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Development of an omnidirectional Automated Guided Vehicle with MY3 wheels☆

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KEYWORDS
Omnidirectional;
Automated guided vehicle (AGV);
MY3 wheel;
Kinematic model;
Guiding method

Summary This paper presents an omnidirectional Automated Guided Vehicle (AGV) with a novel omnidirectional wheel named MY3 wheel. Due to the special structure and material of the MY3 wheel, the AGV has full three DOFs in the motion plane and good capabilities of load carrying and slip resisting. In addition, the kinematic model of the AGV is derived, and the guiding method that can make the AGV to follow a specified path is established. Finally, experiments are performed to verify the kinematic model and guiding method.

Introduction

An Automated Guided Vehicle (AGV) is a driverless transport system used for horizontal movement of materials (Vis, 2004). Nowadays, AGVs have been widely used in industrial applications such as transporting materials around manufacturing facilities or warehouses automatically to increase efficiency and reduce costs (Ronzoni et al., 2011; Bui et al., 2013; Kirsch et al., 2012). In addition, AGVs have also showed great potential value in office, domestic, and outdoor services (Tsumura, 1994; Vamossy et al., 2014).

For most of the existing AGVs, the differential driving method is adopted due to its simplicity and zero-radius turning. However, the differential driving method cannot work effectively in the narrow space, because it cannot perform the lateral translation (Ronzoni et al., 2011; Bui et al., 2013). In order to enable AGVs to have full three DOFs in the motion plane (two translations and one rotation), some researchers have tried to equip AGVs with omnidirectional wheels to construct omnidirectional AGVs (Kim et al., 2012; Kirsch et al., 2012; Kumra et al., 2012).

A variety of omnidirectional wheels have been proposed over the past few decades, and most of them are designed based on the concept that achieving the active motion in one direction and allowing the passive motion in another direction. A general type of the omnidirectional wheel is an assembly of a traditional wheel and some passive rollers mounted at the periphery such as the Mecanum wheel (Muir

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[2] **Suyang Yu**, Ting Wang, Zhidong Wang, Yuechao Wang, Chen Yao, Xiaofan Li, Original design of a wheelchair robot equipped with variable geometry single tracked mechanisms, International Journal of Robotics and Automation, 2015, 30(1), 87-97. 【EI: 20151300675471】【SCI: 000349599300009】

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ORIGINAL DESIGN OF A WHEELCHAIR ROBOT EQUIPPED WITH VARIABLE GEOMETRY SINGLE TRACKED MECHANISMS[1]

Suyang Yu*,***, Ting Wang*, Zhidong Wang**, Yuechao Wang*, Chen Yao*, and Xiaofan Li*

Abstract

This paper introduces an originally designed wheelchair robot equipped a variable geometry single tracked mechanism (VGSTM). This mechanism can actively control the robot shape and track tension to adapt for obstacles by two pairs of flippers, so the obstacle clearing ability of traditional wheelchairs can be improved. With the aim of stair-climbing, an optimal solution method of driving moments is proposed to guide the robot design; a tip-over and slippage stability criterion is established to evaluate the robot performance. Finally, the prototype is built, and the stair-climbing experiment is carried out to verify the obstacle clearing ability of the robot.

Key Words

Wheelchair robot, variable geometry single tracked mechanism (VGSTM), obstacle clearing ability, driving moment, tip-over and slippage stability criterion

1. Introduction

The traditional wheelchair, which is a commonly used mobility assistance device for some physically disabled persons, has high mobility on even terrain. However, when facing obstacles such as stairs, the locomotion of the wheelchair will be limited seriously, and this shortcoming brings great discommodity to the user. In order to improve the obstacle clearing ability especially the ability of stair-climbing, many researchers have tried to equip the traditional wheelchair with locomotion mechanisms of mobile robots to construct a wheelchair robot.

