SYSTEM AND METHODOLOGY FOR THE ANALYSIS, DIAGNOSIS AND CORRECTION OF HUMAN LOCOMOTION

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Abstract: *The paper presents an innovative system – Ergosim – developed for the analysis, characterization and correction of human locomotion pattern, which can be used with very good results in medical rehabilitation situation, for patients with locomotor problems (due to legs traumatisms, neurologic disorder, strokes, etc.) and for improving the locomotor skills of athletes. The solution adopted by the authors is based on the use of visual feedback, available as movement curves on a computer screen, which helps the subjects by bringing to the consciousness level the automatically sequences of the movement engrams, naturally controlled at the subcortical level. Descriptions of the electromechanical subsystem, diagnosis and correction methodologies are provided in this paper.*

Key words: *gait analysis, gait correction, movement pattern, engrams, Ergosim*.

1. INTRODUCTION

Ergosim system (Figs. 1 and 2) represents a novelty in the biomechanical and gait analysis/control fields, offering the possibility to characterise, and then correct and optimize the movement stereotype on the base of a visual feedback which presents the movement curves (Fig. 3).

The system can help the rehabilitation of people suffering from amputations, strokes, spinal injuries, muscular diseases or other medical problems, which caused them modifications of the normal locomotor pattern. Moreover, the system can be successfully used for improving the locomotion performances in different sports such as swimming, running, tennis, etc.

The literature in the field presents researches focused on different methods to assess the gait parameters [1], on developing methodologies to interpret gait analysis data [5], on modelling, simulating and correcting human locomotion [2, 4, and 5].

The analysis of these studies showed that in order to correctly characterizes the gait pattern, a sufficient number of steps and associated biomechanical parameters must be measured and recorded in real time, visual and auditory feedback must be provided to the subject and also improvements of the kinematic analysis systems and of the data acquisition systems must be made [3 and 5]. Motor engrams and gait pattern have to be the basic approaches for an accurate gait analysis and evaluation.

A survey of similar commercial systems (Electronic Baropodometer, Body Analysis Kapture, Biomechanics etc.) shows that they are used mainly for diagnosis purposes and do not offer the possibility to vary the movement conditions, to determine the component of the propulsion force along the movement direction nor to characterize the stereotype stability, consequently not allowing its correction.

In this context, Ergosim system is proposing a novel approach in which the parameters contributing to the propulsion of the center of mass of a human subject are evaluated in real time and displayed on a computer screen as a visual feedback (Fig. 3), which acts like an interface between the subcortical and the conscious gait control. Without this visual feedback, the conscious locomotor movement is limited only to a simple transmission of the gait parameters, the subject not having the possibility to see and assess the results of his/her movement and thus to control them.

Furthermore, Ergosim offers the possibility to parametrically control the conditions in which the movement is taking place by modifying moving forward resistance coefficient, initial speed etc.

The electromechanical system and the force transducer are used for collecting information about the force of propulsion, which is then sent to specialized software for real time analysis and evaluation.

Fig. 1. Ergosim system.

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Systems for data acquisition were developed to be able to acquire also biological signals for movement control (electromyographical, electroencephalographic), in order better understand of the way in which the gait is generated and how it can be corrected or optimized.

Ergosim contains the following main subsystems (Fig. 4):

- SSM - mechanical subsystem;
- SSAD - data acquisition subsystem;
- SSS - software subsystem;
- SSC - control subsystem;
- SSV - visualization subsystem.

This paper presents details about the design of the mechanical subsystem and diagnosis/correction methods, as well as conclusion regarding the functioning and efficiency of the prototype model.

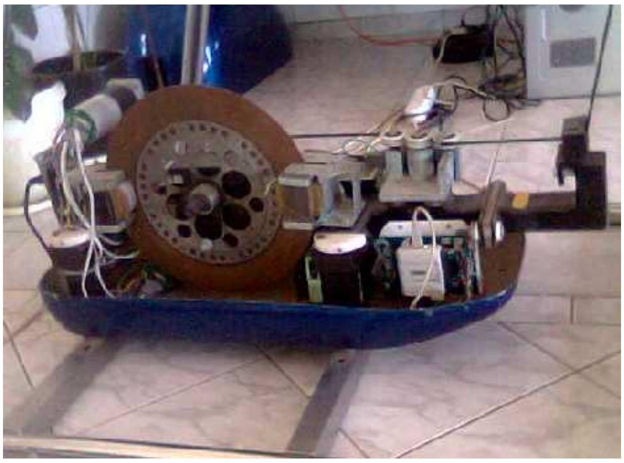

Fig. 2. Top view of the electromechanical system.

