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Original Article

# Preview Distance Index for the Analysis of Powered Wheelchair Driving

H. Zatla [a,b,*], Y. Morère [b], A. Hadj-Abdelkader [a], G. Bourhis [b], K. Demet [c], G. Guilmois [c], N. Bigaut [c], K. Cosnuau [c]

[a] *Laboratoire d'Automatique de Tlemcen, Université de Tlemcen, BP 230, Tlemcen 13000, Algeria*
[b] *LCOMS, Université de Lorraine, 7 rue Marconi, 57070 Metz, France*
[c] *Centre de Médecine Physique de Réadaptation pour Enfants, IRR de Nancy, 54630 Flavigny sur Moselle, France*

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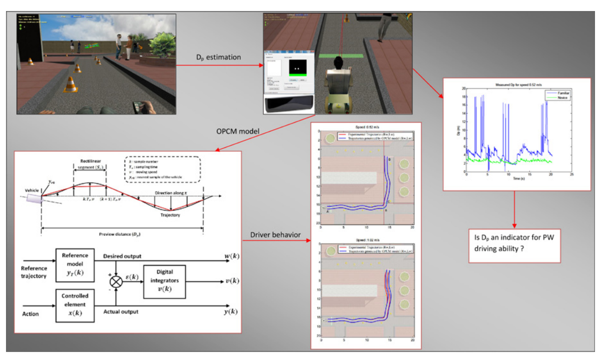
## Highlights

- Analysis of the behaviour of the Pilot–Wheelchair system by optimal preview model.
- Preview distance Dp estimated using an eye tracking system.
- Distance Dp for healthy subjects can be used as driving indicator.
- Distance Dp for people with disabilities can be used as performance indicator.

## Graphical abstract




## Abstract

*Background* This article deals with powered wheelchair (PW) simulators. In any application of simulation (learning, medical prescription, experimentation of new features, etc.) it is necessary to define driving performance criteria. The aim of this work is to validate a new performance index for PW driving analysis.

*Methods* The validation was carried out in two stages. First, we modelled the human-machine system consisting of the pilot and the PW with the OPCM model (Optimal Preview Control Model) and we deduced the importance of the preview time $T_p$ or its equivalent, the preview distance $D_p$. Experiments on a panel of 15 healthy subjects were carried out on the 3D simulator ViEW (Virtual Electrical Wheelchair) associated with an eye-tracker system and allowed to validate this modelling. In the second stage, the healthy panel was separated into two skill-level groups (accustomed/novice).

*Results* The experimental results showed that the parameter $D_p$ is representative of the driving quality: accustomed drivers get greater values of $D_p$ than the novice users during the driving. To illustrate this assertion, we conclude by a case study conducted on five subjects with motor disabilities.

*Conclusion* This work showed that $D_p$ allows to differentiate accustomed users from the novice ones using a test on healthy subjects. A second test on subjects with disabilities showed that this indicator can be used for analysing their abilities to drive the PW.

* Corresponding author at: Laboratoire d'Automatique de Tlemcen, Université de Tlemcen, BP 230, Tlemcen 13000, Algeria.
*E-mail address:* hicham.zatla@gmail.com (H. Zatla).

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*Keywords:* Driving simulator; Powered wheelchair; OPCM model; Eye-tracking

## 1. Justification

Powered wheelchair (PW) has become an essential assistive technology for people with severe motor disabilities. It can however be dangerous for the driver or for other persons nearby if it is not properly controlled. Correct use involves evaluating the existing control skills of the driver, at the time the wheelchair is medically prescribed or, for young children, following a PW driving training or even at regular time intervals in the case of an evolving pathology. However, real PW experiments need to address safety issues and, also, it is technically difficult to extract non-trivial quantitative parameters to analyse objectively the driving behaviour. For these reasons, since the early 90s, a number of studies focused on the design of PW driving simulators to experiment and evaluate various driving situations in an efficient way [1,3,4]. They are not, so far, commonly used in rehabilitation. Software development began mainly with 2D environments. It is today conducted in 3D environments due to fast developing 3D design software and the use of more robust computers. This is particularly the case of the simulator ViEW (Virtual Electrical Wheelchair) developed by our research team and used in the present study [5,6]. It has several objectives: safe driving training [6], testing control skills relative to user-specific wheelchair prescriptions [5], providing aid for PW parametrization, settings and testing new features [7].

