

Inverse Dynamic Reconstruction of Truck Cabin Ingress/Egress Motions

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ABSTRACT

This paper investigates the feasibility of calculating joint forces and moments during a whole body truck cabin ingress/egress motion. For such a task, it is difficult to evaluate a future truck instep as the influences of the architecture parameters are complex over the motion and the discomfort feeling. In order to evaluate the future product at an early stage of the design process, Digital Human Models (DHMs) are interesting tools. However, most existing DHM simulation packages can only efficiently evaluate the kinematics of postures where the dynamics of the whole motion is necessary for such a task. The enhancement of DHMs towards a dynamic analysis and modeling is therefore necessary.

In this study, the motions of subjects entering and exiting an adjustable truck cabin were measured by mean of an opto-electronic motion capture system and six load sensors. The joint angles were then calculated using an inverse kinematics method. And the joint loads were calculated using a classical Newton-Euler inverse dynamics method during the period when all the contact loads are measured. The comparison of the joint torques and forces at the spine L5/S1 joint calculated from the going up and going down methods show a good consistency and validate the moments and forces calculated at the other joints. In order to evaluate the joint loads when a sensor is missing, two methods are also presented, the first one making no assumption on the missing contact force, and the second one assuming that the center of pressure is known. The results show that more consistent joint loads were obtained using the method with assumption.

These results validate the dynamic motion reconstruction method and open the way for a discomfort evaluation of truck cabin ingress/egress based on joint moments and forces.

INTRODUCTION

As for truck drivers, truck cabin ingress and egress is a very important and frequent task. Unfortunately for truck designers, this task is difficult to evaluate for a future truck instep as the number of architecture parameters is high and their combined influences are complex over the motion and the discomfort feeling. Frequently, truck designers have to build a physical mock-up and ask experts to evaluate it; thus costing time and money. In order to evaluate the future product at an earlier stage of the design process, Digital Human Models (DHMs) are interesting tools ([1], [2]) and have previously been used to evaluate such a task over a population of manikins [3]. However, most existing DHM simulation packages are limited to the kinematics of postures where the dynamics of the whole motion is necessary to fully evaluate such a task. The enhancement of DHMs towards a dynamic analysis and modeling thus appears necessary.

The final goal of the study is therefore to evaluate the correlation between truck instep architecture parameters, subjective discomfort and biomechanical criteria (such as joint angles and joint loads). Subjective discomfort can be obtained via questionnaire and

methods to calculate joint angles are well known. This paper investigates the feasibility of calculating joint forces and moments during a complex motion (whole body truck cabin ingress/egress) by inverse dynamics in the case where all the contact loads are known and in the case where one foot contact is unknown.

Inverse dynamics methods are largely used for medical and rehabilitation applications [4] and most often only lower limbs and walking sequence are analyzed [5]. Recently, whole body inverse dynamics was applied to balance control [6]. Such methods require full motion capturing and measuring all contact loads between the subject and its environment thus restricting their applications to tasks with a small number of contacts with the environment and performed inside a laboratory. For a complex motion like truck cabin accessibility, it is difficult to measure all external contact loads during the motion. Therefore, it is important to be able to estimate missing contact loads. Such estimations were proposed for simple tasks such as gait analysis: inverse dynamics methods based on kinematic data only were proposed by constraining the gait motion [7] or modeling the feet contact [8].

At first, the experimental protocol is presented. Inverse kinematics and dynamics motion reconstruction methods are then detailed in the case where all contact loads are measured. After having verified the consistency of the calculated joint loads, two methods for evaluating joint loads when a contact load is unknown were proposed. The values obtained were compared to those obtained with the sensor data in order to identify the best method. Enhancements and applications of inverse dynamic methods are finally discussed.

MATERIAL

SUBJECTS

Eight volunteer subjects participated in the experiments. They were selected amongst Volvo 3P workers in order to cover a large anthropometric range of value (see Table 1). In all, 18 anthropometric values were measured for each subject.

Table 1. Anthropometric data of the 8 subjects.

	mean	std	Min	Max
Body Height (mm)	1722	94	1600	1890
Weight (kg)	76	14	57.5	100.7

MOCK UP

The mock-up is composed of a floor, a seat, a steering wheel, two handles, a door frame, a door and steps (see Figure 1). Most of these elements can be adjusted. Six sensors were included on the mock-up, each measuring

3 moments and 3 forces. Two of these sensors were force plates located on the ground and on the first step (Bertec®). The other 4 sensors were located at the top and at the bottom of each handle.

An experimental design composed of twelve different configurations from two steps to four steps cabin was used.

EXPERIMENTAL PROCEDURE

The subjects were asked to realize and evaluate ingress and egress motions into truck cabins. Kinematic, dynamic and discomfort data were measured.

Kinematic data were measured by use of an opto-electronic system (Vicon ®) running at 100Hz. In all, 44 marker trajectories distributed over the human body were captured. The markers were either stuck on the subject skin (most of upper limb markers) or fixed on extensible straps (most of lower limb markers). Contact loads on the ground, first step and two handles were measured at 100Hz by mean of two force plates and of four sensors. Contact loads were not measured on the other steps, on the floor, seat and steering wheel. Subjective discomfort feelings were measured by mean of a questionnaire using a ten point discomfort scale. Subjects could enter and exit the cabin as many times as necessary in order to fill the questionnaire. Once it was completed, the motion was captured and another configuration was presented to the subject. In all, the experiments lasted approximately 2h30 per subject.