According to equipped locomotion mechanisms, the existing wheelchair robot that has the ability of stair-climbing can be categorized into three types: the wheel cluster typed robot, the leg typed robot and the track typed robot. The wheel cluster typed wheelchair robot can realize the stair-climbing performance, but the orbital motion may be uncomfortable for passengers [2]–[4]. Moreover, if the robot is equipped with single cluster, the security cannot be guaranteed without appropriate assistance [2], and if the robot is equipped with dual clusters or single cluster with balancing sliders, the mechanism will be too large and heavy [3], [4]. The leg typed wheelchair robot has high ability of stair-climbing, but the mechanism structure and control will be excessively complex [5], [6]. Compared to the above two types, the track typed wheelchair robot has better stationarity because of the large contact area with the stairs [7]–[10]. However, when climbing to the peak of the stairs, if the robot is equipped with the common single tracked mechanism, it will be difficult to realize the stable variation of the robot posture [7], and even if the robot is equipped with the multi-section tracked mechanism, the climbing process will still not be smooth enough [8]–[10]. In order to improve the common track typed wheelchair robot, a new-style wheelchair robot equipped with a variable geometry single tracked mechanism (VGSTM) is proposed [11]–[14]. This robot can actively control the robot shape and track tension to adapt for obstacles by two pairs of flippers, so it will have better ability of stair-climbing [15].

During stair-climbing of the wheelchair robot equipped with the VGSTM, driving components such as the driving wheel and the flipper must supply sufficient driving moments to make sure that the robot can complete the climbing process. Moreover, the tip-over of the robot and the slippage between the track and stairs are also intractable problems that affect the stability of the robot performance seriously. Therefore, in this paper, an optimal solution method of driving moments is presented based on the Lagrange dynamic model of the robot [16], and then the

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[1] This paper is an extension of the paper "A tip-over and slippage stability criterion for stair-climbing of a wheelchair robot with variable geometry single tracked mechanismin" in Proceeding of 2012 IEEE International Conference on Information and Automation [1].

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[3] 于苏洋, 王挺, 王志东, 王越超, 姚辰, 基于倾翻与滑移稳定性准则的轮椅机器人爬楼梯控制方法, 仪器仪表学报, 2014, 35(3), 676-684. 【EI: 20141617586385】

基于倾翻与滑移稳定性准则的轮椅机器人爬楼梯控制方法*

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摘 要: 提出一种采用单节变形履带机构的轮椅机器人。这种机器人能够通过前、后2组摆臂同时控制履带形状与张紧力,使履带更好地与障碍物相适应,从而提高传统轮椅及现有履带式轮椅机器人的越障能力。针对机器人爬越楼梯过程,提出一种过约束状态下履带与楼梯间作用力的近似求解方法,并结合履带与楼梯间的滑移分析建立了一种能够同时评判机器人倾翻与滑移情况的稳定性准则。在所建立稳定性准则的基础上,进一步制定了机器人自主爬越楼梯控制方法,并通过实验验证了控制方法的有效性。

关键词: 轮椅机器人; 单节变形履带机构; 倾翻与滑移稳定性; 自主爬越楼梯

中图分类号: TP242 **文献标识码**: A **国家标准学科分类代码**: 510.8050

Stair-climbing control method of a wheelchair robot based on tip-over and slippage stability criterion

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Abstract: A wheelchair robot equipped with variable geometry single tracked mechanisms (VGSTMs) is proposed. This mechanism can actively control the track shape and track tension to adapt for the obstacle through rotating the two pairs of flippers, so the obstacle cros sing capability of the traditional wheelchair and tracked type wheelchair robot can be improved. Aiming at the stair-climbing process of the robot, an approximation solution method of the force between the track and stairs for the situation that the robot is over-constrained is proposed, and the slippage between the track and stairs is analyzed systematically, based on which a new tip-over and slippage stability criterion is established. Finally, on the basis of the established stability criterion, a robot autonomous control method for stair-climbing is proposed, and an experiment was performed to verify the effectiveness of the proposed control method.

