

AN AUTOMATIC METHOD TO IDENTIFY HUMAN ALTERNATIVE MOVEMENTS: APPLICATION TO THE INGRESS MOVEMENT

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Abstract:

Alternative movement techniques identification is primordial in many studies of biology, medicine and ergonomics. Few studies in literature propose quantitative techniques to achieve this purpose. Park et al. [19] proposed a biomechanical index based technique named JCV. This method finds its limits when dealing with three-dimensional complex movements. In the present study we propose a modification of this method so that it will be applied to complex movements. We consider a non-habitual end effector (Midpoint between Hips). We obtain other indices, 3BJCV, to which a non-supervised clustering technique is applied. We have applied our method to the ingress movements of 37 young and elderly subjects with or without prosthesis entering in a minivan vehicle. Our method allows the identification of the two big classes of ingress movements observed by Ait El Menceur et al. [4].

Keywords: joint contribution vector, automatic classification, automobile ingress movement strategies, young and elderly drivers, and biomechanics.

1. Introduction

Alternative movement techniques contribute to the movement understanding, ergonomic analysis or movement simulation. Many alternative movement techniques (motion strategies) are presented in literature like Assiante [10] with the description of the evolution of the equilibrium strategies for children, Burgess-Limerick and Abernethy [11], Zhang et al. [21] in the determination of the lifting strategies, Alexandrov et al. [6], [7] in the human trunk forward bending strategies.

Some authors identified alternative movement techniques in order to apply them in industrial applications. Among these studies there are studies dealing with vehicles. For instance, Monnier et al. [18] identified three belt-fastening strategies; Andreoni et al. [8] identified two seating strategies when studying drivers' posture. Some alternative movement techniques of ingress and egress are presented in literature as well. Like Andreoni et al., who defined three ingress movement strategies and one common egress strategy in 1997, Ait El Menceur et al. [4] present 5 automobile ingress strategies and 3 egress strategies observed on 4 vehicles covering a wide range of vehicles present on the market for young and elderly population with or without hips and/or knees prostheses, Kawachi et al. [14] present two ingress strategies, Lempereur et al. [15] present another two ingress strategies, and Lempereur [17] presents other three ingress strategies.

Few studies propose quantitative methods to identify alternative movement techniques. For example some objective indices are defined in literature to differentiate the two squat and stoop strategies of the weight lifting. Among these studies, Burgess-Limerick and Abernethy [11] defined a static index based on the ratio between knee flexion and the sum of the ankle, hip and lumbar flexions to describe the initial position of the lifting motion. Zhang et al. [21] combined an inverse kinematics technique with a trial and error heuristic optimization procedure to determine an index made from two parameters, assigned to the two legs, that quantifies the contributions of the velocities of the back and the legs relative to the linear velocity of the shoulder. Park et al. [19] proposed a biomechanical parameters-based index JCV (Joint Contribution Vector) to quantify three dimensional whole body movements. They consider the contribution of joint articulation angles through the estimation of the distance between one movement and another one similar to the movement, where a joint degree of freedom (DOF) is eliminated. After that a semi automatic classification is practiced to these JCVs. Lempereur et al. [15] used this technique to identify two classes of ingress movement strategies. However, the approach as presented by Park et al. [19] presents some limits like the fact of considering just goal-directed task movements. Also their method is not able to quantify complex movements like running, jumping... (Adams and Cerney, [5]).

Though Lempereur et al. [15] used this method to identify ingress alternative movement techniques; they have just considered one body chain (the right lower limb). While the ingress movement is a three dimensional and complex movement involving the whole body motion coordination.

Ingress movement consists to set the centre of gravity of the driver far enough towards the rear of the vehicle (Way et al. [20]). That contributes to its staying near to the body. Some studies assimilate the body centre of gravity to the centre of gravity of the trunk (De Leva, [13]). We define the ingress movement as the action of setting the bassin on the seat and that by respecting many constraints (minimizing discomfort, collision with some vehicle parts avoidance...).