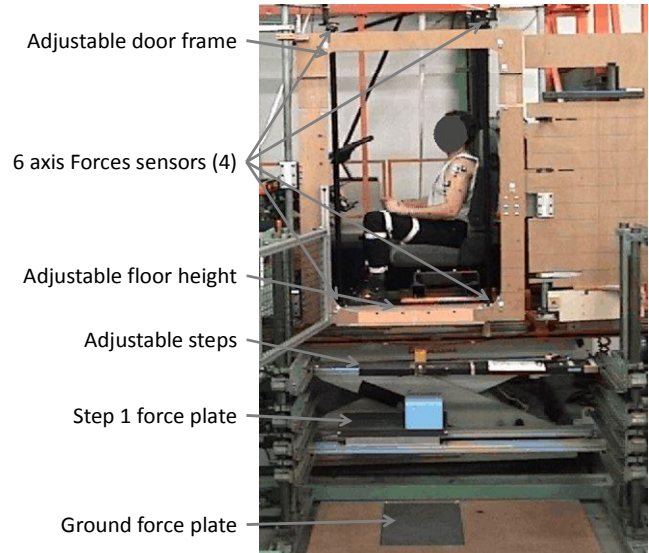


Figure 1. Adjustable mock-up used in the experiments.

In this paper, only the preliminary results obtained with one subject in one configuration are presented. The subject chosen is 1.775 m tall and 83.3 kg.

MOTION RECONSTRUCTION METHODS

KINEMATIC

The kinematic model used in this study is based on Human Builder (Dassault Systemes®) as this DHM is currently used by Volvo 3P in their design process. The origin of the global coordinate system is defined on the heel point, X pointing to the back of the truck, Y laterally and Z upward.

The inverse kinematic motion reconstruction process is composed of 3 steps [9]:

1. Definition of a digital twin of the subject. This was done using the 18 external measures and the Human Measurement Editor of Human Builder.
2. Attachment of the markers in the local coordinate systems. This was done using a static reference posture for which no marker was missing and by super-imposing the manikin on calibrated pictures.
3. Minimization of the distance between the captured and reconstructed marker by inverse kinematics.



Figure 2. Reconstructed ingress motion super-imposed on a video of the motion.

The mean distance between the captured and reconstructed markers along time is 15mm for all the markers. The largest errors were obtained for markers located on the left antero-superior iliac spine and on the left upper leg markers (45mm). This may be due to one of the left thigh strap which moved during the experiments. The low errors at the other markers on the left leg show how robust is the inverse kinematic method as it is not sensitive to marker measurement errors. Finally, the motion was validated by visual inspection (see Figure 2).

The contacts during the ingress motion were then analyzed based on the reconstructed motion and load sensor data: the contact periods of each end-effector were identified (see Figure 3). All the load contacts were measured only for part of the ingress/egress motion.

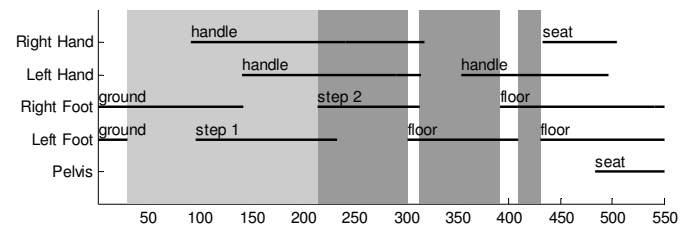


Figure 3. Description of the contact periods of each end-effector during ingress. The light grey period corresponds to the period when all the load contacts are measured. The dark grey period corresponds to the period when only one contact is not measured.

DYNAMIC

A classical Newton-Euler recursive algorithm was used to calculate the joint loads (forces and moments) during the movement. It consists in isolating each body segment from the most distal one to the root, and solving their dynamic balance equation. In this way, given the kinematics of the segments, their inertial properties and the external loads applied on the end-effectors, the inter-segmental forces and moments can be recursively calculated from the most distal segment to the root. The homogeneous matrix formalism [10] was used. A classical gradient method was used for the double derivation of the kinematic (joint angles) and dynamic (load sensors) data, with filtering at each step. The filter used was a low-pass butterworth 2nd order with a cut-off frequency of 5 Hz.

The Body Segment Inertia Properties (BSIP) were derived from one set of scaling equations proposed by Dumas et al. [11], which improve the consistency of the results compared to those proposed by De Leva [12] (see [6]).

Two different recursive strategies were used to calculate the loads acting in the joints (see Figure 4). The first one, called “going-up” strategy, starts from the force plates loads applied on the feet and goes up to the abdomen. The second one, called “going-down” strategy, starts from the force sensors located on the handles applied on the hands and goes down to the pelvis. Comparison of the joint loads calculated by these two methods makes it possible to check the consistency of the human model and measurements and to give an idea about their accuracy. In this paper, this was done only for the ingress motion during the period of time where all the contact loads are measured: from the frame where the left foot leaves the ground to the frame where the right foot reaches the second step (light grey period of Figure 3). During this period, contacts start (or end) at two main key frame: the first one is when the right hand reaches the handle and the left foot the first step. The second one frame is when the left hand reaches the handle and the right foot leaves the ground.