Keywords: wheelchair robot; variable geometry single tracked mechanism; tip-over and slippage stability; autonomous stair-climbing

1 引 言

轮椅是下肢行动不便者重要的代步工具,其特点是在平地上运动灵活,但越障能力较差。为了提高传统轮椅的越障能力,尤其是对楼梯这种典型障碍的爬越能力,国内外很多研究尝试将移动机器人的越障机构与传统轮椅相结合,研制轮椅机器人。

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[4] **于苏洋**, 王挺, 王志东, 王越超, 姚辰, 李小凡, 采用单节变形履带机构的新型越障轮椅机器人, 机械工程学报, 2013, 49(13), 40-47. 【EI: 20133316623529】

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采用单节变形履带机构的新型轮椅机器人*

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摘要：提出一种采用单节变形履带机构的轮椅机器人。该机构能够通过两组摆臂的转动对履带形状与张紧力进行主动控制，以使履带形状更好地与障碍物相适应，从而提高传统轮椅的越障能力。在对比现存各种轮椅机器人越障机构特点的基础上，介绍这种新型轮椅机器人的机构方案及对楼梯这种典型障碍物的爬越过程。针对爬越楼梯这一越障运动，将轮椅机器人转换成等效串联机器人，建立用于描述机器人位置及履带形状的几何模型，并给出基于拉格朗日动力学方程的机器人主动构件驱动力矩的优化求解方法。通过仿真得到了轮椅机器人爬越楼梯过程中各主动构件驱动力矩的变化情况，进而指导完成了机器人驱动系统与机械结构设计并制作出原理样机。通过样机爬越楼梯试验验证了轮椅机器人的越障能力。

关键词：轮椅机器人 单节变形履带机构 越障能力 驱动力矩
中图分类号：TP242

Wheelchair Robot Equipped with Variable Geometry Single Tracked Mechanisms

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Abstract：A wheelchair robot equipped with variable geometry single tracked mechanisms(VGSTMs) is proposed. This mechanism can actively control the track shape and tension to adapt to the obstacles by rotating the two pairs of flippers, so it becomes possible to improve the obstacle clearing capability of the traditional wheelchair. Following a presentation of some typical mechanisms for obstacle clearing, the mechanism scheme and the stair-climbing process of the robot are introduced. With the aim of stair-climbing, the wheelchair robot is translated to a serial manipulator, base on which the geometric model that can describe the position and the track shape of the robot is established, and the optimal solution method of the driving component moment with Lagrange dynamic equations is proposed. In the simulation, the variations of the driving moment during stair-climbing are obtained, and then the design of the driving system and the mechanical structure of the robot are completed with the simulation results. The stair-climbing experiment is performed with the prototype to verify the obstacle clearing capability of the robot.

Key words：Wheelchair robot Variable geometry single tracked mechanism Obstacle clearing capability Driving moment

0 前言

轮椅是下肢行动不便者重要的代步工具。传统轮椅在平地上运动比较灵活，但当遇到障碍物时其运动会受到很大的限制，给使用者带来了极大的不便。为了提高传统轮椅的越障能力，尤其是对日常建筑物中广泛存在的楼梯的爬越能力，国内外很多研究者尝试将移动机器人的越障机构与传统轮椅相结合，研制轮椅机器人。

在国内外现有移动机器人所采用的越障机构中，具有较强的越障能力尤其是能够实现爬越楼梯这种越障运动的主要有星形轮式机构、腿式机构和履带式机构三种。星形轮式轮椅机器人虽然能够完

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[5] **Suyang Yu**, Ting Wang, Zhidong Wang, Yuechao Wang, Di Zhi, Chen Yao, Xiaofan Li, Zhong Wang, Yu Luo, A tip-over and slippage stability criterion for stair-climbing of a wheelchair robot with variable geometry single tracked mechanism, 2012 IEEE International Conference on Information and Automation, Shenyang, China, 2012, pp.88-93. 【EI: 20123915478334】【Best Paper Finalist】

