A New Hybrid Methodology for Motion Emulation in Virtual Environments

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Abstract
Simulation of natural human movement has proven to be a challenging problem, difficult to be solved by more or less traditional bio-inspired strategies. To simulate human-like movements in a virtual environment a sample database of real movements has been first transformed into sequences of instantaneous states of an explicit biomechanical model. These are then associated to an anthropometrical class of reference in order to be interfaced with an artificial neural network, resulting in a new hybrid approach for data aggregation. Experimental tests have been performed on the upper part of the human body, in particular on the movements of arms and head with respect to the trunk. The analysis has been focused on three different tasks, chosen in assembly line, car interior and manufacturing environment.
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1. INTRODUCTION
Human interaction with such complex systems as working places, driving seats, or cockpits is more and more asking for designers to face both the human-machine compatibility ("industrial ergonomics"), and the efficiency of the overall engineering system. Because of the rising costs in product development, the market is issuing a growing demand for advanced ergonomic tools, capable to assist the product designer in evaluating the human behaviour under several perspectives. In particular, the correct simulation of pseudo-human movements in virtual environments could help designers to assess the suitable ergonomic variables and their influence on some product features. This gives the opportunity to avoid both the construction of physical mock-ups and the execution of long experimental runs on real people at an early design stage.

In opposition to several existing solutions, mainly based upon deterministic algorithms [7][8], a data-driven approach is presented herewith, which is able to grasp the natural essence of human movements. The work aims to propose a methodology based on the inference of each pseudo-human (i.e. virtual) movement, starting from a sample database of real ones, previously logged by means of any data acquisition system.

ANNs (Artificial Neural Networks) have shown their suitability in descriptive and predictive generalisation of complex systems. They offer the possibility to take real experimentally acquired kinematical data and to interpolate and extrapolate the movements into conditions that have not actually been recorded.

The nature of the problem suggested a two-step methodology.

In the first step, each real movement is transformed into a set (or sequence) of instantaneous states (or postures) of a parametric biomechanical model. This transformation procedure also allows estimating the uncertainty associated to the biomechanical model parameters.

In the second step an artificial neural network (ANN) has been adopted to learn the way humans perform elementary tasks.

In order to reduce the complexity of the second step, data related to different subjects, or different tasks, can be compared if these different cases are referred to a standard mannequin. Such data are obtained by sampling the movement of suitable checkpoints that, in the actual experiment made herewith, correspond to passive markers (fig. 1) attached to the human body and logged by a specific acquisition system - ELITE – developed at the “Politecnico di Milano” [12].

Therefore an anthropological classification, combined with a suitable data transformation procedure, is given in order to interface the network with a set of mannequins-independent data, representing a standard sequence of postures.

An application of this hybrid approach to a simple experimental case is presented, which proves that the proposed data analysis could be afforded without any underlying hypotheses about the human dynamics.

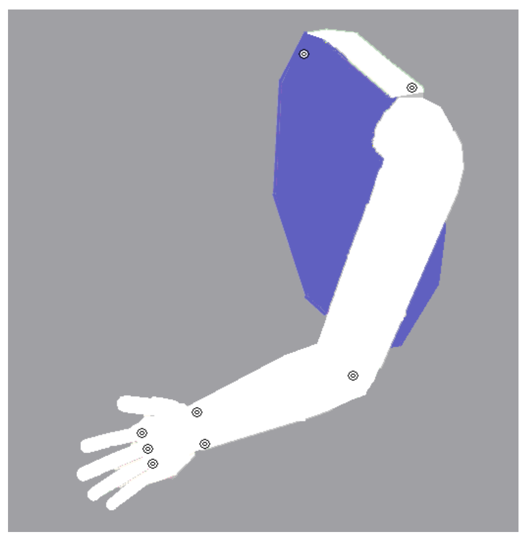

Figure 1: Example of marker position for detecting the movement of a human arm.

2. THE HYBRID METHODOLOGY
In case of complex systems it is hard to assess all the system parameters by means of a set of direct and independent measurements, as the specific context could affect any identification methodology of the very parameters.

Specifically, collected data can be represented as a series of Cartesian trajectories of checkpoints (hereafter referred as raw data), measured in laboratory co-ordinates. In principle, raw data could be completely interpreted by means of an ANN: the latter could learn both the structural (i.e. anthropometrical) and dynamic relations among raw data and other ergonomic factors. Anyway the two faces of the same problem should better be de-coupled upon availability of an explicit model for structural relations only. This hybrid approach is justified by a set of reasons, listed below [3][4].

Since the biomechanical features of the person under test are known in advance, there is no use to make recourse to neural computation in order to determine those constraints imposed by geometric relations among the marker locations, which – in case of tests performed on a single person – are fixed throughout the whole set of experiments. Otherwise, the ANN would be indirectly charged with the target of modelling those time-invariant relations that have a different nature from other time-dependent relations and factors mentioned above.

In case of tests performed on more individuals, relative raw data cannot be directly compared and used to train the same ANN: as a matter of fact, the constraints imposed by geometric relations among the marker locations would be different from person to person, and would ask for further integration to the neural computation.

