

Threedimensional Analysis of Spinal Deformities



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Relational Data Base for Quantitative and Statistical Analysis of Static and Dynamic Biomechanical Spinal Measurements

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Abstract. Computerised multifactorial analysis can be considered today a new concrete possibility of investigation in clinical applications and in particular for pathologies of the spine. In fact the detection of human biomechanical variables is today well supported from a technological point of view, and a number of very sophisticated analysers are able to provide a complete set of data for three dimensional representation of the vertebral column. Conversely the problem to face is how to manage the enormous quantity of data available for each subject, and how to perform a statistical analysis that could involve for each variable a comparison between different groups of data. The aim of this paper is to describe a special developed integrated software package including a relational data base manager and a signal processing algorithm for the management of quantitative and detailed statistical comparison among different kinematic and dynamic patterns.

1. Introduction

Computerised biomechanical analysis of the spine and of the whole body begins now to migrate from the research environment toward clinical applications. In fact the detection of human biomechanical variables is today well supported from a technological point of view and a number of very sophisticated analysers are able to provide a complete set of data (stereoradiography, CAT or NMR scan, optoelectronic systems etc.) for three dimensional representation of both static and in some case dynamic attitude of the spine. This can be considered a kind of analysis that would have been considered unthinkable only few years ago because of the large amount of time and very high costs required to obtain and collect the data. Conversely a new problem must be faced, that is the handling of the enormous quantity of data available for each subject coming from different devices, and the creation of a standard protocol to perform a statistical analysis and comparison between different groups of homogeneous variables. In this paper an integrated software package for the analysis of clinical and biomechanical data will be presented. It includes two main blocks: a specially developed relational data base manager that allows to collect anamnestic and anamnesic data, anthropometric and biomechanical measurements, clinical images and other information about each patient; a signal processing algorithm for the management and quantitative and detailed statistical comparison among different kinematic and dynamic patterns.

2. Methodology

As cited above the integrated software package has been developed with the aim to allow a statistical comparison taking into account a Multifactorial approach. The Multifactorial approach involves the analysis of kinematic, dynamic and electromyographic variables that can be directly recorded (by means of motion analysers; force platforms; electromyographs; radiographic, rasterographic and tomographic images etc.) or derived (as for instance velocity, acceleration, joint torque, power etc. by means of signal processing algorithm, mathematical body model etc.) from which it is possible to extract a number of correlated parameters of clinical significance. In this case, given the availability of the new relatively low cost information technologies, it is possible to collect a large quantity of data, to process them in a statistical way and to proceed in a classification even for large population. The application of the statistical comparison approach can be used in two main different modes: the Intra-individual and Inter-individual mode. For each mode, two different purposes can be pointed out: the first involves directly pathology evolution combined with the therapeutic follow-up, the second involves in general the classification of various pathologies and in particular the classification of the subject's characteristics with respect to a population.

The *Intra-individual* mode is adopted when the matter of interest is to study the single subject variations along time, for instance the evolution of an Idiopathic Scoliosis in a patient during the adolescence, or the monitoring of a particular physical therapy when a rehabilitation period after a trauma is necessary. This allows to establish quantitatively the effectiveness of the treatment with respect to the global results and/or to the various variables of interest.

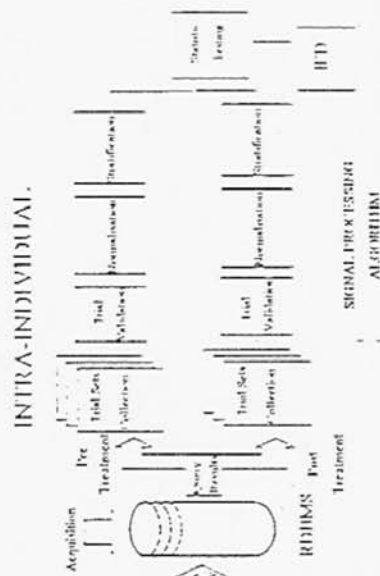


Fig. 1 General Data Flow Scheme for Intra-Individual Analysis.