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A Tip-Over and Slippage Stability Criterion for Stair-Climbing of a Wheelchair Robot with Variable Geometry Single Tracked Mechanism

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***Abstract* - This paper introduces an originally designed wheelchair robot equipped with a novel type of Variable Geometry Single Tracked Mechanism (VGSTM) that can actively control the robot shape and the track tension. So it becomes possible to improve the obstacle clearing capability of the robot by adapting the robot shape for the obstacle. Tip-over and slippage for track typed mobile robots are intractable problems especially in stair-climbing, which is the most fundamental obstacle clearing performance of the wheelchair robot, because of the complex track-stair interaction. In this paper, a tip-over and slippage stability criterion is derived based on the geometric model, the static model, and the track-stair interaction analysis. The stability state of the wheelchair robot during stair-climbing is obtained by simulation.**

Index Terms – Wheelchair robot, Variable Geometry Single Tracked Mechanism, stair-climbing, tip-over and slippage stability.

I. Introduction

The traditional wheelchair has high mobility on even terrain, but when facing some obstacles such as stairs, the locomotion of the wheelchair will be seriously limited, which brings great discommodity to the user. For the purpose of improving the obstacle clearing capability, especially the capability of stair-climbing, many wheelchair robots that combine the traditional wheelchair with the locomotion mechanism of mobile robots have been proposed.

According to the difference in the locomotion type for stair-climbing, wheelchair robots can be categorized into wheeled cluster robots, legged robots, and tracked robots. The wheeled cluster wheelchair robot can perform stair-climbing movement [1], but the climbing process may be uncomfortable for passengers, and the security cannot be guaranteed without appropriate assistance. The legged wheelchair robot has high capability of stair-climbing, but the structure of the mechanism is excessively complex [2-3]. Compared to these two types of robots, the tracked wheelchair robot has better stationarity because of the larger contact area with the stairs, and the structure of the mechanism is compact enough [4-5]. However, when climbing to the peak of the stairs, if the tracked mechanism is in the form of single-section, the robot will have difficulty in stable transformation of its posture, and even if the tracked mechanism is in the form of multi-section, the moving process of the robot will still not be smooth enough.

To improve the terrain adaptability of common tracked wheelchair robots for the peak of the stairs, a wheelchair robot equipped with Variable Geometry Single Tracked Mechanism (VGSTM) has been proposed in our lab [6-7]. Different from general VGSTMs [8-9], this mechanism can actively control the robot shape and the track tension to adapt the robot shape for the obstacles. Thus, the wheelchair robot equipped with this mechanism will have better capability of stair-climbing.

When the wheelchair robot climbs stairs, if the tip-over incident happens, the robot may be damaged, and even the passenger may be bruised; if the slippage between the track and the stairs is too large, the robot will not go on the stairs. Several tip-over stability criteria have been put forward, such as the energy stability margin [10], the zero moment point method [11], the force-angle stability criterion [12], and the supporting force criterion [13]. However, these stability criteria have not considered the slippage between the track and the stairs. A new tip-over stability criterion with consideration of track-stair interaction has been derived in [14], but the slippage motion is limited to the special track grouser. In this paper, first, the design of our wheelchair robot and its stair-climbing performance are introduced. Then the geometric models of the robot and the passenger are presented, and the static model of the robot is established. Following that, a tip-over and slippage stability criterion appropriate for our robot is derived based on the analysis of the interaction between the track and the stairs. Finally, the simulation is performed, and stability state of the robot during stair-climbing is obtained.

II. Robot Description

A. Mechanism and Control System

The mechanism of the wheelchair robot consists of a chassis with a chair on the top and two VGSTMs installed symmetrically at the flanks of the chassis, as shown in Fig. 1.