In the present study we propose a modification of the method of Park et al. [19] to be applied to other movements other than the goal-directed tasks. We propose to consider the midpoint between the two hips (MPH) like the end effector. The position of this end effector can be determined from different body parts (head or feet). Our method consists to quantify the contribution of each degree of freedom (DOF) of each body chain in the posi-

tioning of the end effector (MPH). By the end an index 3BJCV is defined. We have applied our method to quantify and distinguish ingress movement strategies for 37 young and elderly people with or without prosthesis on a minivan vehicle. By this application we want to confirm the ingress strategies observed by Ait El Menceur *et al.* [4], on the minivan vehicle. This step of observation proves very useful for the comprehension of the human behaviours. However, it requires a great expertise and unquestionably suffers from the lack of numerical reference marks. The present study may fill this gap.

2. Method

2.1. Humanoid model

To reconstruct the ingress movement, we consider 20 degrees of freedom three-dimensional humanoid model (Ait El Menceur *et al.*, [3]). The model is made up from three open kinematic chains representing the two lower limbs and the trunk with the head.

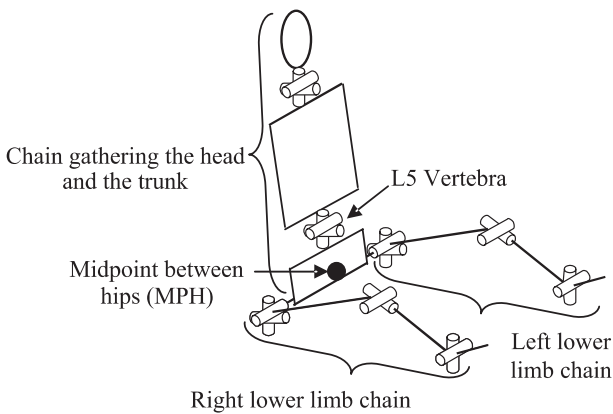


Fig. 1. Humanoid model.

The 20 DOF of the Humanoid model are partitioned as follows: 3 DOF for each hip, 3 DOF for the joint linking the two bodies of the trunk (Lempereur *et al.* [16]), 3 DOF for the joint linking the head to the upper trunk, 2 DOF for each knee and ankle. The humanoid's articulations are rotoid.

To apply our approach, the extremities of the lower limbs and the head are seen like the roots of the 3 open kinematic chains of our model (Fig. 1). We consider three bases with one effector. The bases are the extremities of the two feet and the head. The end effector corresponds to the midpoint between the two hips MPH). The humanoid model is represented in Fig. 1.

2.2. Movement reconstruction

Depending on the base from which we compute, the end effector's (MPH) trajectories are extracted from the following expression:

$${}^{Veh}T_{MPH} = Trans({}^{Veh}Root_N) \times Rot(\theta_{Root_N}) \times Trans({}^{Root}X_N) \times {}^{Root}T_{MPH} \quad (1)$$

With ${}^{Veh}T_{MPH}$ is the homogeneous matrix from which the spatial position of MPH (expressed in the vehicle reference system) is extracted.

${}^{Veh}Root_N$: the spatial position of the origin of the reference linked to each root ($N=1$ for the right foot, $N=2$ for the left foot and $N=3$ for the head). All references are expressed in the vehicle reference system.

θ_{Root_N} : the three joint articulation angles giving the spatial orientation of each root in the vehicle reference system.

${}^{Root}X_N$: the 3D position of each ankle and of the midpoint between C7 at the manubrium expressed in each corresponding local reference system linked to each root.

${}^{Root}T_{MPH} = {}^{Root}T_1 \times {}^{Root}T_2 \times \dots \times {}^{Root}T_{MPH}$ (with $J=7$ for the lower limbs and $J=6$ for the trunk+ head chain) is the homogeneous matrix giving the spatial position of the MPH in the reference system having the same base than each root but expressed either in the ankles or in the midpoint between C7 and the manubrium and that according to the considered chain.

2.3. Three Bases Joint Contribution Vector (3BJCV)

Our method reposes on the same principle that the method of Park *et al.* [19]. We consider that the ingress movement is achieved by occupying a set of postures during a defined time t , with $t \in [0, T_f]$ (with T_f is the final time of the ingress movement). The objective is to set the midpoint between the two hips (MPH) inside the vehicle. Each person has ones own way to do that. The different ways (motion strategies) are characterized by special body motion configurations. The objective is to represent quantitatively the characteristics of each movement, then classify the movements into big groups. The movement characteristics are the individual contributions of each DOF in the final positioning of the MPH on the vehicle's seat.