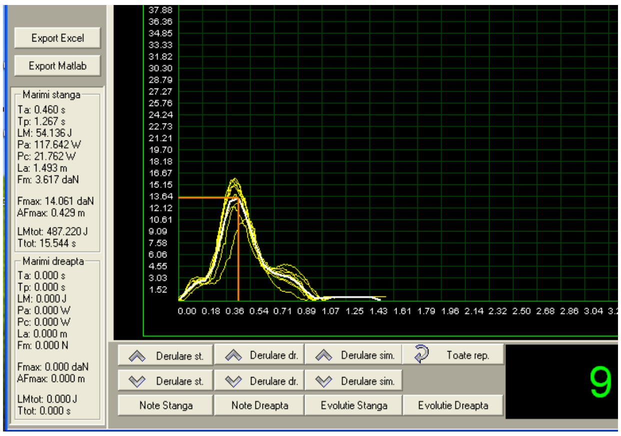

Fig. 3. Movement curves.

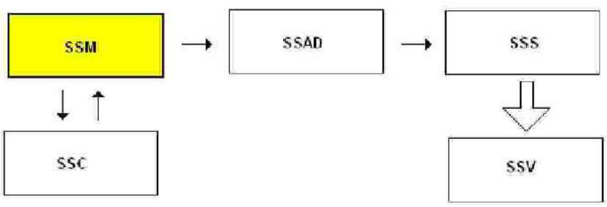

Fig. 4. Block scheme of the functional model.

2. ERGOSIM SYSTEM DESCRIPTION

2.1. Design of the electromechanical subsystem

Figure 5 shows the general scheme of Ergosim, which includes an electro-dynamic break FE and two electric motors ME1 and ME2 (type IM233, Technosoft Company, Sweden) for varying the load depending on the diagnosis and the methodology used for correcting the human subject gait pattern. This way different movement constraints can be generated, allowing the control of the conditions in which the movement is taking place. Motors ME1 and ME2 have digital signal processors, position transducers and analogue-digital converters for force measurement. Information referring to the force of propulsion generated by the human subject *S* is collected by the computer assisted electromechanical system, by force and position transducers, and then used as input for the evaluation software.

The results are presented in real time as curves on the screen *M*, to both to the human subject and the medical assistant for correcting the movement pattern. Also, the system includes position sensors (encoder type), force sensors (tensometrical marks, type 6/350LK11/G from HBM Austria) and pressure sensors (contact type), which are placed in the subject shoes.

The basic scheme was used for digitally modelling the mechanical system in CATIA V5R16 software (Figs. 6−7).

The digital mock-up proved to be useful not only to manufacture the system components, but also to check the assembly constraints (interferences or unwanted contacts) and to verify the functionality of the device before actually building the prototype.

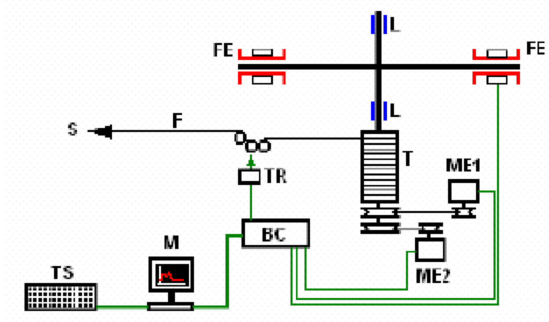

Fig. 5. Basic scheme of Ergosim system.

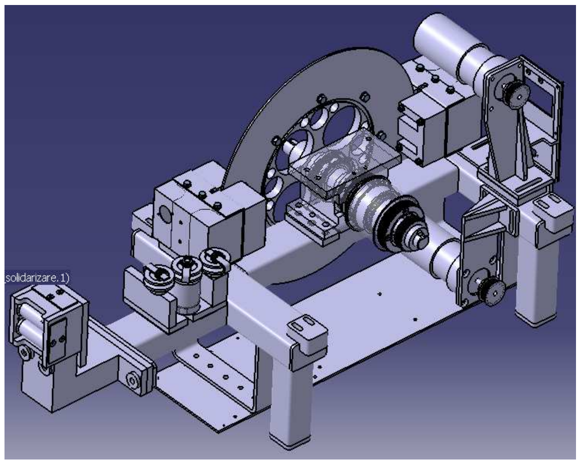

Fig. 6. Digital model of Ergosim, CATIA V5R16.