The *Inter-individual* mode is adopted when the matter of interest is to study a subject's characteristics with respect to other subjects or classes of subjects. For instance in this mode the method allows to distinguish the "normality" from the "pathology" and moreover to distinguish between various differentiating attributes inside a pathology. The classification in various kinds of scoliotic deformities is typically used in order to standardise the treatments and the evaluations of the results obtained. In a wider use adopting this integrated software could be very interesting to build large classes for various specialities. Moreover it is important to stress the fact that the method allows to extract the variables to take into account for the clinical evaluation. In fact a clinician, studying a subject with a certain pathology or trauma with comparison to the class of normal subject, can focus his attention only to those variables which present a statistical significant difference. In order to obtain

such characteristics the software implementation has been subdivided, from a point of view, into two main parts: the specially developed signal processing algorithm and the data base management system engine. The first is devoted to treat the data and perform all the computations necessary to allow the statistical comparison, while the second is devoted to the data file organisation and management in order to allow the data to be used in a "data collection" mode. The meaning of "data collection" is here intended as the data arrangement in homogeneous groups containing all those typical series of biomechanical variables by individuals with similar anthropometric features, age, sex etc. associated with a particular postural state.

INTER-INDIVIDUAL

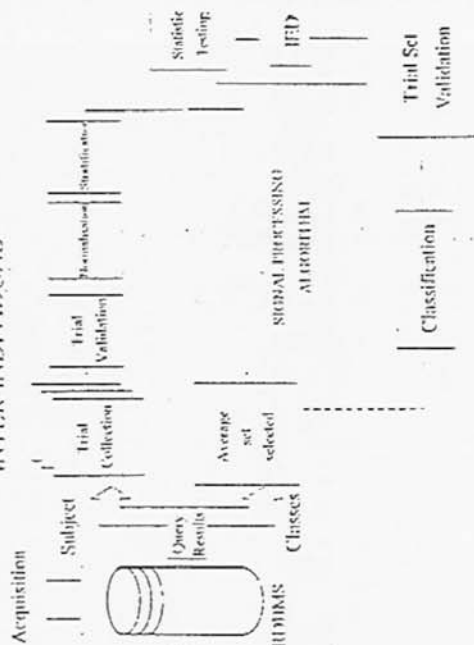


Fig. 2 General Data Flow Scheme for Inter-Individual Analysis.

2.1 Data Processing Procedure

Each kind of performance must be characterised by a data input fixed protocol, to allow the correct data collection and a consistent statistical comparison. Any protocol must consider the following steps summarised in fig. 1 and fig. 2.

a) Data Acquisition: as mentioned above, in this field various kinds of instruments can be employed to acquire quantitative data to be gathered in a Data Base N System. Indeed various are the possibilities to collect information and measure the status of the patient, but in particular for the aim of this work, we focused our biomechanical signals acquired using opto-electronic devices. In fact this technique record, without any disturbance or danger for the patient, a great number of dimensional measurements, so it can be extensively used in massive screening large classes of populations for statistical comparison. This kind of information combined, when necessary, with those deriving from other instrumentation (radiography, CAT scan, NMR scan and so on) and included in the Data-Base, the biomechanical measurements we refer to the use of the AUSCAN system [1]. On the type of postural test to be carried out, a number of small reflective hemispherical markers placed on the patient's body to mark the most proper anatomical reference points. When studying scoliosis, we studied a protocol in which the markers are placed on zygomatic bones, mentum, acromions, sterno-clavicular joints, acrophysis of

anterior superior iliac spines, posterior superior iliac spines, knee joints, heels, and spinous processes from C7 down to S3 every second vertebra. Two couples of (CC) cameras simultaneously work to pick up both the front and the back view of the patient while he is in a standing position for static analysis and during a bending test for a dynamic analysis. The standard protocol consist in the acquisition of at least five trials for both the static and dynamic condition. Other details can be found in [2].

