities and tensions in ligaments, tendons, joints or other tissues structures.
The effect of each category of forces, external and internal is in balance and the sum of all forces and moments acting in the human body is equal to zero for this body being in equilibrium.
In order to maintain the equilibrium in bipodal posture using minimum energy it is important that the body's centre of mass is kept above the base of support and the head position and orientation must allow the gaze direction to orient properly.
That is why only an active control of the 3D position of the body's centre of mass may determine the system to remain stable in the psycho-physiological limits and the body's centre of mass is controlled by non linear control mechanisms. The bipodal position of the human body determines an anisotropic structure, which is in equilibrium as long as there are no external stimuli, of any kind acting upon it (light, audio, mechanical or thermo dynamical).
Unlike the stability state of the human body that is considered a statically balanced state and for which the imposed initial conditions are kept in time, changing only when it is subjected to external stimuli, human gait is a dynamic stability state for which the forces, moments, velocities and accelerations of the entire body and of the component segments are balancing each other in real time by the controlled mechanism of the neuro-muscular system.
Additionally, the human gait represents also a repetitive motion with an energetic consumption divided along all the cycle stages in order to obtain a unitary displacement of the human body segments to overcome the forces of inertia, friction and resistance from the action environment.
In a lot of researches from the biomechanical area (Baritz M. et al. 2008) they consider that the mechanical parameters of the human body affect the gait type, the duration of the gait cycle or the way of reaction to the interaction with the environment, thus resulting a passive dynamics that affects its quality.
The structural analysis of the human body gait model performances uses especially the modeling by inverse dynamics and the model of the double pendulum because the segments mass distribution simplifies the mechanical and mathematical approach.
In this respect, at first the introduction of the system reference points is important both about the environment and about the support surface.
Between these points there is always a set of one-sided or multilateral connections depending on the modules, segments or component junctions that are involved in the stability, gait or specific segments motion processes.
These reference points are: (according to Vukobratovic & Juricic 1969; Vukobratovic & Stepanenko 1973; Takanishi et al. 1985; Yamaguchi et al., 1993; Hirai 1997; Hirai et al. 1998) **the zero moment point (ZMP), foot rotation index (FRP)-**a reference point that assures the connection between the base and the angular acceleration of the foot in the gait initial phase when only one foot is positioned on the support surface.
Another important point is the **centre of the rotation moment (CRM)** which determines also the connection of the human body to the support surface (Herr et al., 2003; Hofmann, 2003; Goswami & Kallem 2004; Popovic et al., 2004).
Another point as important as the centre of mass but may be used for measuring and assessing both the static and the dynamic stability is the **centre of pressure (COP).** This represents the point where the resultant of the ground reaction forces about the human

body weight acts. During the measurements performed in bipedal position – stability – the centre of pressure is generally located in the centre of the plantar surface, the small oscillations of the human body being recorded as an oscillation diagram around an initial position.

The displacement (oscillation area) which is performed by the centre of pressure in order to assure the bipedal stability is engaged in the plantar surface and in its turn is determined by the human subject posture type (strained, relaxed), hands position (in front, sideways, along the body, upwards), base of support size (small, big, normal), position of spine (bent in front, upright, bent to the back, bent sideways), sensors operation conditions (visual – open eyes, closed eyes, acoustic) and not last the environmental conditions (temperature, pressure, humidity, vibrations, noises, light stimuli).

In the system assuring the bipedal posture of the human body, a whole series of elastic and damping properties of the muscles, joints and segments are manifesting, being coordinated and controlled also by *feed-back* type reactions.

This is why the COM displacements correlated to the COP oscillations during the bipedal position assess and measure the chaotic motions (Myklebust et al. 1995) of the stability using non-linear dynamics methods and chaos theories (Schuster 1988).

By applying these theories of adjusting the dynamic mechanism of balance and stability we may develop and introduce specific strategies for preventing and treating postural instabilities due to some previously identified malfunctions.

2. Theoretical aspects of human body modeling process

2.1 Gait cycle and postural analysis

Gait defined as alternative bipedalism is characterized by the unit gait cycle (double step) represented by the distance between the contact point with the ground (heel) for one foot and the immediately following contact point of the same foot. By composing two simple successive steps we get a double step. From functional point of view, the gait cycle is divided in two main stages: the support stage and the balance stage.

Support is the period concerning the contact between the foot and the ground and takes 60% of the gait cycle duration. Balance is the period when the same foot is no more in contact with the ground but is balanced in order to prepare the next contact with the ground. The balance duration is approx. 40% of the gait cycle duration.

In the beginning and at the end of the support stage, there is the double support period (24% of the gait cycle) when both feet are in contact with the ground, allowing thus the body weight transfer from one foot to the other.

The gait cycle is divided into 8 phases, five of them taking place during the support period and the other three during the balance period. These phases are the ones connecting the foot motion to the beginning of this motion within these periods. Thus the 5 phases defining the support period are: **initial contact, load, middle of support, final support and ground separation.**

Within the initial contact the body centre of mass is in the lowest position, thus the inferior limb being maximum extended will determine the pelvis to perform a horizontal adduction motion on the attack part relative to the support limb. This action represents a percent between 0 and 25% from the gait cycle duration.

Load, representing 25-35% of the gait cycle occurs when the plane surface of the foot touches the ground. The contact is achieved in the beginning only by the heel, then on the

entire sole, the subject being in monopod equilibrium so that the maximum length of the inferior limb is limited subjecting the centre of mass to a very important vertical acceleration.
A percent of 35-40% of the gait cycle representing the middle of support phase is happening when the balance foot overpasses the support foot, thus the body passes in a very short time through this position, being supported by a single foot. At this moment the human body has maximum height and the centre of mass is slightly moved to the side towards the support foot for maintaining equilibrium.
Then, a percent of up to 45% of the gait cycle is represented by the period when the heel loses the contact with the ground and the pushing is performed by the *triceps surae* muscles which drive the ankle bending. At the same time with the heel raising the toes still keep contact with the ground, the ankle being in the most upper position.
The end of the support period represents a 53% percent and is called ground separation, occurring when the foot leaves the ground.
In case of the balance stage, the three phases are: acceleration, middle of the balance and deceleration.
The acceleration starts at the moment when the foot leaves the ground, activating thus the hip muscles in order to accelerate the foot forward. At this stage the inferior limb reaches its minimum length, the hip and knee joint is bending, the ankle joint is mobilized to lead the foot in flexion action so that the human subject body weight is entirely supported by the opposed inferior limb.
The positioning action in the middle of the balance takes place when the foot is moving exactly under the body and concurs with the moment the other foot reaches the half support phases. Deceleration describes the action of the muscles that slow down and stabilize the foot expecting the next contact between the heel and the ground. The pelvis is in maximum rotation towards the part the heel will attack and the hip is in flexion.
The closed kinematical chain formed by the locomotion system components acts for maintaining and supporting the body in orthostatic position, for propulsion motions or for damping motions during a fall (on the feet).
The inferior limb acts like an open kinematical chain in the different variants of adduction and abduction motions, external and internal rotation, kicking, pushing and not least in accomplishing the gait cycle, all these actions being included in a system of coordinates.
The stability stance as well as the integral balance around the equilibrium position are determined by the health level of the entire human body and may constitute clear informational sources for the human behavior evaluation in any situation.
The small deviations of the human body posture around the vertical direction determine the occurrence of a torsion moment, which acts upon the entire structure and may unbalance the human body or may create a vibration state.
However, this process of corrective torque generation is not fully understood and controversy remains regarding the organization of sensory and motor systems contributing to the postural stability of the entire human body.
Balanced state of postural sway is controlled by central nervous system, and the upright stance cannot be sustained without this control. It is widely accepted that the corrective torque is generated through the action of feedback control system; the input sources include visual, proprioceptive and vestibular system.
In fig. 3 it is showing the block diagram of the postural sway feedback control and also a simplified pelvic structural model during static upright stance. A, B are the masses of legs, C is the mass of pelvis and D is the mass of upper trunk.

Because the lumbar-sacral always sways in inverse direction of the ankle joint with the same value of θ, the upper trunk is kept perpendicular to the horizontal (the human body symbolic represented is for a subject with leg impairment). Location of COM remains fixed as long as the body does NOT change shape.
In order to locate the center of mass it is necessary to establish some main principles:

- its precise location depending on individual's anatomical structure;
- habitual standing posture;
- current position;
- external support;
- location in human body;
- variations with body build, posture, age, and gender
- infant > child > adult (in % of body height from the floor);
- generally accepted that it is located at ~57% of standing height in males, and ~ 55% of standing height in females;