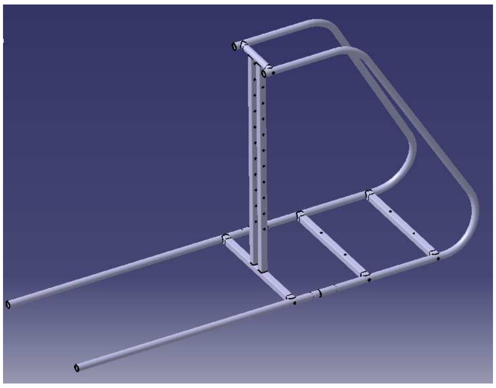

Fig. 7. Ergosim frame.

2.2. Design of the diagnosis methodology

Clinical practice of the post-traumatic recovery of lower limbs showed the necessity of a global approach of the gait pattern. There are situations in which the segmental recovery, usually performed according to the classical methods and medical practice, is solving the problem only for a short term. For longer periods of time (2−3 years) other diseases such as coxarthrose or gonarthrosis (especially for patients over 50) can affect the traumatized limb or knee, due to a deficient gait pattern.

In order to avoid these problems, along to the technical system, the authors proposed also a methodology for analyzing the gait pattern and for evidencing the deficiencies. For this purpose, the human subject shoes contains special inserts containing contact sensors placed at the extremity of the sole (first and last contact between sole and ground, Fig. 8). The sensors signals are sent to the data acquisition system.

The body mass center constitutes the point were the wire is tensed for constraining the movement (Fig. 9), the propulsion force being measured horizontally and vertically. The movement constraints can be varied in a controlled manner, as explained above. The information about the propulsion force is sent to the software which performs the recording and visualization of the propulsion diagram. Two different colours are used for assessing, with time and position, the contribution of each limb to the propulsion (Figs. 9−10).

Qualitative analysis of the curves presented in Figs. 9−10 allow the evaluation of the contribution of each segment of the kinematic chain to the propulsion effort, as well as laterality differences (right-left). These differences can be analytically approached by individually testing the muscular groups from the propulsion kinematic chain, offering the possibility to establish the causes for the movement pattern differences.

Fig. 8. Pressure sensors at the sole level.

Fig. 9. Placement of the wire and sensors on the subject.

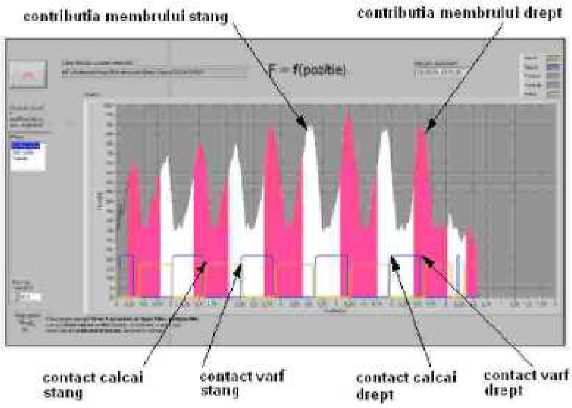

Fig. 10. The evolution of propulsion force with position.

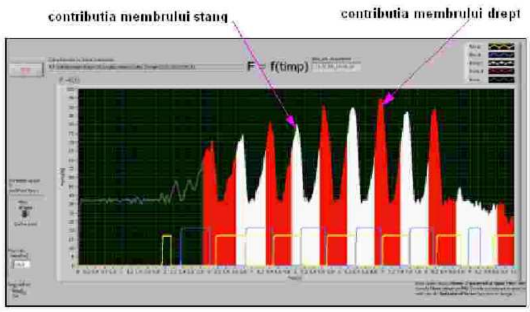

Fig. 11. The evolution of propulsion force with time.

