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Modernization of the Systematic Odometer Error in Nonholonomic Wheeled Mobile Robots

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Abstract

One major drawback of wheeled mobile robots (WMRs) powered by differential drives is their inability to dependably maintain straight lines while navigating smooth interior surfaces autonomously. Because of the inherent weakness of its kinematic design, this considerable dead reckoning error arises naturally as the traveled distance increases. Consequently, the mobile robot's camera resolution is of utmost importance. The use of wheel encoders and the ability to process data quickly from feedback controls is the only way to decrease this wasteful systematic odometer error. This work presents a new and efficient mechanical drive train architecture called dual planetary drive (DPD) for non-homonymic wheeled robots. Its primary goal is to reduce systematic odometer error without using complicated electronic feedback control methods.

1. Introduction

Wheeled mobile robots (WMR) have spread rapidly from the industrial to the service sectors in recent years [1-4]. There were a projected 2.2 million sales of service robots for personal and household usage in 2010, and that figure might rise to nearly 14.4 million units globally by 2020, as reported by the International Federation of Robotics [5]. When it comes to mobile robot (MR) applications, wheels are often the favored means of movement [6-8]. The mobility properties of WMRs allow us to classify them as either homonymic or non-homonymic [2]. Generally speaking, non-homonymic WMRs can only move in two degrees of freedom (2DOF) and must make adjustments to their trajectory to reach a target location (see references [9-11]). The WMR performs a maneuver whenever it slows down to realign its wheels with the intended course. However, the time it takes to complete the series of maneuvers is minimal [12]. 2DOF WMRs are mechanically simpler than Omni directional 3DOF WMRs, according to Muir and Neumann [6], and are just as capable of following any specified route without any issues. The two distinct maneuvering sequences are shown in Fig.1.

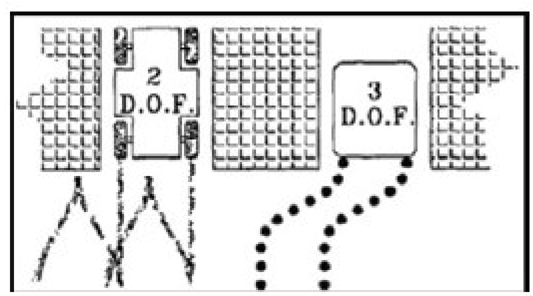


Figure 1: Two-degree-of-freedom vs. three-degree-of-freedom WMR maneuvering sequence

Differential drive kinematic configurations are used to activate the majority of commercially available WMRs [3, 4, and 13]. The plan calls for a set of driving wheels that are perpendicular to one another and positioned on an aligned pivot point. The two wheels are independently powered by DC motors. In Fig. 2 we see how a regular differential drive WMR is put together. The WMR's 2DOF kinematic setup enables it to travel in a straight line, make a 180° turn, or follow a curved route [11, 14].

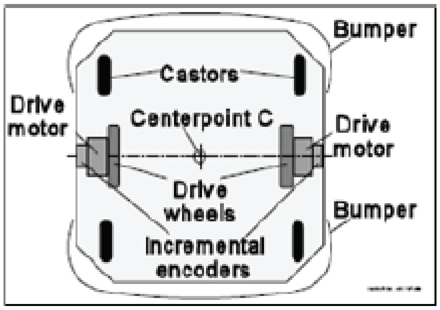


Figure 2: Differential Drive WMR's Internal Structure

To do dead reckoning, classic WMRs like the differential drive robot use incremental optical encoders to track the number of times in which the driven wheels have rotated after an initial set point. The study of distances, or odometer, this technique of relative positioning is calculated using information about the wheel's shape and the amount of pulses from an encoder attached to the wheel [15, 16]. The encoder pulses are translated into linear distances in relation to the surface the WMR is traveling over by a low-level robot controller. When compared to inertial-based systems, which suffer from sensor drift, odometer delivers very accurate location accuracy over relatively short periods of time or distance traveled [7, 15, and 17]. In addition, since the WMR has no access to any other external navigational reference, odometer is the only way it can determine its current location and course [7]. An efficient dead reckoning system will unquestionably minimize the total installation cost of a mobile robot system [17], and it will also prevent the WMR from significantly losing its course.

1.1. Problem Statement

Despite its widespread use, the differential drive has long been recognized as a significant weakness in the design of WMRs. Moving this MR in a straight path over greater distances is challenging [14]. Despite being controlled by the same voltage, the two motors have a tendency to revolve at different angular speeds [18]. The negative effects of this include into a deviation from the planned straight-line course of the WMR, which is both undesired and unexpected [13]. The robot's lateral position error, also known as systematic odometer error, increases exponentially with distance [15]. Both wheels must revolve at the same angular velocity for the robot to travel in a straight path [13, 14, and 18]. Differential drive WMRs have a natural disadvantage unless they include an advanced electronic feedback control system that continually monitors and swiftly synchronizes both their driven wheels [18, 19].