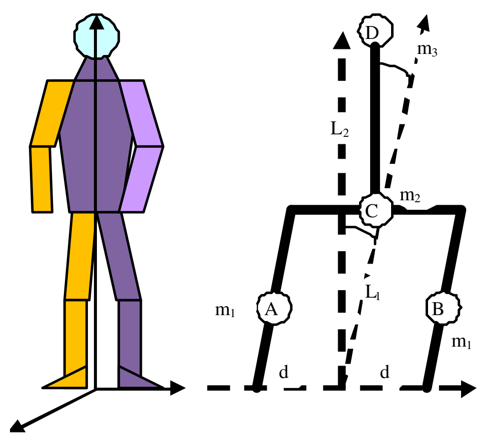


Fig. 3. Bipodal posture diagram

The maintenance of equilibrium in standing position is one of the most important activities for two main reasons: firstly, the center of mass must be located in the support area; secondly, for a major period of the standing action, the body is supported first by two legs and after a short time by a single limb with the center of mass inside the base of support but with the tendency of going outside it.
In elder people especially, up to 70% falls occur during standing and of course, locomotion action or stepping (Baritz M. et al, 2008)
By **the static stability margin** is meant a distance of the GCOM from the edge of the support polygon, measured along a current vector of motion of the gravity center, where:

$$x_{GCOM} = \frac{\sum_{i=1}^{n} M_{xi}}{\sum_{i=1}^{n} F_{xi}} = \frac{\sum_{i=1}^{n} m_i x_{ci}}{\sum_{i=1}^{n} m_i} \quad (1)$$

$$y_{GCOM} = \frac{\sum_{i=1}^{n} M_{yi}}{\sum_{i=1}^{n} F_{yi}} = \frac{\sum_{i=1}^{n} m_i y_{ci}}{\sum_{i=1}^{n} m_i} \quad (2)$$

and m_i is mass of the *i*-th body, whereas x_{ci}, y_{ci} denotes location of the center of mass of the *i*-th body.
With respect to analyses upon the human body static stability, human gait is a motor ability by means of which the displacements are usually performed using the alternative and constant motions mechanisms of the two inferior limbs, as support and as propellant.
As a follow, the motions of the human body are performed by a series of muscles groups, which form a harmonious assembly of muscular-kinematic chains, created according to the motion particularities under the control of the cerebral cortex. The motions performed by the human body have spatial directional characteristics of the motion and of the trajectory length traveled by the body or the body segments. They may be continuous, interrupted or combined according to a certain succession. The ratio between the spatial and temporal characteristics that establish the velocity and also acceleration parameters of the motion and all these characteristics as a whole, represent the kinematic particularities of the motion: where, how much and how is the body and its segments moving, along which trajectories described by the body segments and which controlled way is the complex motion of the human body performed.
All these aspects are important to be known when we analyze the disfunctionalities of the human body locomotion system.
The motions that can be performed by the human body are translations and rotations, complex and in 3D. The locomotion motions may be also cyclic or non cyclic (when the disfunctionalities occur).

2.1 Human body static and dynamic behavior modeling

The computer analysis of the human motions emphasizes a series of features of the gait cycle concerning the forces developed at the contact support, the duration, the forces developed in the joints, velocities, displacements or spatial positioning of different parts of the human body.
Humans possess a unique physical structure that enables them to stand up against the pull of gravity.
To build a model of interaction of human body it is necessary to understand its component parts, the biggest part of the human body is the trunk; comprising on the average 43% of total body weight. Head and neck account for 7% and upper limbs 13% of the human body by weight. The thighs, lower legs, and feet constitute the remaining 37% of the total body weight. There are 206 bones in the human body and almost all bones are facilitators of movement and protect the soft tissues of the body.
The frame of the human body is a tree of bones that are linked together by ligaments in joints called articulations. Skeletal muscles act on bones using them as levers to lift weights or produce motion.
In the human body each long bone is a lever and an associated joint is a fulcrum, acting like a lever which can alter the direction of an applied force, the strength of a force, and the speed of movement produced by a force in moving.
The walking model includes three body parts: an upper link, a lower link, and a foot.
Two joints are represented by the hip and the ankle, the lower and upper links represent the leg and the upper body of the human, respectively and the sources of movements are joint torques and thrust force.
This model was used to simulate human walking in the sagittal plane during the weight acceptance phase, that is, the time duration from heel contact to the middle of the single leg

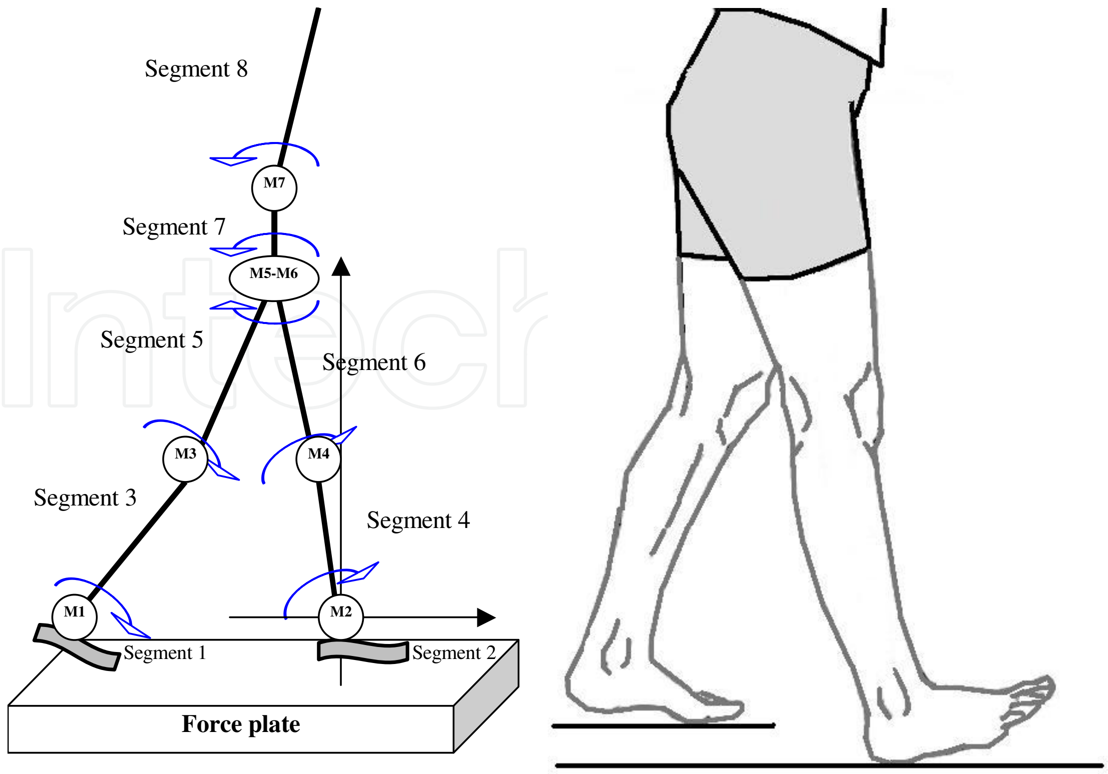


Fig. 4. Locomotion system model

support phase. The equation of motion of the model consists of two parts: the rotational dynamic of the two links and the moving dynamic of the foot. The equation of motion of the links is expressed as follows:

$$[M]\ddot{\theta} = [N]\dot{\theta}^2 + [G] + \tau + F_{TH} \quad (3)$$

where [M] is the mass and inertia matrix; [N] is the Coriolis and centrifugal force matrix; [G] is the gravitational force; τ is the matrix of torques angles and F_{TH} is the thrust force.

Starting from a pre-defined skeleton module and considering the anthropometrical database NASA-STD-3000 we build the shape of the human inferior locomotion system with direct contact to the walking support.

For modeling human gait we considered a series of data connected to motion, trajectory, velocity or acceleration but at the same time we introduced the boundary values of the gait type (normal, malfunction of the right or left foot, jumps or steps, slips or sliding on plane surfaces etc.).

The modeling stages aim at introducing data both for the normal mode and for the one used to model a certain gait type in order to simultaneously visualize these differences.

In fig.5 a block diagram is presenting the steps in which these methodology of human gait and standing stability modeling are fitting the marker configuration, analyze and calculate kinematics, calculate kinetics, study control strategies and simulate human walking or standing stability using experimental data and the model created.

Thus, for a complete analysis of the way the human body acts and reacts in stability position or in gait cycle we approached the inverse pendulum model (IPM) for the lower locomotion system and then we establish the motion or stability equations.

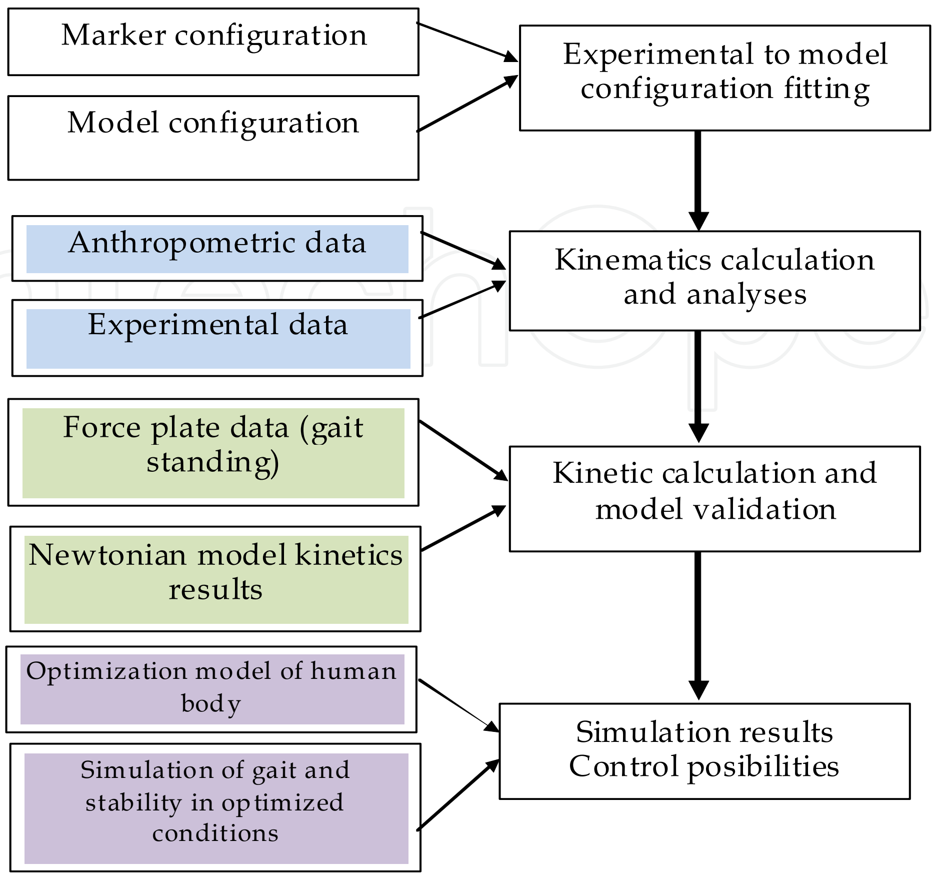


Fig. 5. Block diagram of biomechanic modeling for human bio-behavior

Applying the Newtonian Mechanics we may write the following equations:

