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An automated guided mechatronic tractor for path tracking of heavy-duty robotic vehicles

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ABSTRACT

Nowadays, a large number of AGVs are needed to carry out repeating transport tasks in many manufacturing and warehouse industries. Their extensive application is influenced by several critical factors of equipment expense, vehicle maneuverability, energy efficiency and configuration flexibility, especially in a large-scale AGV system. In order to attain high dynamics and energy conservation while retaining low cost and flexible reconfiguration, mechatronics techniques are introduced to combine high-performance microcontrollers, low-power motors and short-range sensors with a light-weighted chassis, which results in a swift mechatronic tractor for automated guidance of a heavy-duty robotic vehicle on fixed guide paths. Analysis of load carrying for different wheels shows the tractor only carries a partial weight of the whole vehicle by using its suspension layer. Kinematics and dynamics properties of the vehicle actuated by the tractor are investigated, which explains the reasons why low-power motors and short-range sensors can be used for automated guidance of heavy-duty vehicles. When this tractor is equipped with different guiding sensors, such as a magnetic sensor or a camera, the corresponding magnetic or visual guided vehicle can be conveniently developed only by configuring tractors and other passive wheels within a vehicle frame. For instance, a low-cost magnetic sensor is used for the tractor and a magnetic guided vehicle prototype is developed based on it. Experiments of load carrying and path tracking are conducted by using this prototype. The experiment results show the tractor can actuate the heavy-duty vehicle with low power consumption and track its target paths with a fast dynamic response, which provides a possibility of decreasing cost and consumption still preserving maneuverability and flexibility by using mechatronics techniques.

1. Introduction

Nowadays, large numbers of AGVs are needed to carry out repeating transportation tasks in many application areas of distribution, transshipment and transportation [1]. There are several critical factors influencing their further popularization and application. Equipment expense may be the first crucial factor considered for a large-scale AGV system (up to 400 AGVs [2]), especially in cost-sensitive industries. Single AGV expense is determined by guiding sensors, driving motors, power batteries and vehicle controller roughly. Recently, technology advances and cost reduction in microelectronics and microcomputers permit to develop an intelligent onboard control system that can store routing instructions, make decisions and even take part in traffic control of the global system for AGVs meanwhile at an affordable price. However, three other elements are still on a relatively large portion of AGV hardware cost.

Vehicle maneuverability is another critical factor for AGV application, which is relevant to navigation approach as well as wheel structure. As for the former, fixed guide paths are firstly used for AGV systems, and their preferred tracks can be defined by using electric wires, magnetic tapes or reflective tapes embedded in or lay on the floor. Their guiding sensors have a relatively simple working principle and a low manufacturing cost. However, they usually have a short detecting range in the grade of centimeter with respect to guide paths. These AGVs are confined to fixed guide paths and cannot deviate from them dramatically in order to avoid the loss of navigation signals. Path tracking is used to eliminate position deviation and orientation deviation of an AGV and keep it moving along guide paths [3–6]. Whatever control techniques are used, an invariable physical fact is that if path tracking of heavy-duty vehicles refers to steering its massive body rapidly and keeping guide paths in its short detecting range, the need of its driving system for high torque and power is unavoidable.

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Another kind of AGVs is free-ranging, which means its preferred tracks are software programmed, and can be changed relatively easily when new stations or flows are added [7]. Some innovative prototypes with vision navigation systems have even removed the dependence on guidance infrastructure by using simultaneous localization and mapping (SLAM) [8–9]. Nevertheless, laser navigation systems may be a most popular choice for implementing free-ranging AGVs [10–11]. At least theoretically, these AGVs can take any guide path to navigate between points as long as it can keep several landmarks in its field of view. Motion planning is used for free-ranging navigation to maintain landmark visibility in the presence of obstacles [12–13]. The detecting range of laser navigation systems (such as SICK NAV350) for reflective landmarks is often more than 35 m, so the free-ranging AGVs can tolerate a larger deviation from target paths in its navigation and its motion control is not so difficult as path tracking on fixed guide paths. However, the laser navigation system is more expensive than a short-range guiding sensor for AGVs tracking fixed guide paths, which is thus not suitable for a cost-sensitive AGV.

If we insist on using low-power motors and short-range sensors for a heavy-duty robotic vehicle on fixed guide paths, its driving chassis with powered wheels and a guiding sensor must be light-weighted. Some valuable instances of energy-efficient vehicles can be found in articulated heavy vehicles (AHV) and over-actuated vehicles with four-wheel steering/driving (4WS/4WD) [14–19]. AHV is a new type of vehicle for mass transit combining the advantages of commuter buses and railroad vehicles. It consists of a powered unit, namely truck or tractor, and towed unit(s), called trailer(s). The capacity of AHV can be increased by connecting several units to one another at articulated points by mechanical couplings. If the towing mechanism of a tractor and its trailer is applied to the vehicle structure of AGVs, the light-weighted driving chassis can be steered rapidly by using low-power motors in order to keep guide paths visible for its short-range sensor. For the perspective of energy utilization, low-power motors may only need low-capacity batteries, which mean high energy efficiency for heavy-duty AGVs.

