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A numerical tool to simulate the kinematics of the ingress movement in variably-dimensioned vehicles for elderly and/or persons with prosthesis

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A B S T R A C T

This paper presents a method for simulating the kinematics of the vehicle ingress movement of elderly people and/or people with prostheses (represented by a humanoid mannequin with a head, trunk, pelvis and lower limbs) in variably-dimensioned vehicles, starting from real experimental data. To solve this "complex" problem, we propose a three-stage method. The first stage concerns the construction of an "exploitable" movement database, containing movements resulting from the numerical processing of the ingress movements measured in experiments carried out on two vehicles with 2 distinct geometries. The second stage, consisting of 4 phases, analyzes and automatically identifies the ingress movement strategies. By the end of this stage, 2 ingress strategies and 6 sub strategies were identified. The third stage is the simulation. It uses the results from stages 1 and 2 to simulate the ingress movement of a subject in the database, adopting a given sub-strategy for a vehicle with a different geometry. The simulation of the ingress movement of the same subject but for another vehicle is formulated as an inverse kinematics problem, which is solved by constrained nonlinear programming.

Simulations involving elderly people and/or people with prostheses made it possible to validate the proposed method for the two ingress strategies. Despite the differences with the measured movements, the simulated movements conform to the sub-strategies adopted by the subjects during the experiments. Furthermore, the simulations made it possible to partially explain the shifts in strategy of some subjects when they changed vehicles during the experiments. Finally, simulations on fictitious vehicles highlighted some of the limitations of our simulation tool. This study opens several perspectives for future research. For example, we could improve the simulation tool by considering the subjects' intra-individual differences.

Relevance to industry: This study can aid ergonomists and car manufacturers to simulate the ingress movement in variably-dimensioned vehicles for elderly and/or prosthesis having persons. The results of the simulations can be used in the products' (Vehicles) evaluation and adaptation processes. The developed methodology can be extended to the simulation of other movements as it can be integrated into digital human models (DHMs) software.

1. Introduction

To evaluate customers' satisfaction, car manufacturers used to ask subjects belonging to the manufacturer's target population to perform ingress–egress movements on prototypes or real-scale physical models in order to obtain their opinions about the ease of the movement. The subjects' subjective judgements were then

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correlated with the dimensions of the vehicle (Sternini and Cerrone, 1995). However, the construction of non-reusable prototypes, the number of subjects and the data analysis generate significant costs. In addition, this evaluation stage is carried out at the end of the design process, and correcting the prototypes is not always possible (Verriest, 2000). In this context, the manufacturers would like to advance this stage upstream in the design process.

The manufacturers see a possible solution in the use of a numerical tool. Thanks to increasing progress of simultaneous engineering, new evaluation methods are emerging. Numerical mannequins, help to significantly reduce production costs and delays (Hanson et al., 2006) and offer virtual models of the human operator, able to represent and even predict operator behaviour and operator interaction with the environment. Using these models products' ergonomy can be analyzed and evaluated in order to deduce information about operator requirements (Wang, 2003).

Some relatively “simple” movements related to the automobile have been simulated: for example, reaching (Zhang et al., 1998; Chaffin et al., 1999; Hanson et al., 1999; Caputo et al., 2001; Lim et al., 2004; Zhu et al., 2004; Kuo and Chu, 2005), clutching (Wang, 2002; Freeman and Haslegrave, 2004; Oudenhuijzen et al., 2004), belt fastening (Monnier et al., 2002) or door handle opening (Mavrikios et al., 2006). To date, only a few studies have examined the ingress–egress movement for evaluation or simulation purposes. The existing researches seem to focus on populations with no motor disabilities. For example, the simulations carried out as part of the European project REALMAN (IST-2000-29357) (Lestrelin and Trasbot, 2005); simulation of the egress movement (Rasmussen and Christensen, 2005); simulation of the movements of young healthy people (Cherednichenko et al., 2006) and simulation of the ingress movements of people with varied anthropometric measurements in a fixed-geometry vehicle (Pudlo et al., 2009) were conducted.

A first step in the simulation of the automobile accessibility movement would be the analysis and the evaluation of this movement in the laboratory. The analysis of such movement requires an experimental platform, most often a movement measurement system, is needed, but it is also necessary to target the phase of the automobile accessibility movement that is of particular interest for the study. Three types of experimental platforms are usually used: a simplified mock-up (Sternini and Cerrone, 1995), a modified vehicle (Petzäll, 1995), and a variable mock-up (Loczi, 1993; Andreoni et al., 1997; Giacomin and Quattrocolo, 1997; Rigel et al., 2003; Cherednichenko et al., 2006).