Each kinematic chain is represented by a set of joint angles: $\theta(t) = [\theta_1(t) \dots \theta_j(t) \dots \theta_J(t)]^T$, with $J=7$ for the lower limbs chains and $J=6$ for the head + trunk chain. $\theta_j(t)$ are the joint articulation angles of the kinematic chain. For each chain the following algorithm is applied:

Compute the contribution of the motion of the i^{th} degree of freedom during a movement $\theta(t)$ by comparing $\theta(t)$ with a hypothetical "almost identical" movement $\theta^i(t)$, in which the motion of the i^{th} joint articulation angles is eliminated.

$$\theta^i(t) = \begin{cases} \theta_j(t) & \text{if } i \neq j \\ \theta_j(0) & \text{if } i = j \text{ for all } t \end{cases} \quad (2)$$

The first DOF to be eliminated are the most distal.

Compare the movements $\theta(t)$ and $\theta^i(t)$ in the end effector's trajectory domain. The contribution of the motion of the i^{th} joint articulation angles is defined in the task space as follows:

$$C_x^i = \int_{t=0}^{T_f} (x(t) - x^i(t)) dt \quad (3)$$

$$C_y^i = \int_{t=0}^{T_f} (y(t) - y^i(t)) dt \quad (4)$$

$$C_z^i = \int_{t=0}^{T_f} (z(t) - z^i(t)) dt \quad (5)$$

where $[x(t) \ y(t) \ z(t)]^T$ and $[x^i(t) \ y^i(t) \ z^i(t)]^T$ are the trajectories of the end effector in the task space corresponding to the motion $\theta(t)$ and $\theta^i(t)$. These trajectories are computed with the method of the movement reconstruction (see section 2.2).

- Normalize the motion contributions to be represented on a proportional scale defined between $[-100,100]$:

$$PC_x^i = 100 \frac{C_x^i}{\sum_{j=1}^7 |C_x^j|} \quad (6)$$

$$PC_y^i = 100 \frac{C_y^i}{\sum_{j=1}^7 |C_y^j|} \quad (7)$$

$$PC_z^i = 100 \frac{C_z^i}{\sum_{j=1}^7 |C_z^j|} \quad (8)$$

- Build The 3 vectors,

$$JCV_x^N = [PC_x^1 \dots PC_x^J] \quad (9)$$

$$JCV_y^N = [PC_y^1 \dots PC_y^J] \quad (10)$$

$$JCV_z^N = [PC_z^1 \dots PC_z^J] \quad (11)$$

With $J = 7$ for the "lower limbs" chains and $J = 6$ for the "trunk + head" chain, $N=1$ for the right foot, $N=2$ for the left foot and $N=3$ for the head.

- Build the vectors

$$JCV_{RLL} = [JCV_x^1 JCV_y^1 JCV_z^1] \quad (12)$$

$$JCV_{LLL} = [JCV_x^2 JCV_y^2 JCV_z^2] \quad (13)$$

$$JCV_H = [JCV_x^3 JCV_y^3 JCV_z^3] \quad (14)$$

with JCV_{RLL} is the index of the right lower limb, JCV_{LLL} the index of the left lower limb and JCV_H the index of the trunk and head chain.

- Gather the three vectors in a single vector

$$3BJCV = [JCV_{RLL} JCV_{LLL} JCV_H] \quad (15)$$

The vector is used as a movement index for each subject.

2.4. Identification of movements

Our method receives as inputs the ingress movements. Each motion is represented in terms of 3BJCV. Hierarchical clustering method using the furthest neighbour aggregation distance is applied to the 3BJCV dataset to form clusters of 3BJCVs by similarity. Each cluster represents a distinct movement strategy. In a previous study (Ait El Menceur *et al.*, [1]), we partitioned the ingress movement into three sub-phases. Just the second sub-phase is considered in the present study as it is the most characterizing sub-phase for the ingress movement strategies (Ait El Menceur *et al.*, [4]). The subphase is the

ingress movement adaptation phase, which starts with the take off of the right foot from the ground (prior to its positioning inside the vehicle) and ends with the take off of the left foot from the ground (prior to its positioning inside the vehicle).