It's helpful to be able to walk in a straight line because of all the doors and hallways you'll have to navigate within a building [18]. When calculating the shortest distance between two points, straight-line trajectories always win [13]. Non-systematic errors become prominent when operating the WMR on rugged or undulating outdoor type terrain [15], whereas the negative consequences of systematic odometer errors are more apparent when operating the WMR on well paved and organized indoor facilities. The mechanical misalignment that occurs between the differential's two driven wheels is another key problem in the design. This systematic odometer mistake [13] is caused by the unproductive lateral drag that is created by the coaxial misalignment. The WMR's dead reckoning accuracy is likely impacted by these design-specific mechanical flaws [15]. It is widely known that WMR motion control and wheel slip characteristics are heavily influenced by the kinematic design [6]. Intelligent design techniques that enhance mechatronic simplicity, innovation, and resilience without compromising performance or functionality are becoming more important as WMRs map new areas of application [20]. While the MR Field as a whole has made great strides, the mechanical design of the mobility control system has received comparatively less attention from academics [3, 6]. Non-homonymic motion planning and control issues were the primary focus of the majority of the previously mentioned WMR documentations [1]. Similarly, researchers in the area of artificial intelligence have taken the lead in efforts to increase the precision of WMR odometer. Their methods relied heavily on feature extraction and map integration, but ignored the mechanical details of the mobile robot's construction [15].

2. Objective

In order to address the drawbacks of the differential drive kinematic arrangement, the research introduces a novel mechanical design technique. This article explains the mechanism's operating principle and how the complete drive train design ensures a capacity for continuous straight-line travel while reducing systematic odometer inaccuracy. Indoor uses for WMR are discussed. An existing mechanical solution designed to propel a non-homonymic WMR in a straight path was also compared conceptually with the suggested design to see which was preferable in terms of mechanical design.

2.1. Existing Mechanical Solution for Driving Straight

The dual differential drive (DDD) was an experimental drive train developed by Carver [18] that he proved could propel a WMR in a straight path without the need of closed loop feedback control electronics. His DDD mechanism is shown in construction in Fig. 3. The angular velocities of the two driving wheels were matched by using a single motor to activate a pair of differential gearboxes for the left and right wheels. These identical differential gear boxes were also employed to enable the robot's in-place rotation through a second motor driving an odd number of gears. The DDD method failed to satisfy the underlying mechanical design necessity to maintain both its powered wheels coaxially aligned, despite the benefit of assured straight-line movement when perfectly built. This is an obvious need for maintaining steady control of straight motion and reducing systematic odometer inaccuracy. Torque is transmitted from the motors to the driven wheels through a bevel gear system, which is cinematically inefficient [21].

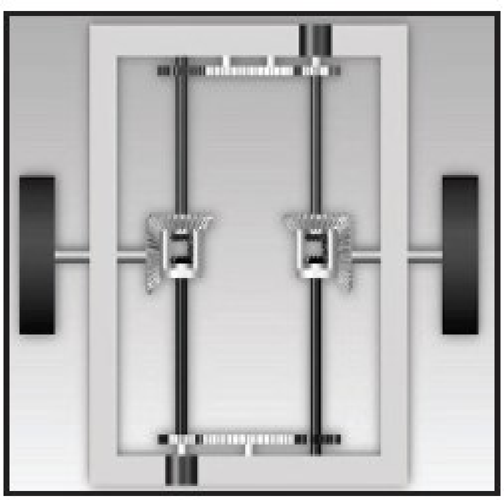


Fig.3. Dual Differential Drive construction

3. A Novel Drive Train Solution to Minimize Systematic Odometer Error for Non-holmic WMRs

Differential drive and direct drive differential (DDD) were analyzed, and a novel drive train design using two planetary gear trains (PGT) and two DC motors was developed as a compromise. The goal was to achieve constant, mechanical wheel-to-wheel synchronization of the driving wheels without resorting to sophisticated electrical mechanisms. This fresh approach the name given to this technique was "dual planetary drive" (DPD). The robot may be driven in a straight line or made to turn on the spot with the use of just a single motor. Both motors were active only when the robot needed to take a curving path.