Though the use of the simplified mock-up is widely sufficient for studying the accessibility movements (90% of the subjects questioned judged the simplified mock-up (representing a simplified vehicle) and the real vehicle to be equivalent (Sternini and Cerrone, 1995)) having many real modified vehicles or a variable mock-up allows testing the variability of the vehicle parameters on that movement.

Researchers recommend using optoelectronic motion capture systems with passive markers to measure the automobile accessibility movement (Petzäll, 1995; Sternini and Cerrone, 1995; Andreoni et al., 1997, 2004; Giacomin and Quattrocolo, 1997; Nakahama and Nemoto, 2000; Rigel et al., 2003; Lempereur, 2006; Cherednichenko et al., 2006; Hanson et al., 2007; Pudlo et al., 2008). Despite of the instrumental and experimental errors to which the optoelectronic systems can be exposed, they are still among the most suitable systems for studying complex movements such as the automobile accessibility movement (Giacomin and Quattrocolo, 1997) thanks mainly to their advantage of being unobtrusive.

The automobile accessibility movement analysis also includes its quantification and classification in order to either refine the analysis or use the motor strategies thus identified to simulate the movement (Cherednichenko et al., 2006). Some of the researchers studying the accessibility movement consider the totality of this movement (both ingress and egress) (Andreoni et al., 1997; Ait El Menceur et al., 2008a), while others consider only parts of this movement (either ingress (Rigel et al., 2003; Kawachi et al., 2005; Lempereur et al., 2005) or egress (Chateauroux et al., 2010)). Some studies define strategies by studying the human body in its globality, whereas others are focused on specific parts of the human body, notably the head (Gransitzki et al., 1994; Andreoni et al., 2004).

Some studies highlight the influence on the automobile accessibility movement of some parts of the vehicle, such as the door sill (Giacomin and Quattrocolo, 1997), seat height (Loczi, 1993) and the cant rail (roof) (Sternini and Cerrone, 1995; Giacomin and Quattrocolo, 1997). These vehicle parts' obviously need to be considered when evaluating and/or simulating this movement. Other studies highlight the importance of some parts of the subjects' bodies, such as the head (Sternini and Cerrone, 1995) or the trunk (Andreoni et al., 2004). However, no study has highlighted the importance of the upper limbs to the ergonomics of the automobile accessibility movement. The absence of discomfort associated to the upper limbs can explain this omission.

There are a few studies dealing with the vehicle accessibility movement of elderly and/or motor-disabled people: for example, studies by Petzäll (1995), Llaneras et al. (1998), Karazman et al. (2000), Nakahama and Nemoto (2000) and Shaheen and Niemeier (2001). To our knowledge, until 2004 and the HANDIMAN Project, there were no studies focussing on simulating the vehicle accessibility movement for these individuals, despite the importance of this movement for this population (Cappelaere et al., 1991) and the increasing presence of this population in industrialized countries (Brutel, 2002; Pochet, 2003). The HANDIMAN project (RNTS 2004) tried to provide a solution to the problem of vehicle accessibility (Pudlo et al., 2008). Chateauroux's (2009) pioneering research attempted to simulate the vehicle accessibility movement of the elderly population of the HANDIMAN project, using the mannequin RPX. Although the simulation results were visually acceptable, they were not compared with the real movements performed by the subjects, which means this simulation method, in its current form, cannot be used for ergonomic evaluation.

The objective of this paper is to present a numerical tool for simulating the kinematics of the ingress movements of elderly people and/or people with prostheses in variably-dimensioned vehicles. This simulation tool uses experimental data issued from the analysis/evaluation of this movement for this population (Ait El Menceur et al., 2007). This simulation tool brings a first solution for car designers concerning the automobile ingress simulation for our targeted population, as it can be used by ergonomists to evaluate the kinematics of the ingress movements and to check whether some ingress movements are realizable or not.

2. Related work: simulation of the kinematics of the automobile accessibility movement

The human movements' kinematics simulation techniques can be gathered in several classes. Some authors speak about techniques based on “kinematics”, “dynamics” or on “movement modification” approach (Gorce and Vanel, 1997; Multon, 1998; El Hafi and Gorce, 1999; Baerlocher, 2001; Julliard, 2001). Other authors consider two great classes: the class of techniques based on “knowledge about the movement” and the class of techniques using “the bases of movements” (Monnier, 2004; Lempereur, 2006; Wang, 2008).