For both cases, given any other set of conditions, a demand for wider integration would negatively reflect on the total uncertainty of the ANN prediction.

Another reason arises from the fact that the ultimate purpose of this work is to reproduce a realistic simulation of human movement by means of a virtual mannequin, implemented in a CAD environment. The latter obviously imposes its own geometric relations, thus giving rise to unavoidable discrepancies between the mannequin movements and the information got back by the ANN (based on raw data, whatever real test they may represent).

As to what has been stated above the sampled raw data are first used to evaluate the parameters of an explicit model for the structural relations among marker locations. The fitting model is used to define a referring posture at every time step, which in its turn is identified by the set of model state variables (i.e. angular values of rotational joints). In such a way, raw data are transformed into a sequence of values for such variables, representing the information quota strictly related to the dynamic characteristics of human movements.

The proposed structural model, in its overall form, consists of a cinematic chain with *G* segments and *M* joints, and with a total number of *D* degrees of freedom (DoFs).

A *local reference system* is attached to each segment S_j in order to reconstruct its position and orientation in the space.

Denote with L_j and L_w the *local reference systems* of two consecutive segments, respectively S_j (descendent) and S_w (parent). If $\boldsymbol{P}_k^j$ is a column vector specifying the homogeneous co-ordinates of a generic point *k* in the local reference system L_j, the vector $\boldsymbol{P}_k^w$, specifying the homogeneous co-ordinates of the same point in the parent *local reference system* L_w can be calculated as

$$\boldsymbol{P}_k^w = \boldsymbol{A}_j^w \boldsymbol{P}_k^j = \begin{vmatrix} & \boldsymbol{R}_j^w & & x_j \\ & & & y_j \\ & & & z_j \\ 0 & 0 & 0 & 1 \end{vmatrix} \boldsymbol{P}_k^j \quad (1)$$

where (x_j,y_j,z_j) are the co-ordinates of the origin of the local reference system L_j with respect to L_w and $\boldsymbol{R}_j^w$ is the rotation matrix of L_j with respect to L_w.

By identifying the origin of each *local reference system* with the rotation joint centre that links the current segment with its parent, the co-ordinates (x_j,y_j,z_j) allow for the straight recover of the distances between joint centres, that is the anthropometrical lengths or structural parameters of the biomechanical model.

Now denote with $S_0\, S_x\, S_y \ldots\; S_w\, S_j$ the polygonal that belongs to the cinematic chain starting from the root, up to the segment S_j, where the elements of the polygonal are selected according to the topology of the current chain. The laboratory homogeneous co-ordinates $\mathbf{T}_k$ of a checkpoint *k* integral to the anatomical segment S_j can be recovered starting from its local homogeneous co-ordinates $\boldsymbol{P}_k^j$ with respect to L_j as follows:

$$\mathbf{T}_k = \boldsymbol{A}_x^0 \boldsymbol{A}_y^x \ldots \boldsymbol{A}_j^w \boldsymbol{P}_k^j \quad (2)$$

where the elements of eq. (2) are again selected according to the topology of the current chain. From the homogeneous co-ordinates $\mathbf{T}_k$ it's easy to obtain the laboratory co-ordinates $\mathbf{t}_k$ by selecting the first three elements of the array.

The biomechanical model establishes clear-cut hypotheses as to the nature of raw data before processing takes place. That is:

1. All the checkpoint positions measured on the same individual during the same experimental session derive from the same instance of the biomechanical model, which means that the model structural parameters are time-invariant.
2. All the checkpoint positions that belong to the same posture derive from an instantaneous state of that instance (i.e. not only the structural parameters, but also the DoFs are fixed).
3. Discrepancies between the measured raw data and checkpoint positions arise because the formers are affected by noise.

Of course the biomechanical model is not perfectly faithful. Strictly speaking there exist no "true" values of its structural parameters and DoFs. However "optimal" (i.e. maximum likelihood) values can be found through a suitable fitting procedure provided that a noise model is given.

3. MODEL FITTING

The model is characterised by *G* free structural parameters h_j (segments lengths: pelvis, trunk, clavicles, arms, legs,…), *M* joints and *D* degrees of freedom $\omega_{i,l}$ (rotation computed for *G* reference systems angles and translation co-ordinates of the *local reference system* attached to the root with respect to the laboratory system). Further unknowns are the locations $\mathbf{p}_k$ of the checkpoints with respect to the local reference systems.

The functional form (2) depends on the above-mentioned structural parameters whose values have to be determined to see the model practically behaving as a human emulator. So identification is necessary. The simplest way to proceed in this identification is to measure them with independent procedures for each frame starting by the marker positions registered by ELITE (intra-frame procedure). The estimates of the anthropometrical lengths are the mean values of the obtained samples. This way to identify the parameters is the simplest, but it can be criticised for two reasons:

- it is based on hypotheses about the locations $\mathbf{p}_k$ of the checkpoints with respect to the local reference systems.
- it doesn't provide the optimal estimate of the model