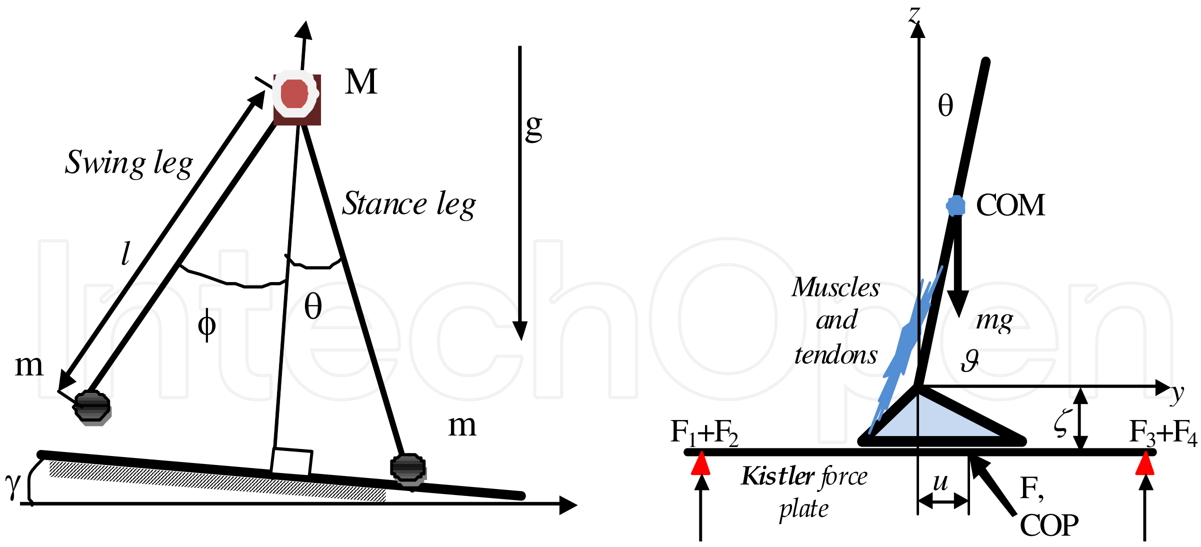
$$\begin{cases} m\ddot{y} = F_y \\ m\ddot{z} = F_z \\ I\ddot{\theta} = mgL\sin\theta - N \\ N = uF_z + \varsigma F_y \end{cases} \tag{4}$$

where I represents the moment of inertia of the body considering the ankle segments joints; m represents the body mass; g represents the gravitational acceleration; L is the distance from the ankle joint to the centre of gravity (COG); F_y and F_z are the components of the reaction force from the support surface relative to N-torque produced at plantar level by the muscle system that counterbalances the gravitational moment mgy.

From the above equations we may determine in certain conditions of approximation the coordinate u anterior/posterior (A/P) of COP that changes according to the muscles activity.

In case of the human body dynamic action we may define the laws of motion for the inferior limbs as follows: the two coupled second-order differential equations of motion are given below for the swing phase of the motion, where $\beta = m/M$ and θ; ϕ are functions of time t.

These equations represent angular momentum balance about the foot (for the whole mechanism) and about the hip (for the swing leg), respectively.



a) b)

Fig. 6. Typical diagram of a step (a) and the forces developed by the foot on the force plate (b) (Borg F. 2005)

$$\begin{bmatrix} 1+2\beta(1-\cos\phi) & -\beta(1-\cos\phi) \\ \beta(1-\cos\phi) & -\beta \end{bmatrix}\begin{bmatrix}\ddot{\theta}\\ \ddot{\phi}\end{bmatrix} + \begin{bmatrix}\beta\sin\varphi\left(\dot{\phi}^2-2\dot{\theta}\dot{\phi}\right) \\ \beta\dot{\theta}^2\sin\phi\end{bmatrix} + \begin{bmatrix} \left(\frac{\beta g}{l}\right)\left[\sin(\theta-\phi-\gamma)-\sin(\theta-\gamma)\right] - \frac{g}{l}\sin(\theta-\gamma) \\ \left(\frac{\beta g}{l}\right)\sin(\theta-\phi-\gamma)\end{bmatrix} = \begin{bmatrix}0\\0\end{bmatrix} \tag{5}$$

These are the equations of motion for a simple double pendulum (Garcia M, et al., 1998). In this situation we assume that the foot mass is smaller than the entire human body mass and we adopt the value β=0 in the next equations.

$$\ddot{\theta}(t)-\sin\left[\theta(t)-\gamma\right]=0 \tag{6}$$

$$\ddot{\theta}(t)-\ddot{\phi}(t)+\dot{\theta}^2(t)\sin\phi(t)-\cos\left[\theta(t)-\gamma\right]\sin\phi(t)=0 \tag{7}$$

Equation (6) represents thus a simple inversed pendulum (the stance leg) that is not affected by the motion of the other foot and the equation (7) represents the swing leg like a simple pendulum moving on a circular arc.

The variation parameter in these equations is γ, the base inclination angle.

For the modeling and determination of the gait cycle parameters we integrate the above equations by applying a transition law between the support leg towards the swing leg and the activation of the contact conditions with the support surface.

Another model for the human gait study is represented by the model that assumes the central nervous system becomes a super system (SCNS) and is connected to the mobility control system, together they will coordinate the locomotion and the gait cycle.

Thus applying the fractals and multifractals theory upon the recorded data during the investigations there is the possibility of estimating the Holder correlation coefficients defined for wavelet transformations.

By estimating the Holder exponents and their spectra using a wavelet transform, it can be possible to show that the stride-interval time series is weakly multifractal with a main fractality close to that of $1/f$ noise. The time series is sometimes non-stationary and its fractal variability changes in the different gait mode regimes (normal, with disabilities, without complete locomotion system etc.)

2.3 Analysis techniques of the human body behavior

Maintaining a competitiveness level of the systems, increasing their performances as well as highlighting their weak points, the aspects requiring improvements based on the system analysis need at first data provision for the system "diagnosis".

Due to the importance presented in analysis, the collection of data should provide the necessary information in time, these information being based on real data.

Obtaining the data concerning the activities developed within the system and reflecting upon the studied problem is based on various investigation techniques.

According to the conditions upon the activities of the persons that are to be observed, the systems investigation techniques are divided in controlled and non-controlled techniques.

The controlled techniques are characterized by the fact that the information are directly collected from the persons that perform the activities upon which the study is focused.

The observation takes place in-situ or in a controllable environment used for the simulation of various tasks (laboratory observation).

Activity analysis. This technique aims at the observation of an activity by help of those working on it, human subjects that have to be carefully selected.

This way we aim at the identification of working level, errors occurring during the activity performance and thus the factors that influence in a negative way the obtained bio-behavioral performances.

We identify in this respect, the execution frequency, the materials and information required by the execution, the encountered difficulties, connections to other activities, connections and interactions with adjacent systems.

In order to establish a correct result, the "acquirer" training, executant's selection and accomplishing a valid observation schedule with experimental data validation possibility are very important.

An activity data acquisition system may be the computer, in this case it is necessary to know the accomplishment parameters of the observed events.

This way we assure a fast analysis, very little influenced by errors, by the human factor bias, things that compensate to a smaller or larger extent their inflexibility towards some initially unforeseen elements.

Protocol analysis. This technique is based on the observer-participant status of the operator of a certain activity and aims at the identification of the conscious bio-behavior of the person performing the activity in order to assess the performance level.

The time of performing this investigation is represented by the period when the desired action takes place, thus we can survey the decisions made by the operator, his options, causes of the occurred errors and not last the observer attitude towards the performed activity.

Direct observation techniques are influenced by a series of factors such as:

- effects due to the observer manifested both upon the system operation and upon the operator;
- sampling effects due to the inadequate size of the human subjects number whose activity is investigated and the choice of a time period with a small relevance to the covered objective;
- observation limiting effect occurred in case of selecting human subjects unable to offer the necessary data for analysis.

The main reason for this is the wrong choice of the observation-assessment scheme, increased time pressure, leading to the ignorance of some important aspects of the investigated activities.

Non-controlled techniques. These investigation methods of a system may be classified according to the observation subject.

Thus, we can distinguish between the individual, group and informational techniques.

Individual investigation techniques. Their use assumes the collection of data for each human subject, concerning his anthropometric dimensions, environmental conditions and the performed activities.

Within them we can distinguish several classes according to the existence or absence of an analysis system at the time of data collection or according to the temporal position of the data collection time with respect to the analyzed activity.

Individual interview technique. The individual interview represents a personal investigation technique, physiological history type that may be developed in real time but also retrospectively. This requires several stages.