3.1. Key Design Criteria for Dual Planetary Drive

To maintain a straight course, the DPD-driven, non-homonymic WMR cannot use electronic feedback control to synchronize its driven wheels. It's also crucial to include in a mechanism that keeps the driven wheels aligned in a coaxial fashion. No kinematic inconsistencies can exist in the drive train. Too limited, and will need autonomous 2DOF motion control capabilities for optimal navigation of interior spaces with predetermined layouts. The goal of this innovative mechanical design is to reduce systematic odometer inaccuracy to a minimum.

3.2. Operating Principle of Dual Planetary Drive (DPD).

The DPD is based on the same premise as the one-stage PGT that it evolved from. Unlike traditional gear trains, which only provide one input and one output, a PGT may be activated with two inputs to generate a single output [22]. A typical single-stage PGT is shown in Fig. 4. PGTs are also the best option when the transmission of power to the drive wheels calls for a reduction in speed and an increase in torque [23]. Specifically, PGTs have a lower operating noise and vibration level, a better torque-to-weight ratio, a larger load-sharing capacity, and a smaller footprint. The DPD uses the sun gear or the carrier as input to move and steer the WMR, but the ring gear is always used as the output. Torque is transferred from the motor to the driven wheels of the robot in one of three actuation modes, as shown in Table 1.

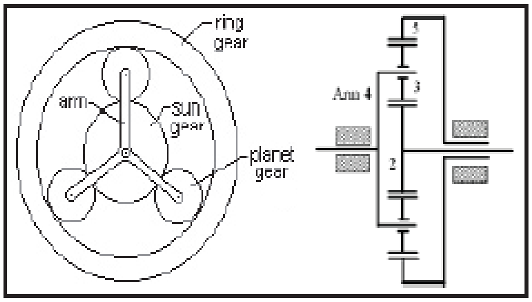


Fig.4. Construction and schematic of a single stage PGT.

Table 1. PGT configurations and activation modes for DPD

DPD Mode	Input Element	Fixed Element	Output Element	Resultant Trajectory
I	Sun Gear	Carrier	Ring	Straight
II	Carrier	Sun	Ring	On the Spot Rotation
III	Sun + Carrier	None	Ring	Curvature

The PGT is intelligently built into the MR wheel as shown in Fig. 5 and Fig. 6. One PGT assembly is housed inside each driven wheel of the WMR. The ring gear is the final element that transfers the torques from the motor to the ground.

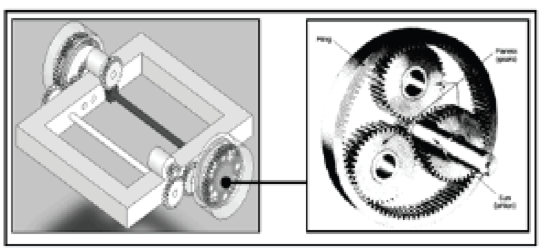
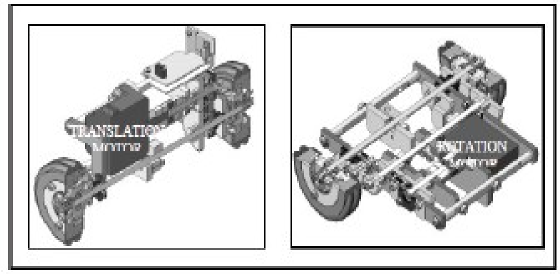


Fig.5. Two sets of single stage PGTs drive the wheels of the mobile robot

3.3. Driving in a Straight Line

Straight forward motion is achieved by immobilizing the carrier and powering the solar gear. The ring gear may be made to revolve in the opposite direction as the sun gear by turning off the rotation motor and starting the translation motor. The sun gears on the left and right PGT wheels, however, are locked to a shared driving shaft. Moved by the motor responsible for translation. Therefore, the left and right wheels will both spin at the same rate and in the same direction. The WMR may be driven in either direction with absolute precision thanks to its mechanical synchronization. Figure 6 depicts the drive train and its assembly. Fig. 7 depicts the power transmission via the gear train.

In Fig. 8 we see a simplified schematic representation of the gear train.



Mechanical architecture of DPD and drive motors for straight and on-the-spot turns are shown in cross sections in Fig. 6. 3.4. Turning on the Spot

In order for the robot to do a turn with zero radiuses, the solar gear is now immobile while the carrier is propelled. With this case in point, turning off the motor doing the translation and starting the one doing the rotation. Through another common driving shaft attached to the left and right basic gear trains, the rotating motor powers both left and right carriers simultaneously. Because of this function, the left and right PGTs spin at the same rate. The PGTs on the left and right wheels, however, will turn in the opposite direction due to the ring gears. This is due to the fact that these PGTs are actuated by a set of gears with an uneven number on one side and an even number on the other. Fig. 6 depicts the drive train assembly, and Fig. 7 details the related actuation. Fig. 8. 3.5 is a schematic depiction of the gear train. Taking a Winding Route While Driving When the WMR has to follow a winding route, the DPD's two motors are turned on at the same time, spinning in opposite directions and at different speeds. This procedure furnishes the varied curvature radii necessary for the WMR to successfully follow the predetermined course.