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[6] **Suyang Yu**, Ting Wang, Zhidong Wang, Yuechao Wang, Xiaofan Li, Track tension optimization for stair-climbing of a wheelchair robot with variable geometry single tracked mechanism, 2011 IEEE International Conference on Robotics and Biomimetics, Phuket, Thailand, 2011, pp.2774-2779. 【EI: 20122015014070】

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Track Tension Optimization for Stair-Climbing of a Wheelchair Robot with Variable Geometry Single Tracked Mechanism

Suyang Yu, Ting Wang, Zhidong Wang, Yuechao Wang, and Xiaofan Li

***Abstract*—This paper introduces an originally designed wheelchair robot. This robot is equipped with a novel type of Variable Geometry Single Tracked Mechanism (VGSTM) that can actively control the robot shape and the track tension. So it becomes possible to improve the obstacle clearing capability of the robot by adapting the robot shape for the obstacle. The track tension is closely related to the performance of this original wheelchair robot, so with the aim of stair-climbing, which is the most fundamental obstacle clearing performance of the wheelchair robot, the optimization model of the track tension is established based on the geometric model and the static model of the robot. Then the simulation is performed, and the optimal track tension values of the robot for different phases of stair-climbing are obtained. Finally, these track tension values are verified through the experiment.**

I. Introduction

THE traditional wheelchair, as a very important mobility assistance device for some aged and physically disabled persons, has high mobility on even terrain. However, when facing some obstacles such as stairs, the locomotion of the wheelchair will be seriously limited, which brings great discommodity to the user. For the purpose of improving the obstacle clearing capability, especially the capability of stair-climbing, many researchers have tried to equip the traditional wheelchair with locomotion mechanisms of mobile robots to construct a wheelchair robot.

To the authors' knowledge, there are mostly three types of locomotion mechanisms applied in mobile robots that are appropriate for stair-climbing, and they are wheeled type mechanisms, legged type mechanisms, and tracked type mechanisms. Wheelchair robots equipped with wheeled type mechanisms, which are usually in the form of wheel cluster, can perform stair-climbing movement [1], but the climbing process may be uncomfortable for passengers because of the orbiting motion of the wheel cluster, and the security cannot be guaranteed without appropriate assistance. Legged type mechanisms can bring high capability of stair-climbing to wheelchair robots, but the structure of the mechanisms is excessively complex [2-3]. Compared to these two types of mechanisms, wheelchair robots equipped with tracked type mechanisms have better stationarity because of the larger contact area with the stairs, and the structure of the mechanisms is compact enough [4-5]. However, when climbing to the peak of the stairs, if the tracked mechanism is in the form of single-section, the robot will have difficulty in stable transformation of its posture, and even if the tracked mechanism is in the form of multi-section, the moving process of the robot will still not be smooth enough.

To improve the terrain adaptability of common tracked type wheelchair robots for the peak of the stairs, we have proposed a wheelchair robot equipped with a novel type of Variable Geometry Single Tracked Mechanism (VGSTM) [6]. Different from general VGSTMs [7-8], this mechanism can actively control the robot shape and the track tension to adapt the robot shape for the obstacles. Thus, the wheelchair robot equipped with this mechanism will have better capability of stair-climbing.

The track tension plays a significant role in the stair-climbing performance of this wheelchair robot. If the track tension is too low, the tractive force between the track and the stairs may be insufficient, and the skip between the track and the driving wheel may happen. If the track tension is too high, excessive load will be generated on the track and the mechanism system to reduce the power efficiency and the component life. In order to maintain the optimal track tension during stair-climbing, the track tension optimization of the wheelchair robot is indispensable. In this paper, first, the design of our wheelchair robot and its stair-climbing performance are introduced. Then the geometric model that describes the relative position to the stairs and the shape of the robot is presented, and the static model including the track tension is established. Following that, the optimization model of the track tension is established and the simulation is performed to obtain the optimal track tension values for different climbing phases. Finally, the stair-climbing experiment is conducted to verify these track tension values.