The first step would be the investigation, a process that aims at the conception of a set of questions in the form of a questionnaire with a control key.

The content of these questions should be relevant for the objective targeted by the system analysis and should also cover the entire studied problem.

The obtained information will be collected and recorded in the next stage, representation, their validity will be later assessed within interpretation.

All these represent the preoccupations agenda and also an important part in obtaining the necessary information for analysis because it highlights the aspects to be monitored in the investigation activity.

Sample determination should be done according to the requirements connected to representativeness and considers also the problem complexity, its content and research objectives.

Starting from these, we will determine the human subjects' sample that will be investigated so that all those included are able to provide the necessary response and are aware of the data that the researcher is trying to collect in the interviewing process.

3. Experimental setup for investigation

3.1 Setting the investigation configuration

In order to perform the analyses upon the human factor that develops various working activities, we accomplish an analysis configuration consisting of a series of device modules dedicated to these biomechanical measurements and also the analysis modules (anthropometric, gait cycle, stability in different conditions). This configuration is presented in fig.7. (Rogozea L. 2009)

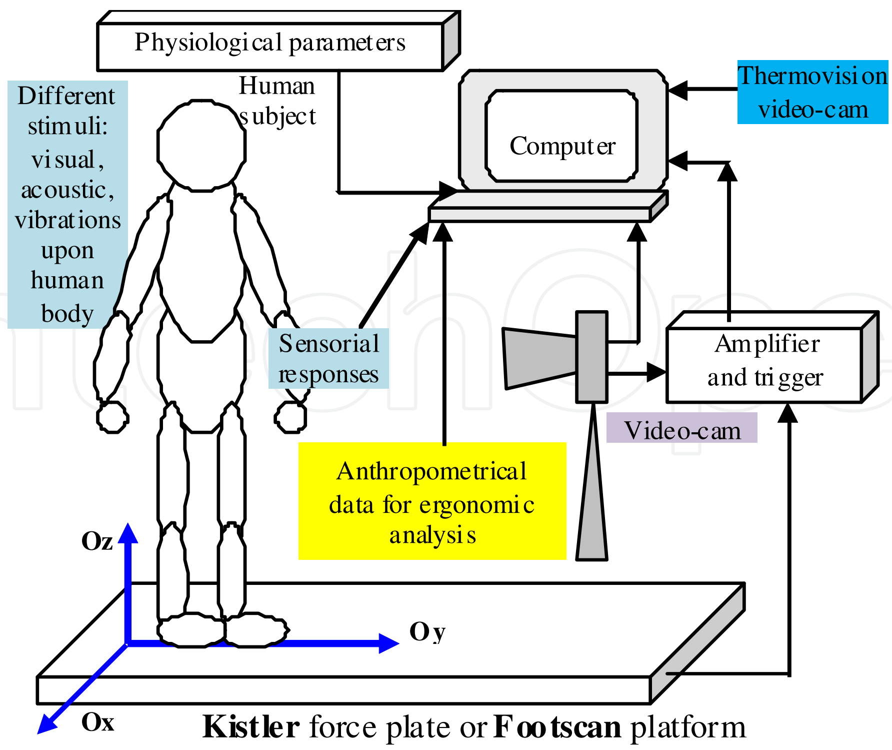


Fig. 7. Recording configuration of the human behavior along the working activities

Using this modular equipment structure we performed some analyses and recordings in order to correlate the information concerning the human bio-behavior in different working activities. The equipments structure consists of: a Kistler type force plate for measuring forces and moments developed by the human body during the stability and gait cycle evaluation along the three (Ox, Oy and Oz); a set of anthropometric devices for measuring the locomotion system quantities; a set of devices used for recording the physiological parameters of the subjects involved in the experiment; an evaluation and goniometric measurements of the relative positions of the human body segments; a high speed video cam for recording the successive positions of the human body along the gait cycle duration; a "sensor glove" type system for assessing the handling performances along the working activities; computer and modeling software compatible to the above mentioned equipments.

The analysis performed upon the subjects started by establishing an investigation protocol, which aimed at a large range of measuring the bipedal stability (big support base with different polygons, small support base trapeze shaped, open eyes and arms along the body, in three moments of the day – morning, afternoon and evening) and walking inside.

The corresponding soft for the values acquisition is **Bioware**, which allows the recording of the forces and moments values, measured along the three directions by help of some piezzo-electric sensors of the force plate. We also aimed at the fact that the bipedal position of each subject is centered on the plate, with no high heels shoes, arms relaxed along the body, open eyes and the eyes oriented straight ahead.

3.2 Data recording

In first stage of the experiments we established and kept the parameters of the laboratory environment. Temperature into laboratory was 22^{0}C, air humidity 80% and atmospheric pressure 755 mmHg. [4]

In the second stage we measured the physiological parameters of the human subjects (weight, height, age, blood pressure, temperature, pulse, visual and audio acuity, lactic and glucose parameters) in relaxed stance, without any general health problems and with a good metabolism (example: blood pressure 155/82 mmHg, pulse 78-88, face temperature 36,7^{0}C, height 170-185 cm, weight from 50-95 kg).

Fig. 8. Acquiring and creating the physiological database for the analyzed subjects

All these parameters are necessary to establish a common modeling base to measure and to evaluate the human body bio-behavior in working activities. It is very important to keep these initial conditions in all investigations procedures to have the same initial line of human behavior analysis.

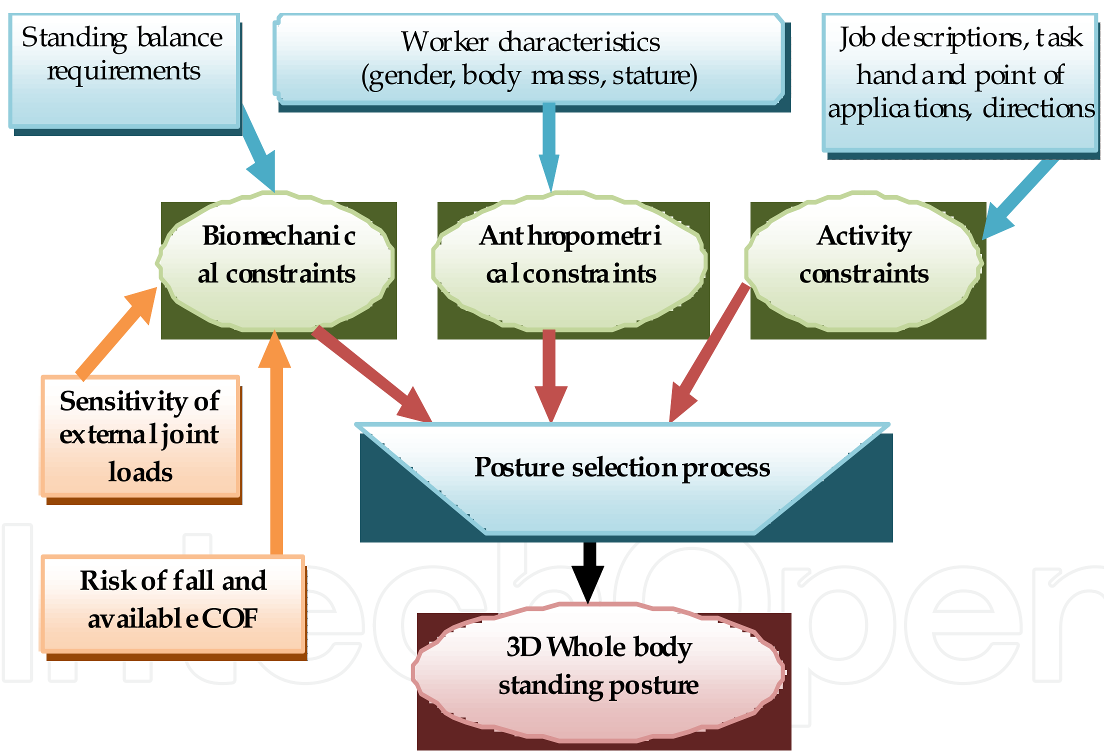


Fig. 9. Postural analyses subjected to anthropometric, biomechanic and activity constraints

The initial analysis posture was determined by the vertical position, hands along the body, big/small base of support, open eyes, gaze straight ahead.
About this position considered as initial, we established a series of different postures, considering both the orthostatic changes (fig.10) and the hands position relative to the body or the head and respective the eyes position (fig.11.) also the use of some perturbing stimuli (audio, visual) that may affect the postural stability.

