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On the kinematic functionality of a four-bar based mechanism for guiding wheels in climbing steps and obstacles

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ABSTRACT

This paper describes a design of a mechanism that aims a wheel to climb obstacles, steps, or slopes with a suitable smooth path. The proposed four-bar linkage can be installed on each wheel of a vehicle, which therefore can be capable to climb stairs with suitable comfortable motion. An algorithm is formulated to design an optimum solution of the mechanism fulfilling those task requirements. A straight-line trajectory for the centre of a wheel is ensured through an easily controlled motion, and the compactness of the mechanism design makes it suitable for staircase climbing wheelchairs for aiding people with disability. Experimental tests have given satisfactory results and are shown for a practical application.

1. Introduction

The number of applications for mobile robots increases continuously. One of the most interesting and useful applications is related to powered wheelchairs. These vehicles greatly improve the mobility of people with disability but they can become useless when they face obstacles, which still exist in many cities and buildings. These obstacles can be modelled as steps, slopes, and stairs with different characteristics.

Several systems have been developed and still are under development to make a mobile robot capable of climbing and descending steps, slopes and stairs (see the CLAWAR conference series). Examples are shortly overviewed in the following to stress problems and solutions for wheeled systems that have motivated investigation for herein proposed mechanism. Conventional wheeled vehicles have a limited capability for climbing steps and therefore, several other solutions are proposed in literature as attempting a design for efficient and comfortable vehicles. The most used solutions make use of tracks or clusters of wheels. A track is an endless belt in self-propelled vehicle, and it helps the vehicle to distribute its weight more evenly over a larger surface area than wheels contacts only. In obstacle climbing, tracks emulate a wheel with infinite radius so that an obstacle can be over passed as a slope by using track extension as bridge.

Track is a quite common solution as outlined for example in [1], in which an improved track is proposed to generate larger forces at the step contact. Other systems that use tracks are proposed in [2,3] and [4]. However, tracks have important drawbacks: these vehicles are more uncomfortable than wheeled ones. A high friction coefficient between step edge and track is also needed to generate a proper tangential force that allows the vehicle to climb an obstacle. Another problem is that initial and final phases are difficult to control and they can represent dangerous situations in climbing and descending staircases.

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Nomenclature

d	distance between centres of a wheel clusters
D	step thread
r	radius of wheel
H	step height
λ	slope angle
M	initial point of the trajectory of the wheel centre
M'	final point of the trajectory of the wheel centre
P	extreme of the Sliding Support
L	length of the straight-line segment of the trajectory of the wheel centre
CXY	frame for the kinematic analysis of the four-bar linkage
OX_0Y_0	frame for the experimental acquisition of the coordinates of the markers
x_0, y_0	coordinates of wheel centre at the initial point of its trajectory
a	length of the frame
b	length of the input crank
c, q, p	length of the coupler
d	length of the output crank
Γ	angle between p and q links
Θ	angle between c and q links
α, α_0	angle of the input bar. Angle at the initial point
β, β_0	angle of the output bar. Angle at the initial point
θ, θ_0	angle of the coupler. Angle at the initial point
$\Delta\theta$	swing of the coupler between the initial and the final point of the trajectory
S	area of the difference between the straight-line segment and the real trajectory
u	maximum distance among points of the mechanism
F	objective function of the optimization problem
G	constraint function of the optimization problem
w_1	weighting factor of function S
w_2	weighting factor of function u

This problem can be solved by using more than two tracks. A tracked wheelchair is proposed in [5]. This vehicle has two pairs of tracks that can adapt their geometry to the initial and final phases in climbing and descending stairs.

An alternative solution consists of a cluster of wheels that are attached to a rotating link. Two commercial available stairs-climbing wheelchairs are shown in Fig. 1a and b. For example, in Fig. 1 a only one pair of two-wheel cluster is used, [6]. An assistant is needed to ensure stability, as shown in Fig. 1a. Another cluster stair climber is shown in Fig. 1b. It uses two pairs of four clusters of wheels [7]. The wheelchair that is proposed in [8] uses two clusters of three wheels. A wheelchair with two pairs of clusters of two wheels is proposed in [9] for climbing a tall single step. Indeed, there are several problems in using cluster of wheels. A first problem concerns with that each wheel of a cluster must have its own transmission system, and therefore a vehicle can be very heavy. But the most relevant drawback is related to the fact that the geometry of a cluster

Fig. 1. Examples of existing of staircase climbing vehicles: (a) wheelchair iBOT with two-wheel clusters, [2]; (b) Tamagawa staircase climbing wheelchair Freedom with four wheel clusters, [3].