3. Experimentation

The experiments were conducted as part of the French HANDIMAN (RNTS 2004) project. This project aims at integrating the ingress/egress discomfort for elderly and/or disabled persons in first stages of new vehicle conception for these populations. This project considers several trials of ingress and egress movement of 41 test subjects on four vehicles representative of a large part of vehicles present in the trade (Ait El Menceur *et al.*, [2]). In the present study only the ingress trials of 37 subjects on one vehicle are considered. The trials are performed on a mini-van vehicle.

An optoelectronic motion capture system Vicon® 612 at sampling rate of 60 Hz is used to capture the different movements. The system is equipped with 8 CCD cameras.

Fifty-three anatomical markers are set on the different body segments of the subjects to capture their movements during the different acquisitions (Ait El Menceur *et al.*, [2]).

The subjects are asked to enter in the vehicle in an ordinary manner. After these experimentations we obtain three-dimensional positions of the different markers. These positions constitute our data.

3.1. Off-line data processing

Some off-line data processing was done on the data issued from the different acquisitions. These processing integrate: data filtering, joint centres estimation, body segment lengths computation and joint articulations angles computation. Most of the processing stated above is similar to the ones presented in (Lempereur *et al.*, [15]).

3.2. Joint articulation angles computation

The joint articulation angles are computed for each chain. The recommendations of ISB are followed in the definition of the different body references. To apply our approach, the order of the angles computation starts from the most distal body (base) and ends at the end effector (midpoint between the two hips). The joint angles express, in this case, the spatial orientation of the proximal bodies compared to their immediately distal bodies.

3.3. Movement correction

Due to the experimental discrepancies, the computed angles are biased (Cappozzo *et al.*, [12]). Recently we have proposed a multi-objective optimization based procedure to correct these problems (Ait El Menceur *et al.*, [3]). By the end we obtain a movement database, allowing a movement reconstruction close to the measured one, to be used in our method.

3.4. Three bases joint contribution vector computation

Ones the movement database is obtained, the 3BJCV algorithm is applied on the 37 subjects ingress movements. For each subject's movement a 3BJCV, character-

rizing the contribution of each DOF in the positioning of the MPH, is computed.

4. Data analysis

With the obtaining of the 3BJCV set, an aggregation method is used in order to identify the different ingress movement strategies. We have used the Furthest neighbour aggregation distance. The 37 3BJCV and their proximity relationships are represented on a dendrogram (Fig. 2).

The dendrogram contains 69 nodes. The aggregation distances are represented in Figure 3. The aggregation distance of the node 69 is 25 and 24.5 for the node 68, while it is 19.5 for the node 67. The big loss of distance is observed between each two successive aggregation distances is observed between nodes 68 and 67 (5). That suggests us to cut the dendrogram at the level of the node 68. On the other hand a visual inspection of the dendrogram and the aggregation distances histogram confirms the existence of two big classes of movements. The first class contains 31 subjects and the second class contains 6 subjects. In a former study (Ait El Menceur *et al.*, [4]) we have observed two big families of ingress movements, the one-foot ingress movement family and the two-foot ingress movement family. The subjects of the first class identified in the present study correspond to the subjects entering by one-foot strategy and those of the second class correspond to the two-foot ingress movement.