b) Trial Goodness Validation: a constant uniformity among the various trials is compulsory in order to perform a reliable statistical analysis. In this case, this condition requires to do not consider as valid trials, those that do not agree with standard protocols defined for the data acquisition. For example, a standing examination in which subject's movement exceeds a suitable range will not be presumed reliable for extraction of clinical parameters and then for statistical comparison with other trials of the same subject or classes of population; the same will happen when the execution of a bending test is not correctly performed moving for instance the feet or the hips.

c) Pre-Treatment: given the biomechanical signals, further signal processing is performed in order to obtain other derived variables of interest, such as velocities and accelerations of body landmarks, angles, angular velocities and accelerations between body segments. At this step, we use the information just obtained to extract clinical parameters such as Cobb Angles, Scoliosis classification and so on as described in [2]. Other parameters can be obtained by performing the image processing procedure described in [3] on digitised X-ray picture.

d) Statistical Analysis: Considering static analysis (including that achieved elaborating the X-ray images) all the parameters computed in the previous step are sufficient to perform statistical analysis. In fact they may be used by the user to define queries for the Data Base and to build classes of subjects with specific characteristics to be compared, as well as it can be done with the anthropometric and anamorphic parameters. Conversely a further step must be carried on if dynamic data are considered. Actually in this case, the time course of manifold variables have to be "normalised" (both in time and in amplitude), in order to proceed in a point to point statistical comparison between different groups of data. Time normalisation consists of an interpolation/approximation procedure that is necessary to obtain the same number of samples from different data acquisitions of subjects performing the same kind of movement (in this case lateral bending test). Amplitude normalisation is involved when various data sets, featuring different absolute values, but similar morphologies, must be compared. For instance all the values of the various data sets can be referred to the unity by scaling them with respect to the difference between the values of the absolute maximum and minimum of each variable. At the end of this process also for dynamic analysis is possible to proceed into a statistical approach by computing the average trial (from the five acquired) by performing a "data stratification" on the normalised series. Mathematically this is obtained by computing for each *i*-th element of the series the stratified mean values (μ) and the related standard deviation (σ). Finally the statistical analysis is achieved by comparing the average trial of a subject before and after a period of treatment (*Inter-individual mode*) or by comparing the average trial with the average trial representing a population class (*Intra-individual mode*). Analytically the difference occurring between two typical groups of data can be estimated by applying a two tailed t-test to each *i*-th element of the series. The statistical results are synthesised by a merit parameter named I.E.D. (Index of Estimated Differences). The detailed description of the mathematical procedure is beyond the aim of this paper and can be found in [4].

2.2 The Relational Data Base

In order to obtain this kind of elaboration architecture the Relational Data Base must be implemented taking into account the necessity to analyse a large amount of data and also the

possibility to share information with other user and Departments. In this way a database architecture has been designed both from the "conceptual" and the "physical" point of view and they will be shortly summarised hereinafter.

Fig. 3 shows the conceptual scheme based on the Entity-Relationship (ER) model [5,6]. basic concepts provided by the ER model are entities, relationships, and attributes.

a) Entities represent classes of real-world objects: for example in a clinical data PERSON, CLINICIAN, CLINICAL_SESSION are entities and they are graphically represented means of rectangles.

b) Relationships represent aggregations of two or more entities. An example of a binary relationship is TREATED_BY, which relates PERSON and the family CLINICIAN. Relations are graphically represented by means of diamonds. Relations are characterised in term minimal and maximal cardinalities. For example, TREATED_BY is a "one-to-many" relationship between PERSON and CLINICIAN, since each person could be followed treatment by one or many doctors. This is indicated as a number on the links between entities.

c) Attributes represent elementary properties of entities and relationships: NAME is attribute both of relationship PERSON and CLINICIAN. Attributes are associated to a domain with a cardinality and are graphically represented by a stick with a small circle on top.