II. Robot Description

A. Mechanism and Control System

The mechanism of the wheelchair robot consists of a chassis with a chair on the top and two VGSTMs installed symmetrically at the flanks of the chassis, as shown in Fig. 1. In the VGTSMs, two back flippers can be driven synchronously to control the robot shape, and two front flippers can be driven synchronously to control the track

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[7] 于苏洋, 王挺, 李小凡, 姚辰, 一种新型轮椅机器人爬越楼梯过程倾翻稳定性分析, 中国机械工程, 2010, 21(21), 2740-2745.

一种新型轮椅机器人爬越楼梯过程倾翻稳定性分析

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摘要:提出了一种采用新型变形履带机构的轮椅机器人,这种新型机构能够在主动张紧力控制的基础上配合"凸"形地形使履带构型产生"凹"形变。针对爬越楼梯这种典型的越障运动,给出了机器人构型变化规律以及乘坐者姿态描述方法,并利用Force－Angle方法通过系统质心计算以及危险倾翻边线判定得到了能够反映机器人爬越楼梯过程倾翻稳定性状况的倾翻稳定角。仿真分析了机器人在自身不同运动状态及乘坐者不同姿态等影响下爬越楼梯过程的倾翻稳定性变化情况。

关键词:轮椅机器人;变形履带机构;倾翻稳定性;Force－Angle方法

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Tip－over Stability Analysis for Stair－Climbing of a New－Style Wheelchair Robot

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Abstract: A wheelchair robot equipped with a new－style variable－geometry－tracked mechanism was proposed. This new－style mechanism can adapt to convex terrain and turn to concave geometry by active control of track tension. Aiming at climbing stairs, the transformation rule of the robot configuration and description of the passenger attitude were presented. The tip－over stability angle was gained by calculation of the whole system's COM(center of mass) and judgement of the critical tip－over mode axes with Force－Angle stability measure. Finally, the simulation for stair－climbing of the robot was performed, and the variation of the stability margin under different conditions of the robot movement and passenger attitude was obtained.

Key words: wheelchair robot; variable－geometry－tracked mechanism; tip－over stability; Force－Angle stability measure

0　引言

轮椅是下肢行动不便者重要的代步工具。传统轮椅在平地上运动比较灵活,但当需要爬越楼梯时运动会受到很大的限制,给使用者带来极大的不便。为了解决传统轮椅存在的这种问题,国内外很多研究尝试将移动机器人的移动机构应用到轮椅上构成轮椅机器人。

在现有可供轮椅机器人选用的移动机构中,能够实现爬越楼梯这种越障运动的主要有星型轮式、腿式和履带式3种。其中,星型轮式机构[1]虽然能够实现爬越楼梯的运动,但爬越过程载体波动较大,没有外力辅助时安全性也较低。腿式机构能给轮椅机器人带来极强的爬越楼梯能力,但机器人的结构比较复杂[2-3]。相比之下,履带式轮椅机器人在楼梯中部运动时具有较好的平稳性,且机构比较简易[4],但当其运动到楼梯顶端时,传统单节履带机构无法实现从斜面到平面的姿态平稳转换,多节履带机构则会由于与楼梯接触不够充分而降低爬越过程的安全保障。

为了提高履带式轮椅机器人对楼梯顶端的适应能力,笔者提出一种采用新型变形履带机构的轮椅机器人。传统变形履带机构多是在变形过程中保持构型为凸多边形,且履带张紧程度保持不变或被动改变[5-6],这种新型变形履带机构则能够通过对构型与张紧力的主动控制,配合"凸"形地形使履带构型产生"凹"形变,从而使轮椅机器人能够在楼梯顶端获得理想的运动效果。

为了防止轮椅机器人在爬越楼梯的过程中发生倾翻,需对机器人的爬越过程进行倾翻稳定性分析。在现有比较成熟的移动机器人倾翻稳定性判定方法中[7-11],Force－Angle方法[9]具有几何描述清晰、计算过程简单等优点,非常适合对轮椅机器人爬越楼梯这种机构构型、乘坐者姿态以及履带接地点变化都较大的越障运动进行倾翻稳定性判定。因此,本文介绍了这种新型轮椅机器人的机构组成以及爬越楼梯过程。在此基础上,给

