# Zero-Scrub, Large Contact Area, Three-Degree-of-Freedom Holonomic Ground Vehicles for Mobile Robotics Applications

## 1. Introduction

For ground-surface mobile robots operating in human environments with people present, high mobility—specifically full 3-DOF holonomic motion in the plane—is desirable. Machines without it, though otherwise very capable, can waste time, space, and energy in sub-optimal trajectories, repetitive motions, and excessive wait states—frustrating people around them. For heavy physical work, high load capacity and high efficiency are also desirable. Yet robot designers choosing among current ground vehicle types face trade-offs involving mobility, load capacity, and efficiency.

In this paper, we introduce zero-scrub, large contact area, 3-DOF holonomic vehicles ("ZS-3" vehicles) as a new type of ground vehicle with the potential to combine high mobility, high load capacity, and high efficiency in one vehicle. In section 2 below, we define scrub and introduce and characterize ZS-3 vehicles with some examples. In section 3, we explore a few aspects of kinematics, dynamics, and control and actuation for a particular embodiment. Finally in section 4, we give suggestions for future work and potential future applications for ZS-3 vehicles and their enabling technologies, including applications to gripper/manipulators and climbing machines.

## 2. Zero-Scrub, Large contact Area, 3-DOF Holonomic ("ZS-3") Vehicles

"Scrub" as used herein may be defined as difference in the nominal motion of paired robot-ground (or robot-object) contacting surfaces during locomotion (or manipulation). Scrub generally reduces repeatability and wastes power. Virtually all current ground vehicle types employ or rely upon scrub—at least in the form of rotation of a ground-contacting surface, relative to the ground contacted thereby—to achieve the maximum mobility of which they are capable.

We propose zero-scrub, large contact area, 3-DOF holonomic vehicles ("ZS-3" vehicles) as a new category of ground vehicle. ZS-3 vehicles have (1) at least one, and desirably two or more, areal ground- contacting surfaces, each of which is (2) endlessly translatable in two independent degrees of freedom and (3) rotatable about an axis neither in nor parallel to the contact plane so as to be able to maintain the same orientation as the ground. Such vehicles are capable of full 3-DOF holonomic mobility with large effective ground contact area and (nominally) zero scrub. We explain in more detail with examples below.

### *A. Areal contact surface*

By "areal contact surface" we mean a contact surface, whether connected or "composite" (composed of multiple separate contacting bodies or surfaces) that provides a continuously two-dimensionally distributed contact patch with the ground. The resulting contact patch of an areal contact surface is thus a contact plane or area, in contrast to a (nominal) contact point or line.

### *B. Endlessly translatable in two independent degrees of freedom*

One example of an areal contact surface capable of endless translation in two independent degrees of freedom is a contact surface formed of a track of tracks 172 shown in the diagram of Fig. 1. Multiple small tracks 174 are arranged in the form of a large track 172, and mounted to be rotatable both in the small-track direction (shown by the arrows in the inset) and in the large-track direction (shown by the arrows in the main portion of Fig. 1). The resulting areal contact surface (located at the bottom of the figure, for instance) thus provides a continuously-two-dimensionally distributed ground-contact surface, one that is also endlessly translatable in two independent degrees of freedom—corresponding to rotation of the small treads 174 for one degree, and to rotation of the large tread 172 for the other. One or both of these degrees of freedom may be driven during operation of the vehicle (that is, the contact surface may be singly or doubly driven).

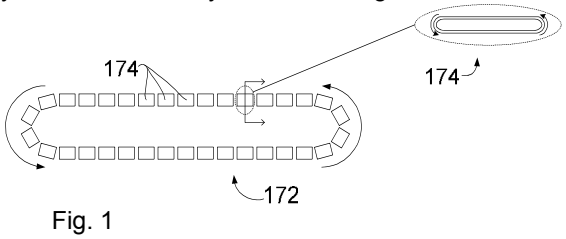

Fig. 1

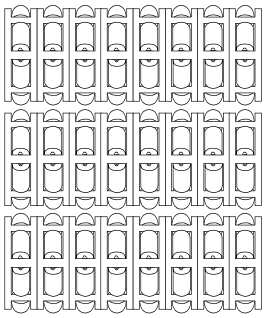

Fig. 2

Other examples include a two-dimensional array of omniwheels such as shown in the drawing of Fig. 2 (with three rows of wheels), and a track having transverse rollers for contacting the ground, such as a track formed from the type of modular belt shown in the photograph in Fig. 3.[1] Movement of the belt of Fig. 3, or rotation of the rows of omniwheels of Fig. 2, provides one degree of endless translation, while rotation of the respective rollers provides the other.