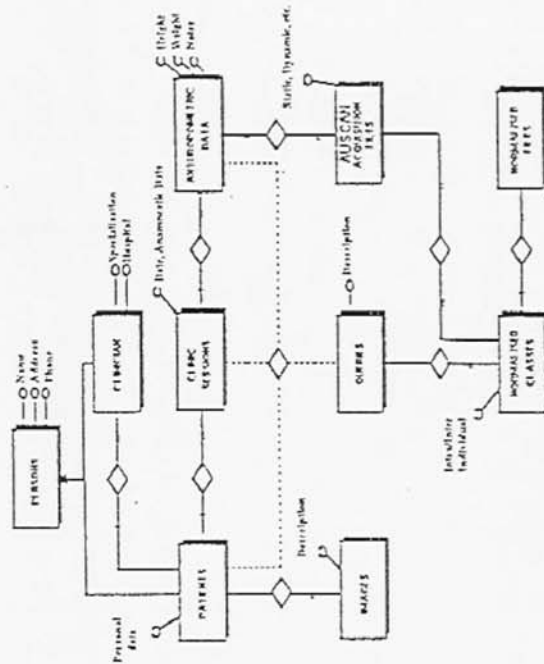


Fig. 3 Database Conceptual Architecture

Fig. 4 describes the planned physical architecture of the database including the acquisition devices and various possible media as a Local Area Network (LAN). Graphic workstations and a number of different storage elements for short and long term archiving depending the access demand frequency.

One or more workstations develop the activities of elaboration, update and normalisation in classes. The integrity of the informative system are guaranteed by the RDBMS. The first level of archiving system allows only the averaged trial per patient's session to remain in the short-term and fast storage while each single file belong

to a subject's trial after the necessary time to complete all the elaboration can be transferred on optical disk for long-term storage.

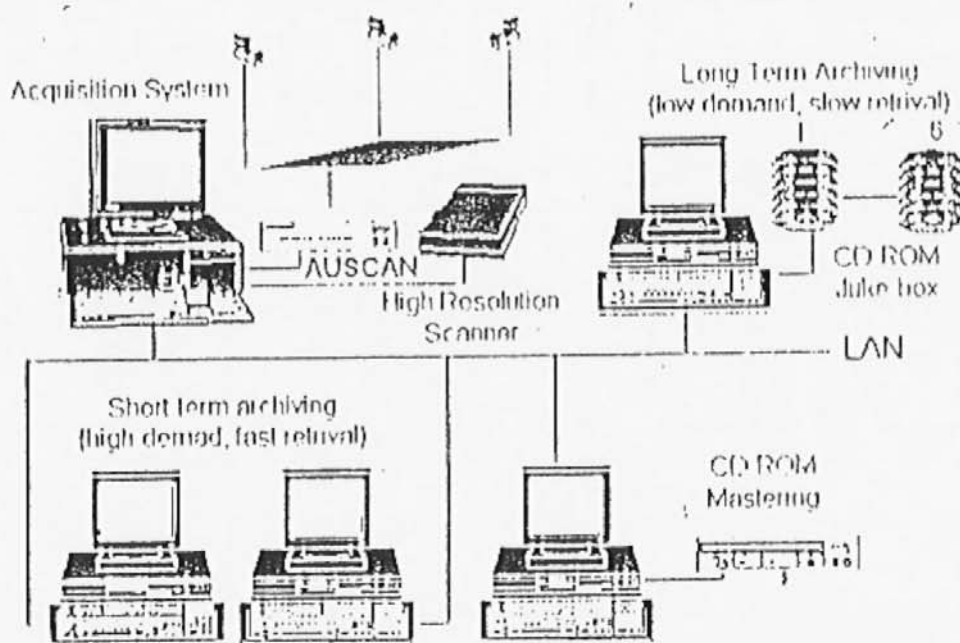


Fig. 4 Database Physical Architecture

3. Conclusions

To present examples of results is beyond the aim of this paper in which only the methodology and the software characteristics are presented. The proposed procedure has been developed in order to offer a wide possibility of use in the clinical field and for various pathologies.

We claim the adoption of a point to point statistical comparison contrarily to the purely visual interpretation of the pattern morphology of the biomechanical variables because it is the proper method to provide a complete description of the motor performance and of the differences occurring between either a single subject or groups of subjects.

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