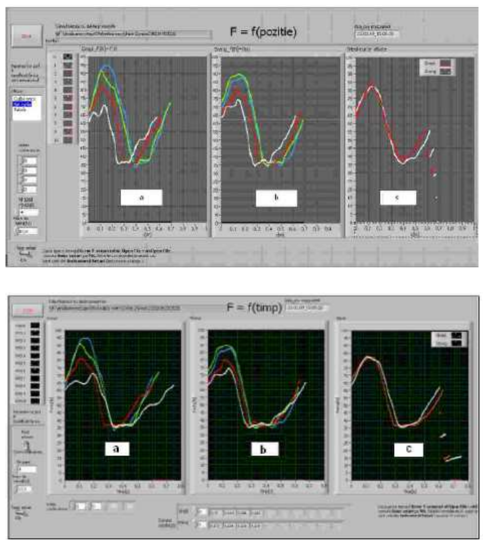

Fig. 12. Superposed curves: *a* – right lower limb contribution; *b* – left lower limb contribution; *c* – mean values.

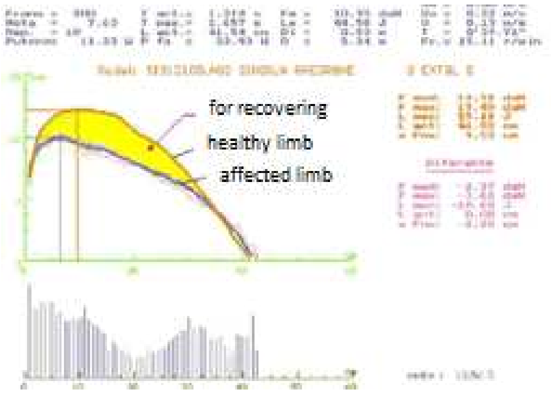

Fig. 13. Force-amplitude curves for healty and affected limb.

2.3. Design of the correction methodology

The correction methodology is based on the system capability to allow analytical correction (on each element of the kinematical chain), as well as global correction of the movement pattern (using the visual feedback in real time). Applying the diagnosis methodology, the following situations were identified:

- Deficiencies localized at the gait pattern level without having a clear cause at the level of analytical components of the kinematic chain;
- Deficiencies localized at the level of kinematical chain;
- Deficiencies localized both at the movement pattern level and at the level of analytical components of the kinematic chain.

According to each category, different recovery protocols can be applied using the visual feedback to correct the amplitude of the movement and the value of the propulsion force for the limb having a deficient pattern. Also, the capability to vary the load in the wire for controlling the propulsion force is used for correcting and optimizing the gait pattern. In these situations, on the base of a battery of tests from the diagnosis phase, treatment programs are established. These programs start with movements which are not causing pain to the patient and are performed gradually until the pain disappears even at maximal contractions levels. This approach leads to the total recovery of the movement muscular control.

Using specific protocols the analytical correction are performed first, thus creating conditions for approaching the correction on the movement pattern, and then protocols for movement pattern correction are applied. The recovery protocol is continued until the difference between the motor characteristics of the healthy and affected limb are recovered (yellow surface from Fig. 13). The accomplishment of the objectives of this recovery phase creates the conditions for correcting the deficiencies at the movement pattern level as well as at the level of analytical components of the kinematic chain.

3. CONCLUSIONS

Specialized statistics shows that there is a continuous growing of cases in which human locomotor functions are affected due to the aging of the global population, accidents, congenital deficiencies, etc., with a major social impact. In this context, researches are made for improving the recovery methodology and specific devices, for decreasing the treatment period.

The current paper presents the prototype of an innovative system for evaluating, correcting and optimizing human gait pattern. The system uses standard subassemblies and components from well known producers from the fields of robotics or data acquisition. The performances are ensured also by the development of dedicated software for monitoring the system functions, for real time visualization and offline processing of biomechanical data for the gait pattern.

Ergosim system prototype was used for accomplishing the following main objectives:

- Experimental assessment of the movement pattern characteristics when subjected to different external perturbations (modification of initial speed, modification of moving forward resistance, etc.) on various categories of subjects (persons − non-athletes − with different type of locomotor problems, athletes with different medical problems, athletes with specific technical locomotor problems which negatively affect their performances);
- Experimental assessment of the movement pattern characteristics when subjected to different internal perturbations (modification of the energetic resources of the human body, etc.) for the above mentioned categories of subjects;
- Improvement of the diagnosis and correction methodologies;
- Improvement of the qualitative parameters of the active simulator based on the testing results;
- Evaluation of the possibility to use Ergosim for other type of applications.
- Also, the functional prototype of Ergosim system evidenced the following problems to be further solved:
  - design and manufacture a system for wire guiding so that to avoid an unequal wound with implication on the movement smoothness;
  - design a solution for fixing the Ergosim frame on the ground, this way avoiding its movements during different exercises.

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