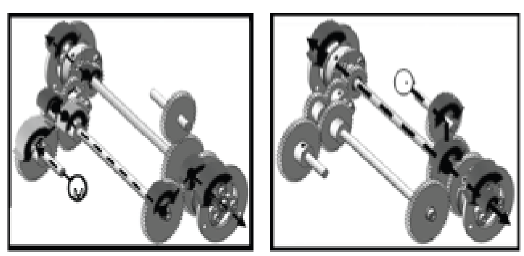


Fig.7. Power flow through the compound gear train and PGTs to provide turning on the spot and straight line motion

4. Advantages of the Dual Planetary Drive

The DPD's greater odometer error control capabilities are evident despite the complexity of its design compared to that of the differential drive. The DPD mechanism's design precludes the requirement for an intricate electronic feedback control system to coordinate left and right powered wheels. . Furthermore, the hardware design naturally incorporates the requirements for coaxial alignment and interlocking between the two driven wheels. Mechanically synchronized left and right wheel velocity enabling precise on-the-spot rotation of the WMR is another key benefit in terms of odometer precision management. Because of the radial arrangement of the gears, the PGT structure is also extremely small and may be installed inside the driven wheel.

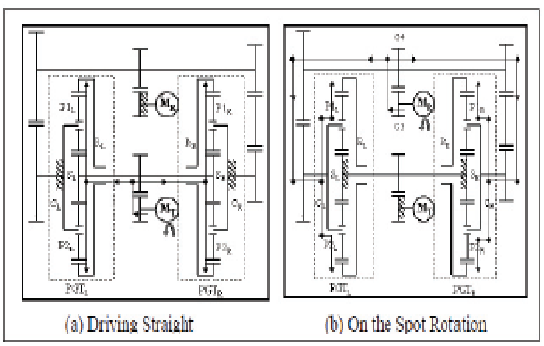


Fig.8. Illustration of entire gear train schematics for the proposed DPD mechanism

5. Conclusion

For indoor non-homonymic WMR, a new drive train mechanism was described that reduces systematic odometer errors. A WMR may be guided in a straight path using this mechanical approach, eliminating the need for sophisticated electrical feedback controllers. Furthermore, this clever layout satisfies the essential need to irrevocably the driving wheels should be kept coaxially aligned. In terms of odometer error reduction and dead reckoning accuracy, the design of the drive train itself is better than both differential drive and DDD. The authors of this study also want to fill in the blanks left by the dearth of research on mechanical design for WMRs. To facilitate more empirical testing, a prototype of the DPD WMR shown in Figures 9 and 10 is now being built. Future publications will gradually assess its performance qualities and publish the results. Last but not least, the benefits of this novel drive train mechanism will undoubtedly shed light on design concepts to enhance autonomous navigation capabilities for outdoor WMRs.

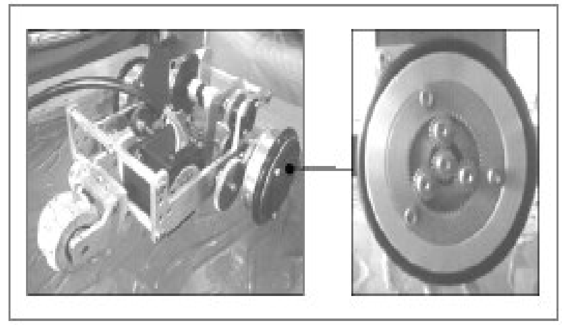


Fig.9. Prototype of the non-homonymic WMR with DPD mechanism

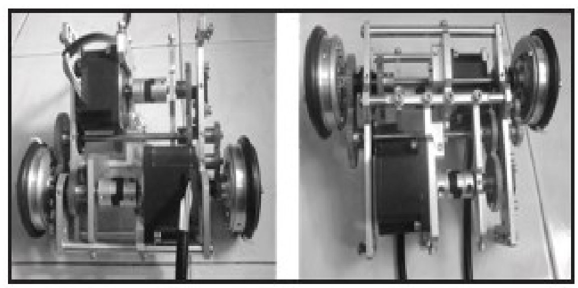


Fig.10. WMR showing concealed PGT, DC brushless motors and fully meshed gear train from top and bottom view of assembly

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