Some novel wheel structures can influence both vehicle maneuverability and energy efficiency, e.g. active dual-wheel caster assemblies [20, 21] and caster-drive wheels [22, 23] have been proposed to improve the controllability of wheel mechanism, to avoid nonholonomic constraints or to decrease the sum of energy consumption. The structure of the active dual-wheel caster, a passive steering axis with offset set in the front of two conventional independent driving wheels, can be used for reference when we design the light-weighted chassis carrying low-power motors and short-range sensors.

Mechatronics is a comprehensively optimized design methodology [24–27] used to develop an automatic mechanical system by considering parallel the characteristics of mechanisms, sensors, controllers and drives. The design conflict of high performance and low cost, efficiency and flexibility, may be solved by using this technique, and an ingenious mechatronic tractor can be developed for automated guidance of a heavy-duty robotic vehicle. When this tractor is equipped with different guiding sensors, such as a magnetic sensor or a camera, the corresponding magnetic or visual guided vehicle can be conveniently developed only by configuring tractors and other passive wheels within a vehicle frame. Furthermore, configuration flexibility can be witnessed when more than one tractor are arranged in some types of layouts (such as tandem or parallel) to construct a more complicated robotic vehicle with multi-sensor guidance and multi-motor drive, e.g. a prototype of heavy-duty robotic vehicle has been developed by two automated guided tractors with on-board camera [28]. Camera fixed on each tractor constitutes the initiative multi-camera guiding system, and a collaborative calibration method has been investigated.

The rest of paper is organized as follows. Mechatronics design of an automated guided tractor is presented in Section 2. The vehicle configuration containing this mechatronic tractor is illustrated and the kinematics of this AGV is discussed in Section 3. Load distribution of different wheels is considered and the dynamics of this AGV is analyzed in Section 4. A robotic vehicle based on a magnetic-guided tractor is developed and several experiments of load carrying and path tracking are conducted in Section 5. A conclusion and some potential research points are given in Section 6.

2. Mechatronics design

In order to avoid the disadvantages of low-power motors and short-range sensors for automated guidance of a heavy-duty robotic vehicle, the towing mechanism of a tractor and its trailer, and the structure of the active dual-wheel caster are introduced as reference. The objectives of mechatronics design for an automated guided tractor are to achieve: (a) light-weighted, in order to reduce the self-weight of this tractor; (b) few-load-carrying, in order to decrease the load portion of this tractor imposed by the whole vehicle; (c) extended-detecting, in order to extend the detectable range of the guiding sensor; (d) driving-with-sensing, in order to integrate motors and sensors into an independent guiding unit. Owing to the decreased load of the tractor, it can steer the short-range sensor towards its guide paths at a high response rate but still tow the heavy-duty robotic vehicle along the guide paths. How mechatronics techniques solve the design conflict of high performance and low cost, efficiency and flexibility can be described briefly in Fig. 1.

This tractor is a dual-layer two-wheel differential-driving steering mechanism, as shown in Fig. 2. The upper layer is a suspension-like mechanism fixed with the vehicle frame. It is used to help the

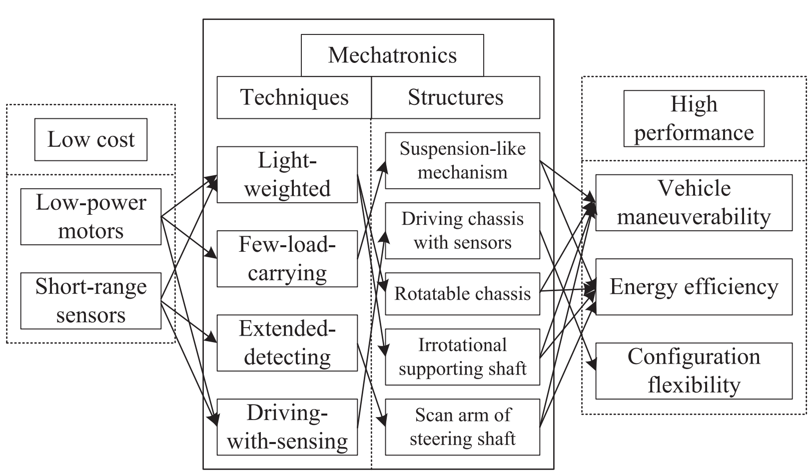

Fig. 1. Mechatronics design of the mechatronic tractor.

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