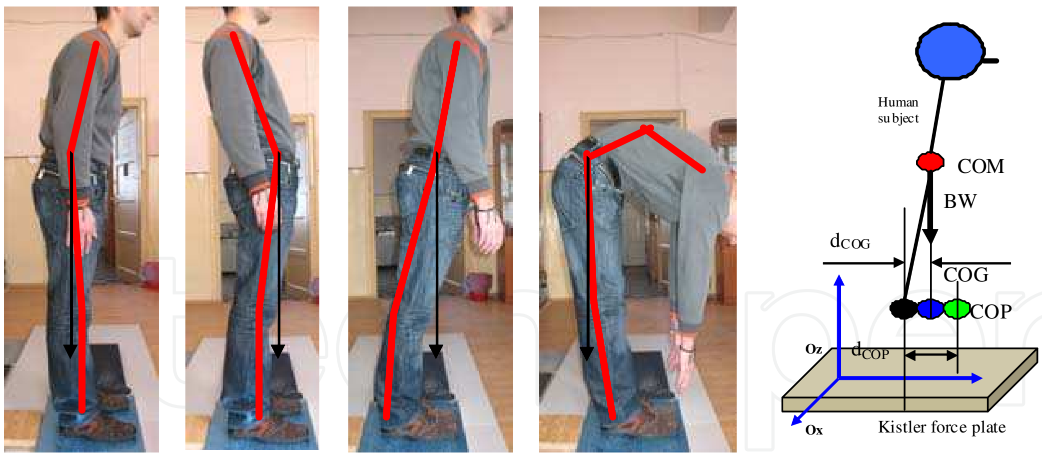
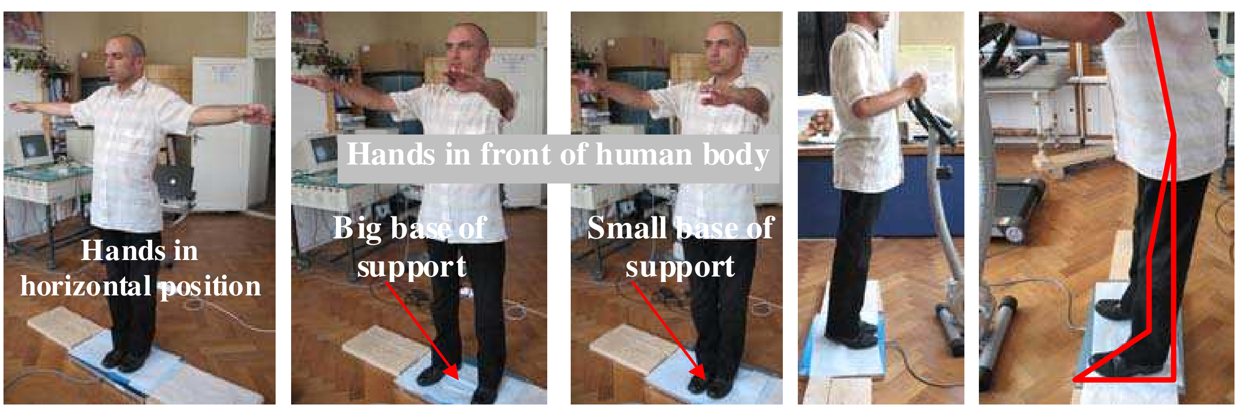


Fig. 10. Selection of orthostatic position for bipodal equilibrium



a. b. c. d. e.

Fig. 11. Relative position of hands and head, and eyes respectively during recordings

Thus, we chose the following recording variants of the human subject's behavior in analyzing the postural stability, taking into account as many bipodal postures as possible to be encountered in the subjects' working activities:

- Vertical position, small/big base of support, hands along the body, open eyes, gaze straight ahead;
- Vertical position, small/big base of support, hands along the body, closed eyes;
- Vertical position, small/big base of support, hands in horizontal position sideways, open eyes, gaze straight ahead;
- Vertical position, small/big base of support, hands in horizontal position sideways, closed eyes (fig.11.a.);
- Vertical position, small/big base of support, hands in front of the body, open eyes, gaze straight ahead (fig.11.b. and c.);
- Vertical position, small/big base of support, hands in front of the body, closed eyes;
- Vertical position, small/big base of support, hands along the body, closed eyes and use of different external stimuli (audio, visual)
- Vertical position, small/big base of support, hands on a vertical support, open eyes (fig.11.d. and e.)

For the analyses along a gait cycle (fig.12.) we considered the following situations:

- normal gait starting with the right/left foot;
- added steps gait, starting with the right/left foot;

- dragged gait, starting with the right/left foot;
- normal gait holding a weight with both hands;
- normal gait holding a weight in the right/left hand;
- stepping on stairs, up/down with the right/left foot (fig.13.)

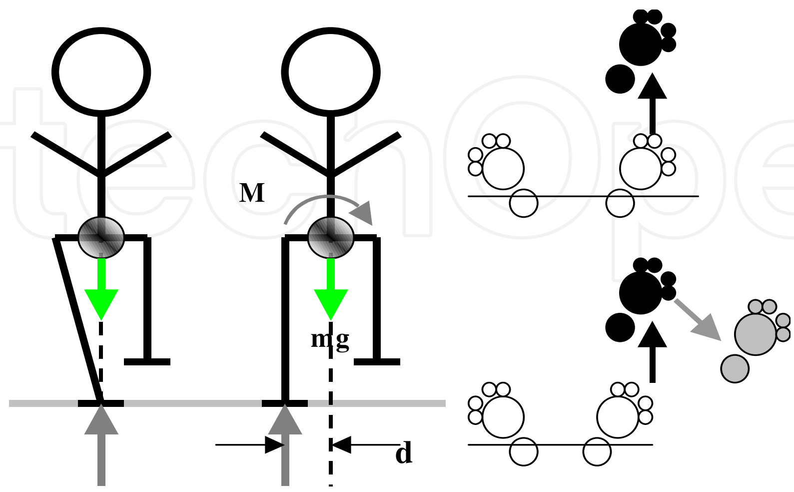


Fig. 12. Changing the stability on gait cycle

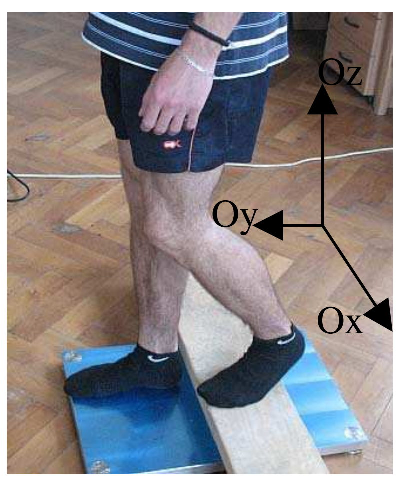


Fig. 13. Up/down the stair

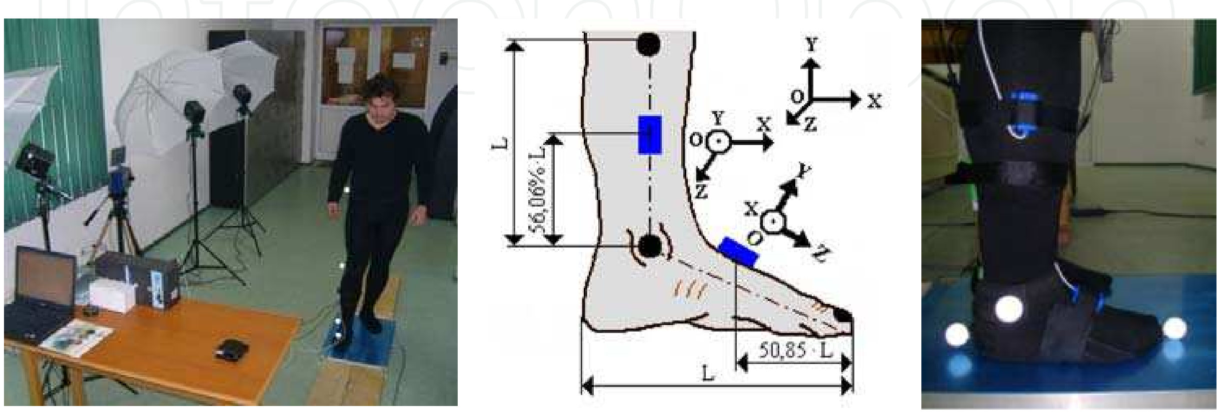


Fig. 14. Acquiring and measuring system, Biopac type, for the foot and lower leg linear accelerations

In order to perform the correlated analyses upon the subjects locomotion system behavior, we used a system for measuring linear accelerations of the foot and lower leg along the displacement directions, respectively on a perpendicular direction during the ground support phases of the foot (Radu C. 2007)
The experiment was developed in two stages, as follows: the initial setting of the used system, Biopac type and respectively acquiring the values of the linear accelerations specific to the foot and lower leg (fig.14.)
At the same time it was necessary to use a high speed video cam (500 frames/sec) to record and draw, by software means, the joints trajectories during the displacement in a gait cycle.
Finally, all these recordings are correlated by means of the *LifeMod* software for developing a virtual model for the human subject analysis, subjected to different actions, in various conditions of environment and activity.

4. Results and conclusions

4.1 Bipodal posture stability

The analyses performed using this experimental structure and advanced investigation technologies have the final goal of highlighting some correlations between the different measured quantities, on various types of subjects involved in the same types of recordings.
Thus, one of the most important recordings performed by this experimental structure was the one that manifested the changes in the stability areas with respect to the subjects' posture, hands position, eyes and respectively the effort level developed by the organism.
In the example below we analyze the evolution of this area (measured along Ox and Oy) for a subject with the following features: female, height 1,68m, age 53, no general health problems but with a knee impairment, weight 80kg, for which we analyzed the stability area and the force evolution along Oz axis, in three moments of the day (morning, afternoon, evening) without any source of additional *effort induced to the body…*(use of ergometric bicycle), with hands near body and open eyes.
As we can notice from the diagrams analysis in fig.15, the evolution of the stability area in this case presents a compact and symmetrical surface for the first time in the morning, a smaller and more concentrated area for the afternoon and a substantial change of balance – slightly shifted along Ox for the evening recording.
This manifestation can be found in all the analyses performed on the selected subjects allowing a unitary evaluation of the stability area.
As far as the recorded force on Oz is concerned, these results are presented in fig.16 (morning, afternoon, evening).
The recording time was each time the same – 16 sec and the data set was stored in the measurements database used for evaluation.
In the case of force evolution analysis we observe the same type of manifestation for the recording performed in the evening, emphasized by an increase of the variation limits of the force along Oz, but also by a higher frequency of their occurrence, values that indicate an increased instability of the human body and a fatigue state at the inferior limbs level.
In this situation and correlating with the age and the influence of the poor sensorial system we may confirm that the installation of the fatigue state as a follow of a normal daily activity takes place in the second part of the day determining a motor activity deficit and the diminishing of the orientation perception.