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Configuration and Tip-Over Stability Analysis for Stair-Climbing of a New-Style Wheelchair Robot

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***Abstract*—In this paper, a wheelchair robot equipped with new-style variable-geometry-tracked mechanism is proposed. This new-style mechanism can adapt to convex terrain and turn to concave geometry by active control of track tension, based on which the terrain adaptability of the wheelchair robot is improved. Aiming at climbing stairs, the transformation rule of robot configuration is presented, the description of passenger's attitude and action is established. Following that, the tip-over stability analysis and simulation are performed with Force-Angle stability measure, and the variation of the tip-over stability margin of the robot under different conditions of passenger's attitude and action during stair-climbing is obtained. The analysis and simulation results provide a valid reference to the wheelchair robot's potential application.**

I. Introduction

WHEELCHAIR is a very important mobility assistance device for some aged and physical disabled persons. Traditional wheelchair has high mobility on even terrain, but when facing stairs, the locomotion of the wheelchair will be limited seriously, which brings great discommodity to the users. For improving the ability of stair-climbing of traditional wheelchair, many researchers have tried to equip the wheelchair with the travel mechanism of mobile robot to build wheelchair robot.

To the authors' knowledge, there are mostly three types of travel mechanisms applied in mobile robot which are appropriate for stair-climbing, they are wheeled type mechanism, legged type mechanism and tracked type mechanism. Wheelchair robot equipped with wheeled type mechanism which is usually in the form of wheel cluster can perform stair-climbing movement [1], but the climbing process may be uncomfortable for passengers as the orbiting motion of the wheel cluster, and the security can not be assured without appropriate assistance. Legged type mechanism can bring high ability of stair-climbing to wheelchair robot, but the structure of the mechanism is excessively complex [2-3]. Compared to these, wheelchair robot equipped with tracked type mechanism has better stationarity as the large contact area with the stairs, and the structure of the mechanism is compact enough[4], but when the tracked type wheelchair robot climbs to the peak of the stairs, if the tracked mechanism is in the form of single-section, the robot will have difficult in stable transformation of posture, if the tracked mechanism is in the form of multi-section, the contact between the track and the upper floor will not be sufficient enough.

To improve the terrain adaptability of common tracked wheelchair robot especially at the peak of the stairs, we propose a wheelchair robot equipped with new-style variable-geometry-tracked mechanism. General variable-geometry-tracked mechanisms usually retain the geometry to be convex polygon during transforming on the condition that the track tension keeps invariable or varies passively [5-6], so they can not adapt to convex terrain as example of the peak of the stairs very well. On the contrary, this new-style variable-geometry- tracked mechanism can adapt to convex terrain and transform to concave geometry by active control of track tension, so the wheelchair robot equipped with this mechanism will have better ability of stair-climbing.

When the wheelchair robot climbs stairs, it will result in a series of problems such as robot damage even passenger injury if tip-over incident happens, so it is indispensable to perform tip-over stability analysis for stair-climbing before the robot is devoted to application. Several researchers have tried to propose a suitable criterion for tip-over stability evaluation such as Energy-Equilibrium Plan measure [7], Zero Moment Point measure [8], Force-Angle measure [9], Normal Supporting Force measure [10] and Moment-Height measure [11], where the Force-Angle stability measure has the advantage of clear geometrical description and low computational effort and is very appropriate to evaluate the tip-over stability of stair-climbing of this new-style wheelchair robot during which the varieties of robot configuration, passenger attitude and ground contact points are all very large. So, in this paper, first, the new-style wheelchair robot and its stair-climbing procedure are introduced. Then the transformation rule for robot configuration during different climbing phases is presented and the description of passenger's attitude and action is established. Finally, the tip-over stability analysis and simulation for stair-climbing of the robot under the influence of passenger's attitude and action are performed with Force-Angle measure.