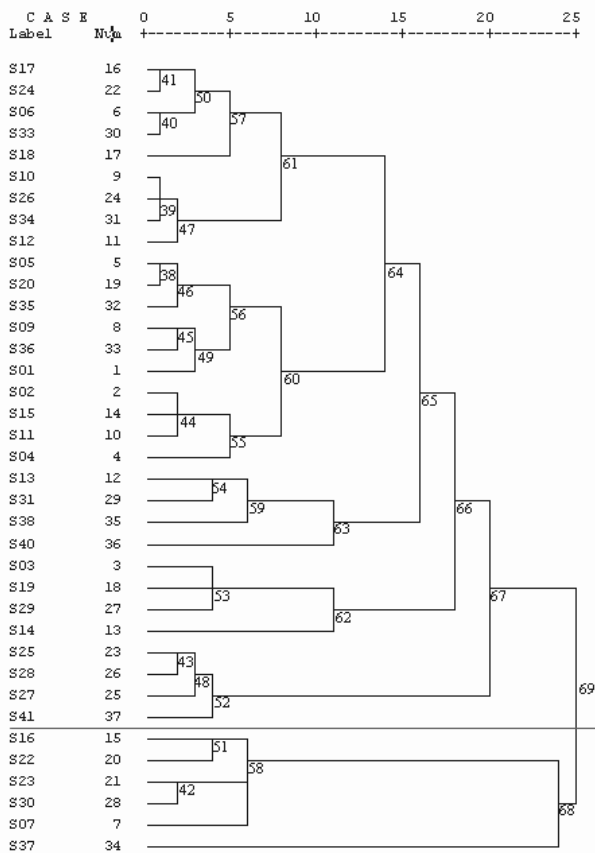


Fig. 2. Horizontal dendrogram.

Figure animations of motions (0%, 25%, 50%, 75% and 100% of the motion) corresponding to the two motion clusters are provided in figure 4 and 5. These motions will be used like phases to present the identified strategies.

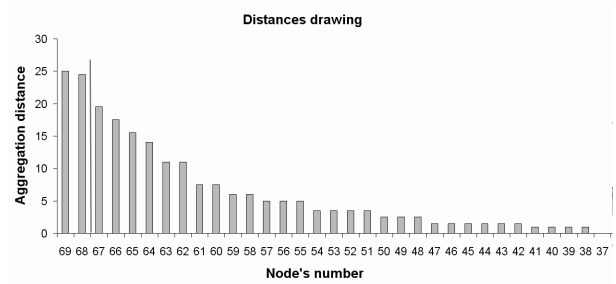


Fig. 3. Aggregation distances histogram.

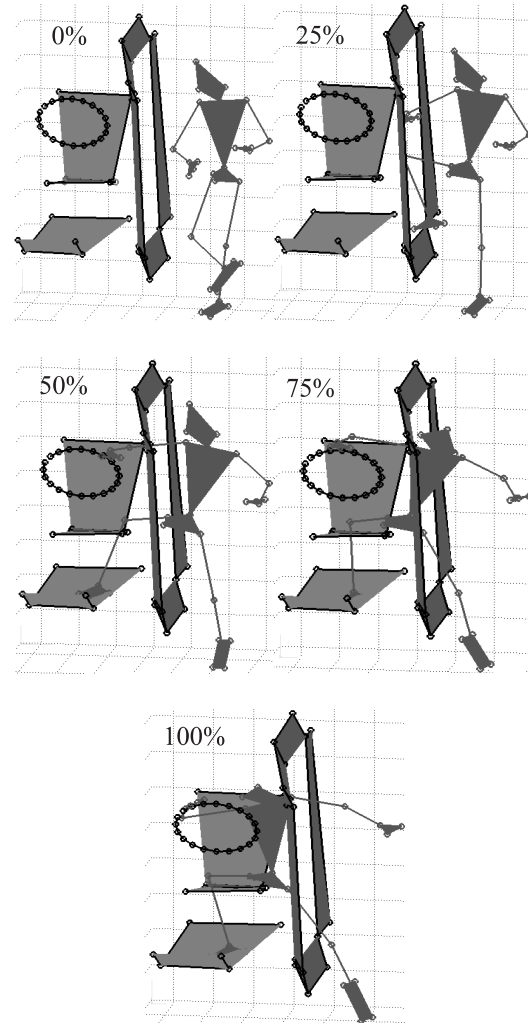


Fig. 4. Ingress movement of the first class.