A major interest of simulation is to be able to measure driving performance indices in a simple way: duration of a mobility task, number of movements on the joystick [2], spectral analysis of movements [8], velocity, average deviation compared to a reference [9] or compared to an optimal trajectory [8], the length of a path or the number of collisions [4,10]. These various indicators inform about the driving quality but are not directly correlated with the driving behaviour. For a more accurate analysis, we propose to model the pilot/PW system to deduce the most revealing parameters of this behaviour.

Since the Fifties, many studies aimed to model the pilot–vehicle systems in manual control tasks (pilot–plane initially, then pilot–car). Three types of behaviour generally govern this system, and they are generally simultaneously present [11]. The first behaviour is compensation, in which the human controller acts in response to an error signal between the reference and the output of the controlled element. This error may be for example the lateral deviation between the position of the vehicle and a reference line. The second behaviour is the trajectory following, which appears in particular when the control inputs need to be anticipated, for example, in the case of a curved trajectory tracking. Finally, a precognitive behaviour acts as an open loop process. It may occur when the pilot has a good knowledge of the vehicle dynamics and of the perceptual field.

Various models are proposed in the literature to represent these behaviours mathematically. The Crossover model for instance, introduced initially into the context of aircraft piloting [12], was validated for a large number of compensation tasks. It states that a well-trained and concentrated pilot adapts his driving behaviour so that if $Y_p(j\omega)$ is the transfer function of the pilot and $Y_c(j\omega)$ is that of the controlled element, we have:

$$Y_p(j\omega).Y_c(j\omega) = \omega_c \frac{\exp(-j\omega\tau)}{j\omega}),$$

near $\omega_c$ "Crossover frequency", and where $\tau$ represents the delays of the process and the operator.

An important step in human-machine systems modelling was the introduction of optimal control techniques. The OCM model (Optimal Control Model) established by Baron [13] uses these techniques. It is composed of two parts, the human operator and the machine. The operator itself is divided into three stages: visual perception, information processing and the action which generates the muscular movement applied to the machine. This model features an actuator, a controlled element and a display with a disturbance input. However, the large number of parameters to be determined empirically makes the OCM model difficult to implement. Many alternatives were developed to address this problem. In all these cases, driving is considered as a dominant visual task [14], often distinguishing the close and the distant fields of view [15–17]. The OPCM model (Optimal Preview Control Model) suggested by Sharp [18] considers the pilot as a mean of acquisition of the visible trajectory samples ahead of him. It is based on the parameter of the anticipated time $T_p$ (preview time) from which we deduce the preview distance $D_p$.

If the human-car system is widely studied in the literature, only few works are related to the modelling of the pilot–wheelchair system in a control task. In [19] Fitts's law is used to evaluate the driving task by considering the path as a succession of targets to be reached. The control of the PW is considered as a compensation task in [9] and the pilot–wheelchair system is represented by the Crossover model. Finally, in [20] the authors take into account first acceleration during the start of the PW which is an important discomfort factor, then consider the pursuit (or trajectory following) behaviour of the pilot.

In this context, the objective of this study is to deduce from modelling of the pilot-PW system significant parameters of the driver behaviour. The OPCM model is well validated in the case of car driving task and can be regarded as combining the compensation and pursuit behaviours. It has thus appeared relevant to assess it in the case of PW driving. In what follows, we first validate this model by an experimentation carried out in simulation on a panel of healthy people. Then we deduce that the preview distance $D_p$ is a relevant parameter to represent the driving behaviour in a given situation. Next, to illustrate this assertion we carry out a case study on five persons with motor disabilities.

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