II. General Procedure for Stair-Climbing

A. The New-Style Wheelchair Robot

The mechanism of the new-style wheelchair robot

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Dynamic Analysis for Stair-Climbing of a New-Style Wheelchair Robot

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Abstract: In this paper, a wheelchair robot equipped with new-style variable-geometry-tracked mechanism is proposed. Different from general variable-geometry-tracked mechanisms, the key feature of this new-style mechanism is that it can adapt to convex terrain and transform to concave geometry by active control of track tension, based on which the ability of stair-climbing of traditional wheelchair is improved. For obtaining the dynamic characteristic of stair-climbing which is crucial to the robot design, the locomotion and transformation rule for the robot during different climbing phases is presented, the dynamic models of the robot whole body and its fundamental components are established. Finally the dynamic simulation for stair-climbing is performed, and the drive characteristic of the robot under different climbing conditions is obtained. The simulation results provide theoretical foundation to the future work of driving system design and mechanical parameters optimization.

Key Words: Wheelchair Robot, Variable-Geometry-Tracked Mechanism, Dynamics, Drive Characteristic

1 INTRODUCTION

Wheelchair is a very important mobility assistance device for some aged and physical disabled persons. Traditional wheelchair has high mobility on even terrain, but when facing stairs, the locomotion of the wheelchair will be limited seriously, which brings great discommodity to the users. For the purpose of improving the ability of stair-climbing of traditional wheelchair, many researchers have tried to equip the wheelchair with the travel mechanism of mobile robot to build wheelchair robot.

To the authors' knowledge, there are mostly three types of travel mechanisms applied in mobile robot which are appropriate for stair-climbing, they are wheeled type mechanism, legged type mechanism and tracked type mechanism. Wheeled type mechanism applied in wheelchair robot is usually in the form of wheel cluster [1]. The wheelchair robot equipped with this type of mechanism can perform stair-climbing, but the climbing process may be uncomfortable for passengers as the orbiting motion of the wheel cluster, and the security can not be assured without appropriate assistance. Legged type mechanism can bring high ability of stair-climbing to wheelchair robot, but the structure of the mechanism is excessively complex [2-3]. Compared to these two types of mechanisms, wheelchair robot equipped with tracked type mechanism has better stationarity as the large contact area with the stairs, and the structure of the mechanism is compact enough[4], but when the tracked type wheelchair robot climbs to the peak of the stairs, if the tracked mechanism is in the form of single-section, the robot will have difficult in stable transformation of posture, if the tracked mechanism is in the form of multi-section, the contact between the track and the top floor will not be sufficient enough.

To improve the terrain adaptability of common tracked wheelchair robot, especially at the peak of the stairs, we propose a wheelchair robot equipped with new-style variable-geometry-tracked mechanism. General variable-geometry-tracked mechanisms usually retain the geometry to be convex polygon during transforming on the condition that the track tension keeps invariable or varies passively [5-6], so they can not adapt to convex terrain as example of the peak of the stairs very well. On the contrary, this new-style variable-geometry-tracked mechanism can adapt to convex terrain and transform to concave geometry by active control of track tension, so the wheelchair robot equipped with this mechanism will have better ability of stair-climbing.

In this paper, first, the new-style wheelchair robot and its stair-climbing procedure are introduced. Then the locomotion and transformation rule for the robot during different climbing phases is presented and the dynamic models of the robot whole body and its fundamental components are established. Finally, the dynamic simulation for stair-climbing is performed and the simulation results are analyzed.

2 STAIR-CLIMBING PROCEDURE OF THE NEW-STYLE WHEELCHAIR ROBOT

2.1 The New-Style Wheelchair Robot

The mechanism of this wheelchair robot consists of a supporting frame, a chair fixed on the top of the supporting frame, and two variable-geometry-tracked mechanisms installed at the flanks of the supporting frame symmetrically, as shown in Fig. 1(a). In the variable-geometry-tracked mechanisms, two driving wheels are driven independently to realize moving and

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