The two classes of the ingress movement identified in the present study are characterized by the special body motion coordination that the subjects adopt. The subjects of the first big class take off their right feet from the ground to put them inside the vehicle's floor. At 25% of their movements, the subjects of this class pass the vehicle's sill with different knees' flexions and hips' flexion and rotation. They curve their heads and trunks, so that they prepare the next phase. At 50% of the movement they set their right feet on the vehicle's floor and they adapt their bodies so as to drive them inside the vehicle. At 75% of the movement more than a half of the body is already inside the vehicle, the angles of flexion of the knees, flexion and rotation of the hips and the curving of the trunks and heads take important values. These angles accentuations are provoked by the body ingress move-

ment coordination influenced mainly by the vehicle's geometry Ait El Menceur *et al.* [4]. The subjects finalize their movements by the take off of the left feet from the ground and by starting the positioning on the seat.

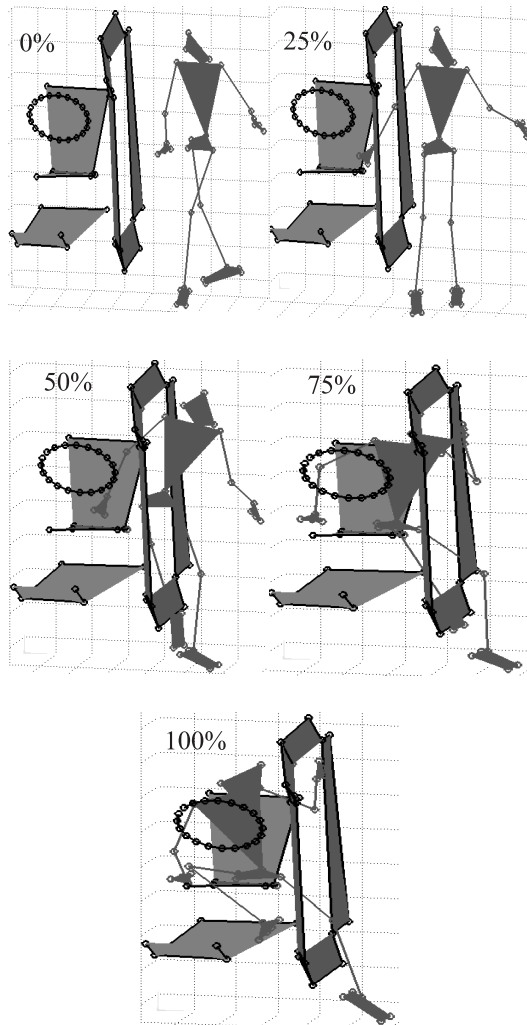


Fig. 5. Ingress movement of the second class.

The subjects of the second big class make a first step at 25 % of the movement so as to turn their backs to the vehicle. They aim to adopt their sitting position. At 50% of the movement, the subjects start to cross the vehicle's door with their basins. They curve their trunks and heads so as to watch the vehicle's cockpit and so as to adopt their movements. At 75% of the movement the subjects already sit on the seat, a large part of their bodies are inside the vehicle. They finalize their movements by sitting completely on the seat, lifting their left feet from the ground and thus starting the positioning on the seat phase.

5. Conclusion

We have proposed an adaptation of the joint contribution method, presented initially by Park *et al.* [19], so that it will be applied for complex movements. An experimental protocol and device were setup to record the ingress movements. Many offline processing allowing the exploitation of the obtained data are performed. Unlike the method of Park *et al.* [19], that considers simple end effectors and which is well adapted for goal-directed

tasks, our method proposes to consider a non habitual end effector (MPH in our case), therefore to take into account the contribution of all body parts, that allows its application to quantify complex movements. To apply our method, the joint articulation angles are computed between the most distal and the immediately proximal joints. Geometric indices, 3BJCV, quantifying the contributions of each DOF in the final positioning of the MPH are computed for each subject. An automatic and non-supervised classification method is applied on the 37 3BJCVs. The hierarchical clustering technique considering the furthest neighbour aggregation distance is the used technique. The number of clusters was determined by the visual inspection of the obtained dendrogram. Two big motion clusters were identified. The first group contains 31 subjects whereas the second group contains 6 subjects. These two motion clusters are coherent with the two big families of ingress movement identified by Ait El Menceur *et al.* [4].

In the present study we showed the applicability of our method on the ingress movement. To generalize our method we propose to test it on other movements.

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