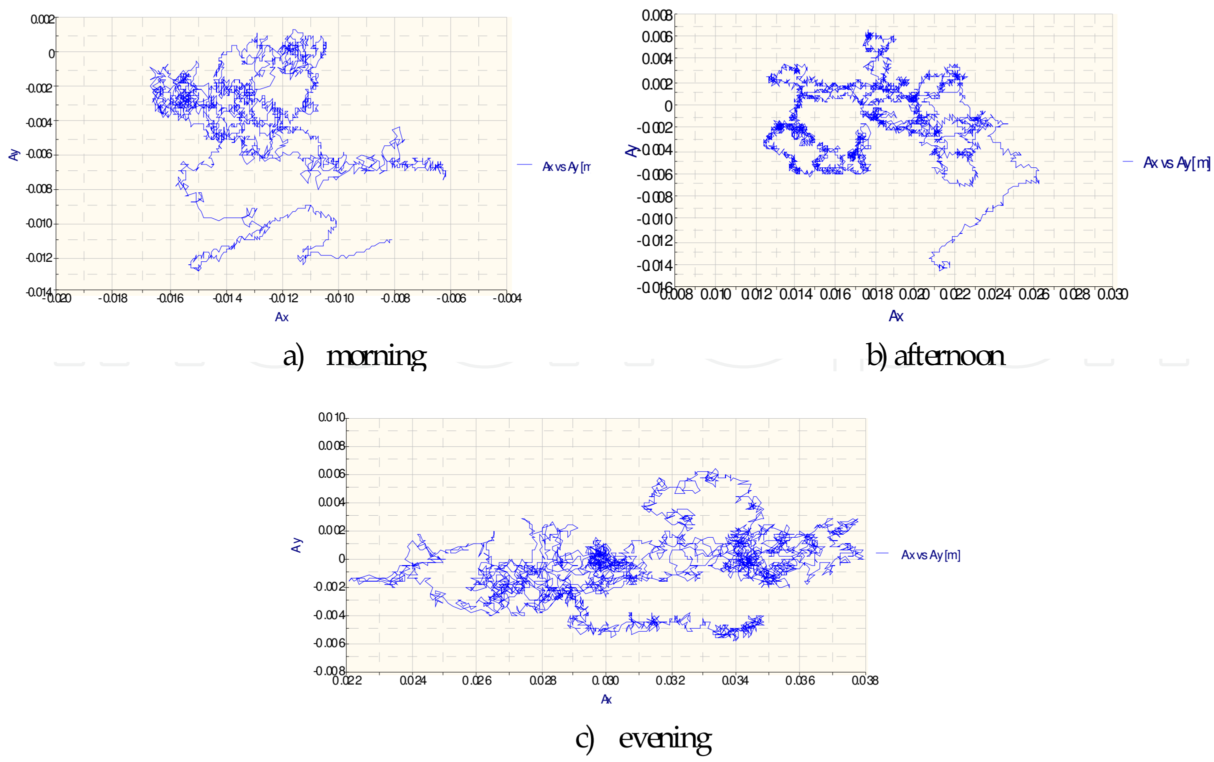


Fig. 15. Example of results for subject stability recordings

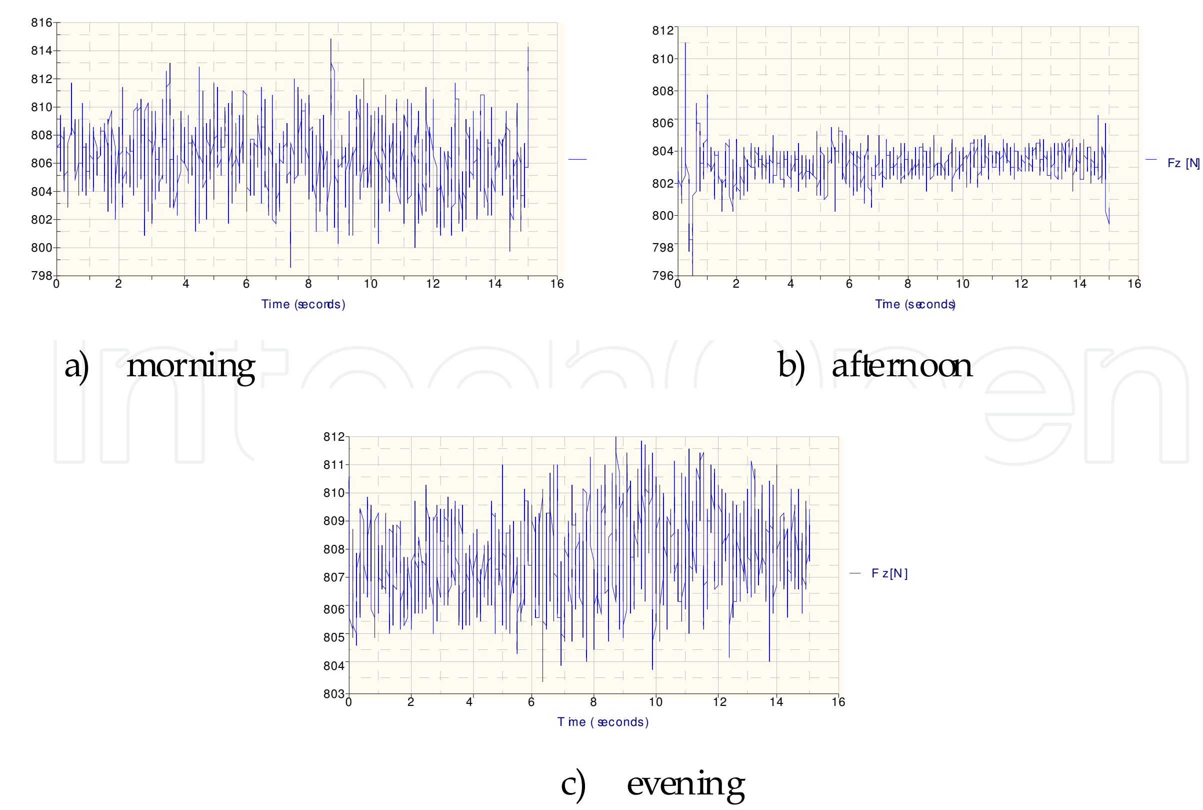
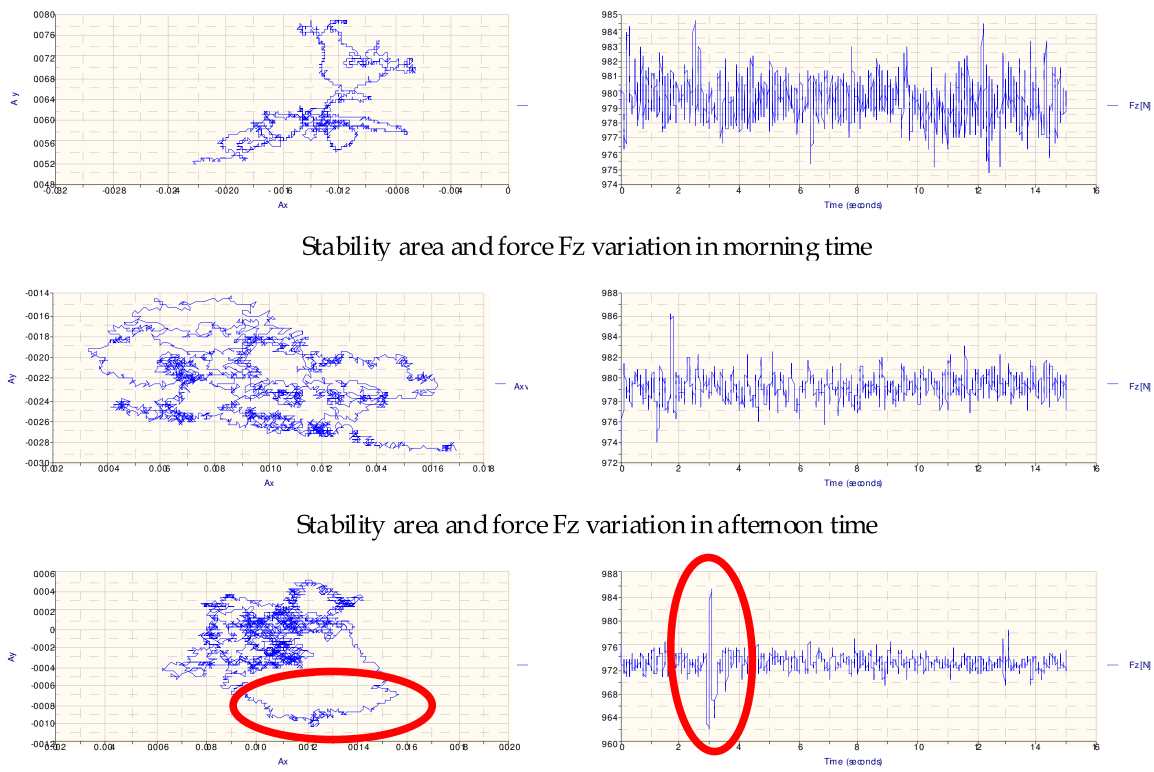


Fig. 16. Manifestation of the Fz force change, acting along Oz, for the same subject

In the case of a male subject age 34, no health problems, not wearing glasses, weight 97kg and height 1,75m, the evolution of stability area in the three moments indicates a more compact and symmetrical shape around the theoretical equilibrium position as we can observe in fig.17. and the forces variation diagram is changing towards the diminishing of the oscillations number for the recordings situation related to those in the morning.
This fact establishes a more equilibrated behavior for which the fatigue due to daily activity does not influence the motor capacity and also does not reduce the resistance to effort.



