Mechanism and Machine Theory 87 (2015) 18–44

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmt

Research on a tracked omnidirectional and cross-country vehicle

Yunan Zhang, Tao Huang *

Department of Control Engineering, Academy of Armored Forces Engineering, No. 21, Du Jiakan, Fengtai District, Beijing 100072, China

A R T I C L E I N F O

Article history:
Received 3 August 2014
Received in revised form 23 December 2014
Accepted 30 December 2014
Available online 10 January 2015

Keywords:
Track running mechanism
Omnidirectional vehicle
Cross-country

A B S T R A C T

Conventional tracked vehicles have superior cross-country capability compared to common wheeled vehicles, but poor maneuverability, especially poor steering performance. However, the existing omnidirectional vehicles have poor cross-country capability despite much higher maneuverability than common vehicles. This paper presents an innovational track running mechanism, a vehicle construction and its unique kinematical and dynamical theories, with an independent electric drive system used to construct a tracked omnidirectional and cross-country vehicle — a tracked-omni-vehicle. The vehicle demonstrates omnidirectional motion on uneven terrains, superior steering efficiency, equal longitudinal motion efficiency, and comparable cross-country performance in comparison to conventional tracked vehicles. The success of the tracked-omni-vehicle has made a breakthrough in the running mode of conventional tracked vehicles and the limitations of omnidirectional vehicles in engineering applications.

1. Introduction

Omnidirectional vehicles are a type of 3 degree of freedom (DOF) vehicles on the ground. They can achieve longitudinal motion, lateral motion, center-point steering motion, and any composite motion of above three, so they are suitable for highly maneuverable, narrow or accurate positioning occasions. Omnidirectional vehicles are characterized by their special running mechanisms. At present, most researchers are mainly focusing research on the wheeled omnidirectional running mechanisms, such as Mecanum wheel, alternate wheel, and ball wheel [1]. Especially, Mecanum wheeled omnidirectional vehicles have been widely used in military [2], storage and transportation [3], social services [4], and other fields, for example the omnidirectional forklift as shown in Fig. 1. However, the wheeled omnidirectional vehicles still have significant limitations in engineering applications despite much higher maneuverability than common wheeled vehicles, because there are some common problems with them. Taking the omnidirectional forklift for example, the problems are as follows:

- Large vibrations. The Mecanum wheel is almost rigid and its ground contact roller is discontinuously changing, so the forklift has large vibrations, even on the flat ground.
- Limited loading capacity. The ground contact area of the Mecanum wheel is extremely small, so the ground pressure is extremely large in the case of heavy loads.
- High road conditions. The omnidirectional forklift is not suitable for running on uneven terrains, and can only work on flat and hard surfaces.

Inversely, conventional tracked vehicles, such as bulldozers, excavators, tanks, and tractors, have stable movements, large loading capacity, and superior cross-country capability to common wheeled vehicles and they are capable of crossing obstacles, trenches or breaks, and are much less likely to get stuck in soft ground. However, they are inferior to wheeled vehicles in their maneuverability,

* Corresponding author. Tel.: +86 18611973725, +86 10 66718706.
E-mail addresses: zhang_yunan@sina.com (Y. Zhang), wdmd_huang@126.com (T. Huang).

http://dx.doi.org/10.1016/j.mechmachtheory.2014.12.016
0094-114X/

Fig. 1. The omnidirectional forklift.

and are especially difficult to steer because of great lateral resistances [5]. In order to promote the steering performance of tracked vehicles, many researchers have carried out a lot of studies on steering gears, control strategies, and so on [5–7], but the results remain unsatisfactory. Furthermore, it is incredible that conventional tracked vehicles can run with omnidirectional motion. Although some researchers have developed several kinds of impressive tracked running mechanisms for omnidirectional motion as shown in Fig. 2, including the omnidirectional spherical tire track [8], the Vuton crawler [9], the crawler–roller running mechanism [10,11], and the omni-crawler [12,13], they have some different problems as follows:

1. Omnidirectional spherical tire track. It consists of several balls and a pair of parallel rods. Motion in the longitudinal direction is achieved by moving the balls along the length of rods; sliding is prohibited and thus the balls rotate about the axes parallel to the lateral direction. Motion in the lateral direction is achieved by rotating the rods about their axes, which in turn rotates the balls about the axes parallel to the longitudinal direction. A vehicle equipped with such two tracks can achieve omnidirectional motion, but has difficulty crossing obstacles in either a longitudinal direction or a lateral direction. Additionally, each ball requires a different angular velocity vector in steering motion, but all balls in the same track are constrained to move with the same angular velocity vector. Consequently, it has large steering lateral resistance which is the same as that of an equivalent conventional tracked vehicle.
2. Vuton crawler. The free rollers of the Vuton crawler are supported by square frame members with rotational motion independence, and the square frame members are connected to the chains at diagonal points separated by a horizon distance. The pair of chains is also offset with the same distance, and the chains are driven simultaneously. A vehicle equipped with such four crawlers can achieve omnidirectional motion, but it has a square layout, which is inapplicable to conventional tracked vehicles. Additionally, such a vehicle has difficulty crossing obstacles, and its gradeability is also inferior to that of a conventional tracked vehicle. Fortunately, it almost causes no wear on the ground in steering motion, because of extremely little lateral resistance [14].
3. Crawler–roller running mechanism. Its free rollers are mounted on the outside with two of them constituting one unit. It has the same running principle as the Vuton crawler, so a vehicle equipped with such four mechanisms also has a square layout. Such a vehicle can steadily run on uneven terrains and cross some small obstacles, but its crossing obstacle is limited to the diameter of the roller, which is much smaller than that of the crawler. Although the smaller rollers that are mounted on the rollers can play a role in crossing some higher obstacles, its ability to cross obstacles is still inferior to that of an equivalent conventional tracked vehicle.
4. Omni-crawler. It is characterized by a circular cross-section. The crawler module has an active rotational axis, which allows it to achieve lateral motion. When the axis of the driving sprocket is perpendicular to the ground, there is a singularity that does not allow for the generation of any longitudinal traction. If the lateral motion is active in an invariant direction, the direction of longitudinal motion will be changed after crossing the singularity. Its control for omnidirectional motion is unrealistic, because the singularities should be sensed and the rotational directions of the sprockets should also be changed frequently. Therefore, the vehicle has difficulty achieving a diagonal motion and can only perform the longitudinal and lateral motion independently. Additionally, it also has large steering lateral resistance which is the same as that of an equivalent conventional tracked vehicle, because all ground contact points on one crawler are constrained to move with the same velocity vector.

In brief, the existing tracked omnidirectional running mechanisms are impossible to apply to conventional tracked vehicles, because the vehicles equipped with such running mechanisms cannot retain the cross-country capability of conventional tracked vehicles, and have inapplicable vehicle construction or unrealistic motion control.

In order to resolve the problems associated with the omnidirectional vehicles and improve the maneuverability of conventional tracked vehicles, a novel tracked running mechanism has been proposed in this paper, with which a tracked vehicle can not only achieve omnidirectional motion to improve the maneuverability of conventional tracked vehicles but also retain the cross-country