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Quantification of the user-wheelchair system stability based on the CoP trajectory within the base of support

Matteo Cognolato[a], Nicola Petrone[a]*, Giuseppe Marcolin[a]

[a]*Department of Industrial Engineering, University of Padova, Via Venezia 1 35131, Padova, Italy*

Abstract

Aim of the work was the introduction of a user-wheelchair Stability Index able to give objective information to find the most appropriate wheelchair settings both for daily and sports use. The Stability Index was introduced after asking two users to assume four pre-defined postures over a dynamometric force platform and measuring the centre of pressure (CoP) trajectory. After identifying the base of support centroid Ctd and the instantaneous CoP, the Stability Index expresses how far is the instantaneous CoP from the sides of the base of support outline: the index is calculated with respect to each direction (forward, rearward, right and left side) and referred to the centroid of the base of support. The Stability Index values increase proportionally with the stability: a zero value means that CoP is on the outline, a unit value corresponds to coincidence between CoP and Ctd. A preliminary evaluation of the Stability Index was performed by varying both back adjustment and user posture. The proposed method only requires a force plate or a stabilometric plate. The evaluation of user-wheelchair system stability can be performed in real time, merging this objective parameter with user subjective feeling in order to propose the most satisfactory solution to users, manufacturers and clinicians.

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* Petrone Nicola. Tel.:+39 049 8276761.
E-mail address: nicola.petrone@unipd.it

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1. Introduction

Wheelchairs allow disabled persons to recovery their social inclusion and are essential assistive products suitable to young and old people willing to have an independent locomotion despite their disability.

The stability of the user-wheelchair system is a fundamental safety requirement from a user's point of view. Theoretically, a user-wheelchair system is statically stable as long as the gravity force line from the centre of mass of the user-wheelchair system is inside the base of support, that is the area on the ground confined by the outline of the contact points of its wheels (ISO 7176-1). In the present ISO standards, the stability of a wheelchair is evaluated after placing a standard dummy on the wheelchair (ISO 7176-11) and evaluating the minimum tipping angle at which any wheel looses contact from the ground in the forward, rearward and lateral directions. Since the location of the centre of mass is in general not known, the tipping angle is determined after placing the wheelchair on a test platform the slope of which can be adjusted. The angle of the slope on which the wheelchair starts to tip is measured. The slope angle of the test platform represents the tipping angle in that direction (ISO 7176-1).

It has to be clear that a wheelchair presenting a small tipping angle, for instance in the rearward direction, is not always a bad wheelchair: in fact, for active users with full ability of upper limbs, being able to lift easily the front castor wheels to overcome a step is again a functional requirement.

The stability property of a user on its wheelchair is usually evaluated empirically by the user and the clinicians in order to choose the best wheelchair or its best adjustment. User's feeling and technicians experience are frequently the criteria used for stability evaluation: this can be seen as a *subjective evaluation approach*. With regard to the usability and safety of assistive products, there is a need of an *objective evaluation approach* to quantify the stability level of the real system constituted by the user and the wheelchair. A quantification of user-wheelchair stability might be used together with the subjective criteria in order to develop an approach that might integrate both subjective and objective information. Thanks to the *integrated approach*, different wheelchair models and settings could be compared, providing useful information to both users and manufacturers for a more aware development and use of the device.

It is a common experience that the tipping of a solid object laying over an inclined surface can occur when the gravity force line (Center of Gravity) of the user-wheelchair system is not more falling inside the base of support, defined as the outline of the polygon individuated by the wheels contact points. On the other hand, the user-wheelchair system Centre of Pressure *CoP* (the point of application of the Ground Reaction Force) contains the system stability information and its instantaneous position could predict a fall, in analogy to the analysis of stability in standing posture (Winter (2009)).

In order to quantify the stability and to proceed towards an *integrated approach*, an index based on the *CoP* trajectory has been defined in the present work. In addition, a preliminary evaluation of this Stability Index has been carried out after changing two of the fundamental parameters for user-wheelchair stability: the wheelchair back support adjustment and, as early reported in Kirby et al. (1995), the user posture.

Nomenclature

SI_F	Forward Stability Index
SI_B	Rearward Stability Index
SI_R	Right Stability Index
SI_L	Left Stability Index
SSI	Static Stability Index
α_{BS}	Back support to seat angle
CoP	Centre of Pressure
Ctd	Base of support centroid
FA	The most forward adjustment of the back support
IA	The intermediate adjustment of the back support
BA	The most rearward adjustment of the back support