Stability area and force Fz variation in morning time

Stability area and force Fz variation in afternoon time

Stability area and force Fz variation in evening time

Fig. 17. Stability area and Fz force variation, along Oz, for the 34 years old subject

When the human subject is subjected to the action of external stimuli, the response of the subjects' behavior is manifested by the changes of the Fz force variation, especially if in the same conditions we change the subject's base of support. As we may notice in the normal posture version the Fz force variation is uniform along the entire recording, without reaching extremely high values or changes along extended durations. In this respect we observe that when the person is subjected to a visual stimulus (controlled) he reacts firstly by a short duration variation of the force, and then the variation returns and presents a peak proving that the body is trying to come back to the previously determined stability position.
Another sort of experiments and recordings are made with the person using an external support to observe the behavior of the human body in balance from the front of the leg to the back, taking in account some external stimulus, like environmental and working activities (fig.11.d, e). In these experiments we record the forces variations, the stability area, the force and moment in the same direction in different situations – with big (test no.1.) or small (test no.2) support base, but with open eyes in the time of recordings.

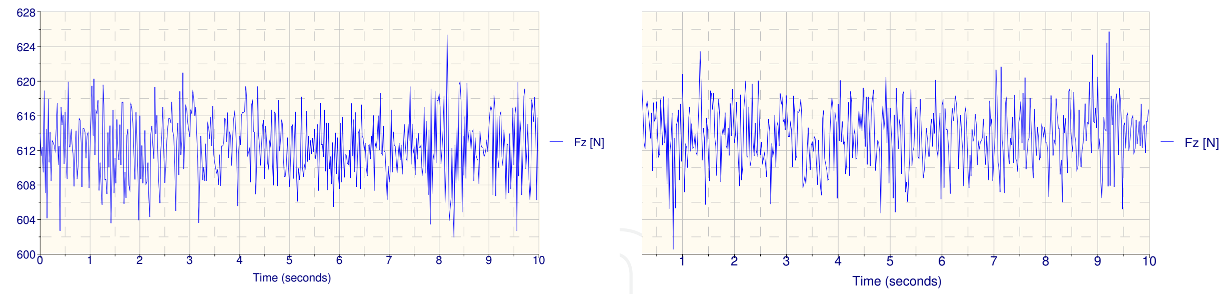


Fig. 18. Force recording on Oz axis without any stimulus and on a big base support

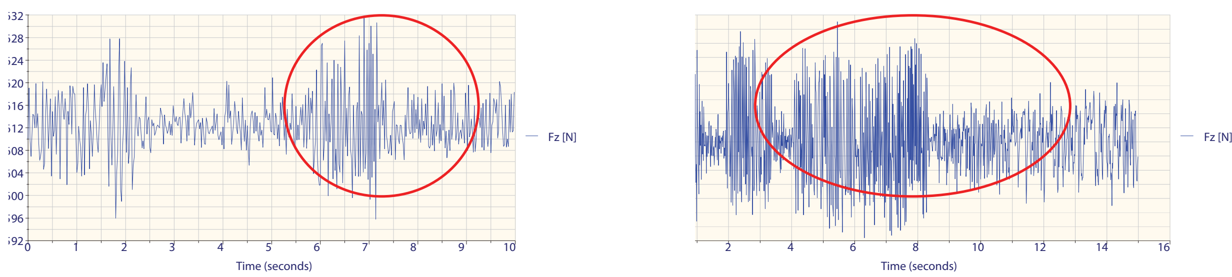


Fig. 19. Force recording on Oz axis with visual stimulus and on a big base support

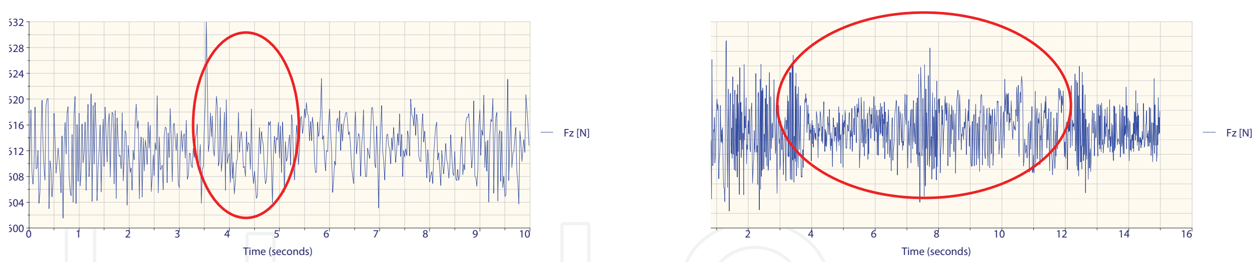


Fig. 20. Force recording on Oz axis without any stimulus and on a small base support

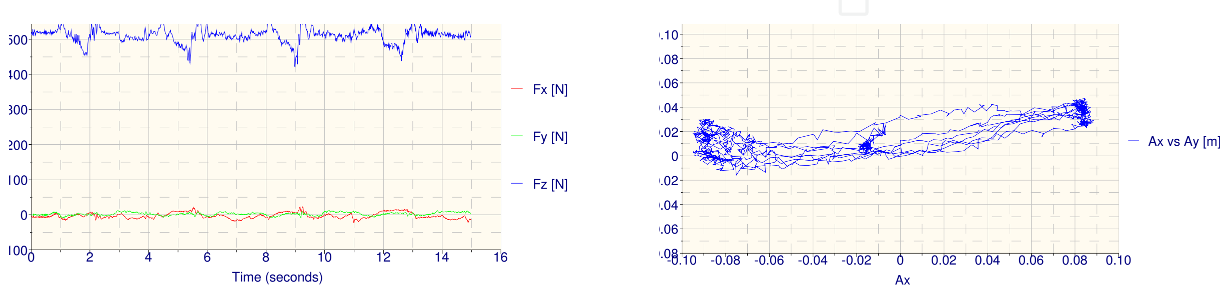


Fig. 21. The forces graph for all directions (x, y, z) and the stability area for the test no.1

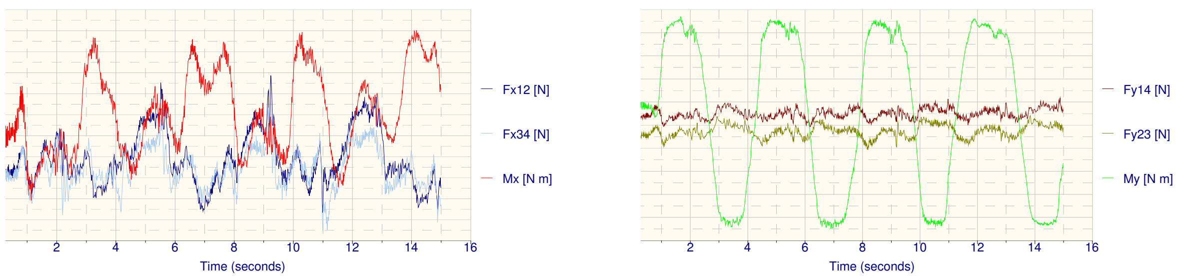


Fig. 22. The force and the moment for Ox direction, also for Oy direction in the test no.1

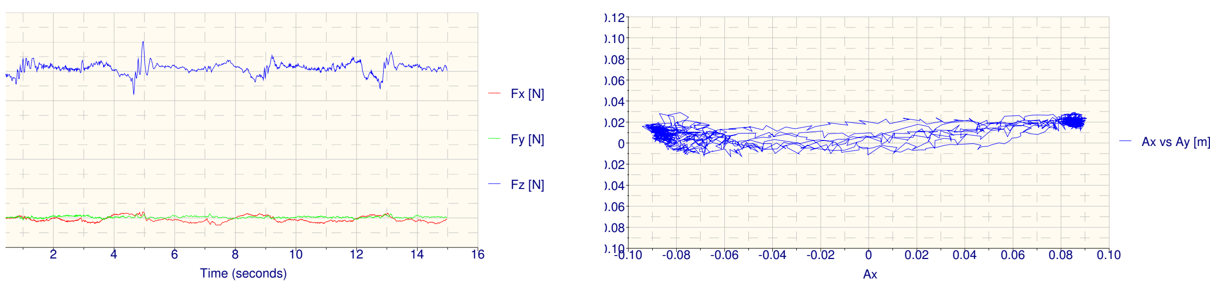


Fig. 23. The forces graph and stability area for all directions (x, y, z) (test no.2.)

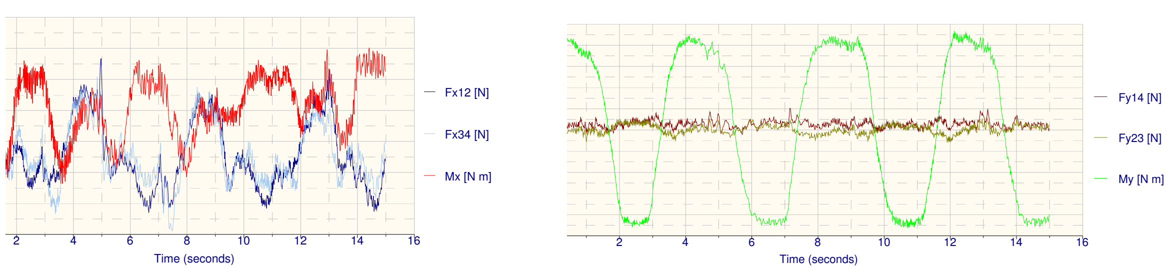


Fig. 24. The force and the moment for Ox direction, also for Oy direction in the test no.2

From these recordings and in according with the initial conditions and the demands of the researches we can observe:

- changes in foot position have been found to affect measurements of standing balance, the location of the line of gravity and the postural sway;
- under normal conditions the size of the base support is a primary determiner of stability;
- the height of the CG relative to the base of support can also affect stability;
- the most important values of the forces are the force components from direction Oz because they can establish the amplitude of the balance in other two directions Ox and Oy;
- changing the size of the support base from small to big one it can observe that the stability areas are different like shape, but almost the same like values;
- the influence of the visual stimuli in the eyes positions are also the most important because the instability will be bigger in the open eyes position than the closed eyes position. This situation is due of the visual or audio external stimuli from environmental space or other kind of stimuli, controlled or not.

4.2 Gait cycle analysis

The gait cycle analysis for the subjects in the used sample considered the same recording procedure as far as the environment conditions are concerned and also the subjects' state. Besides the recordings performed by help of the Kistler force plate and Bioware software, we recorded at the same time the responses of the accelerations measurement system for the lower leg and foot centre of gravity in order to correlate these values. For example in fig.25 and fig.26 we represent the graphical variation of the foot and lower leg centre of gravity accelerations and velocity along the two directions Ox and Oy, for a human subject, 28 years old, having 89,7 kg weight and 1,76 m height in normal effort and environmental conditions.

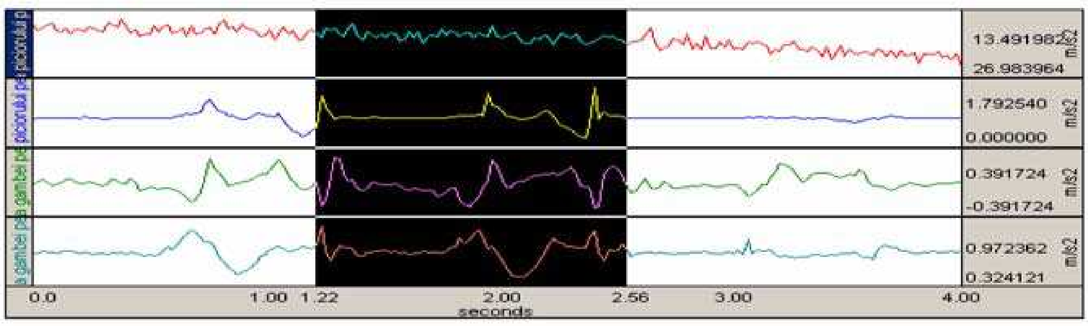


Fig. 25. Variation of the foot/lower leg centre of gravity acceleration on Ox and Oy

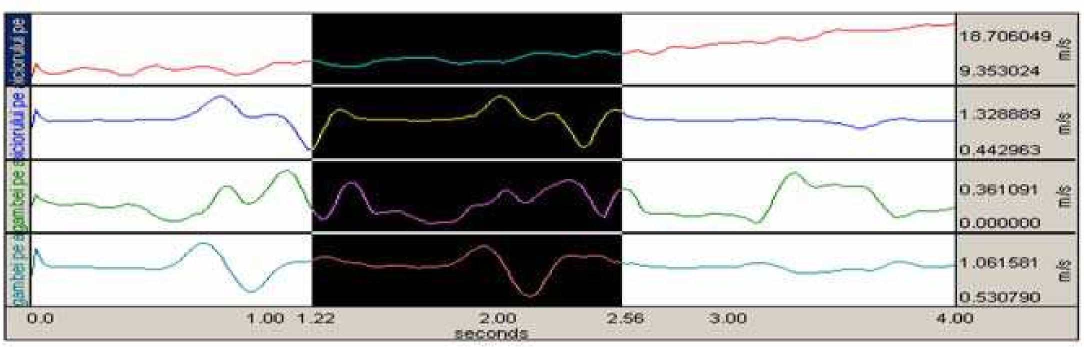


Fig. 26. Variation of the foot/lower leg centre of gravity velocity on Ox and Oy

In the following graphs we present the recordings made with the same subject, in the same conditions (position of hands, day time-morning after a relaxed period, the same environment physical conditions etc.) but in different situations, simulating the influence of the biomechanical effort in the human body.

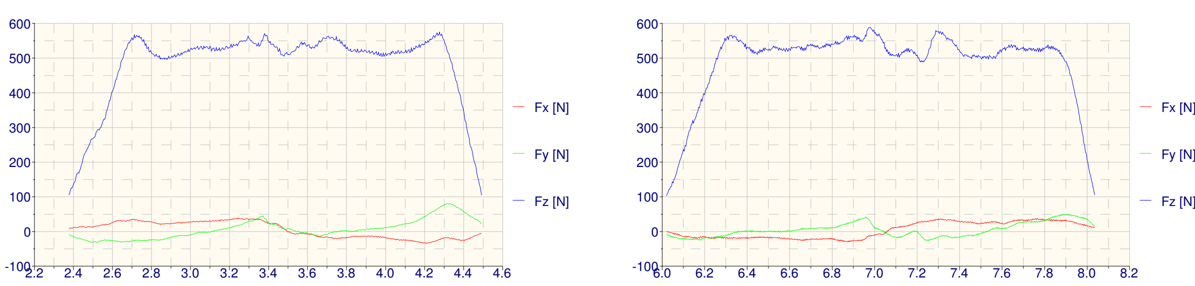


Fig. 27. Recordings of the forces measurements in normal gait before controlled effort

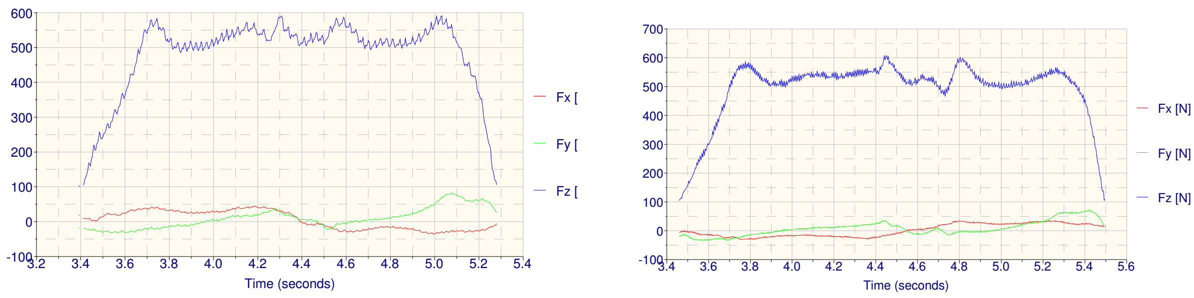


Fig. 28. Recordings of the forces measurements in normal gait after controlled effort

Following these multiple analyses, an evaluation structure was created, based on advanced techniques and focused on the study and characterization of the bio-behavioral performances for the locomotion system by configuring the system in relation to the visual, acoustic and thermal stimuli, with a future development towards a complementary analysis that takes into account also the upper part of the human body.

This system is completed by an investigation technique with computerized correlated systems for obtaining results in real time and setting proper sequences for each subjects sample selected for different assessment procedures.

In the same context and by this proposed investigation structure we establish also that the human subjects are analyzed and compared to the corresponding virtual models of the stability or walking measurements simulations in order to correlate all the influence factors from environmental space (Cotoros D. et al., 2009)

From these recordings and according to the initial conditions and the demands of the researches we can conclude: that the most important force values are the components on the direction **Oz** because they can establish the amplitude of the balance (moments) in other two directions Ox and Oy.

Also the changes in foot position have been found to affect measurements of standing balance, force and stability surface and in normal conditions the size of the support is a primary determiner of stability.

Other influences were the light stimuli on the visual system because they are the most important stimuli inducing the instability that will be bigger in the open and fixed oriented eyes position than free gaze even if the optical stimulus was the same.

This situation is due to the unknown visual external stimuli reactions and concentration on the automatic activities.

Other applications of these modeling and simulation structures represent the subject of a more extended research, which allows the developing of an investigation-assessment-rehabilitation protocol for the hip implant patients or for the patients with different walking impairments or for disabilities developed into working activities or for analyzing the ergonomy of a working place (Hausdorff M.J. 2005).

Thus, for a quick response in the analysis of the gait type and forces developed in the subject locomotion system or stability, the created methodology can estimate and correlate data at different recording times and respectively for different anthropometrical dimensions or mobility restrictions to improve by advanced techniques the ergonomy and capabilities of working places.

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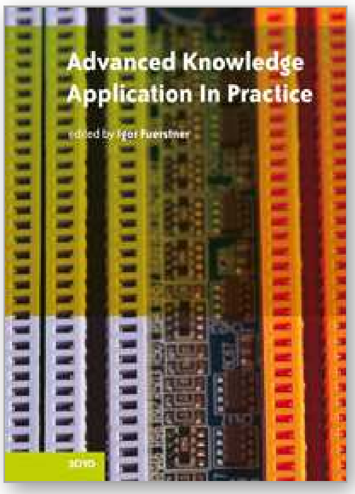

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