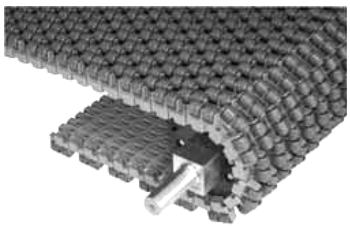

Fig. 3

*C. Rotatable about an axis neither in nor parallel to the contact plane*

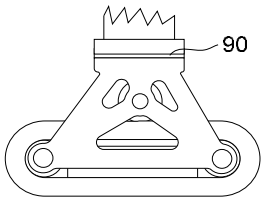


Fig. 4

A rotary joint with an axis generally perpendicular to the contact plane, such as joint 90 in Fig. 4, may be desirable for many applications. The axis need not always be perpendicular to the contact plane nor in its center—it may instead be offset, angled, and/or variable, such as within a cone C1 or a cone C2 as shown in Figure 5. What is significant is that the axis should remain neither in nor parallel to the contact plane, such that the areal contact surface may be permitted or constrained to keep the same orientation as the ground when the vehicle rotates or turns. Areal contact surfaces keeping their orientation as the vehicle rotates or turns are illustrated in Fig. 6 (for the case of one vehicle body with four doubly-driven contact surfaces). The result is full 3-DOF holonomic mobility, large ground-contact area, and nominally zero scrub—all in the same vehicle.

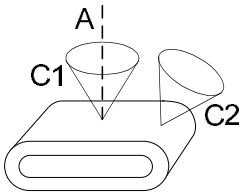


Fig. 5

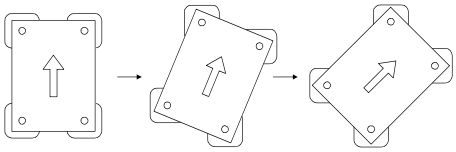

Fig. 6

[[This section continues with discussion of various alternative embodiments and their expected advantages and disadvantages.]]

**3. Control and Actuation of ZS-3 Vehicles Having Singly-Driven Contact Surfaces**

One example of a ZS-3 vehicle employing singly-driven contact surfaces is shown in Fig. 7. A vehicle body 152 is supported by four singly-driven contact surfaces 154 arranged with their respective driven directions as shown by the arrows. The contact surfaces are mechanically linked or programmably controlled to rotate in unison about their respective (centered) rotary axes (not shown).

Translation of the vehicle body in any direction and rotation of the vehicle body about any point are always available, by an appropriate combination of driven motions of the contact surfaces, with or without the rotary axes driven. (ZS-3 vehicles with only two or three singly-driven contact surfaces have driven rotary axes to avoid singularities.)

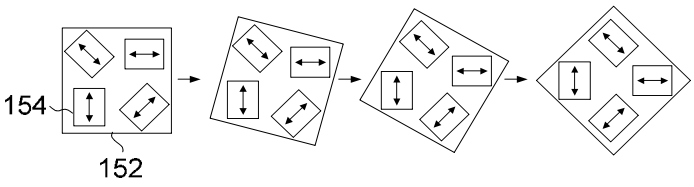


Fig. 7

[[This section further treats some issues of kinematics and dynamics of ZS-3 vehicles having singly-driven contact surfaces and reports testing of control programs in a MindStorms-based physical model of a ZS-3 vehicle having three singly-driven contact surfaces (photo in Appendix).]]

**4. Future Work and Extended Applications**

[[This section will contain prophetic examples and directions for future work.]]

[1] Intralox Corp.

APPENDIX


**Photo of a Mindstorms model of a singly-powered three-contact-surface ZS-3 vehicle ready for testing (with a pair of omniwheels on a common axle standing in for an array of omniwheels at each of the three vertices). (Omniwheels are from the School Of Robotics, 200 Jalan Sultan, #08-06 Textile Centre, Singapore 199018, available for purchase at www.holonomicwheel.com.)**

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Greg received the Juris Doctor degree (summa cum laude), simultaneously with the Bachelor of Science in Applied Physics with a double major in Philosophy, all from Brigham Young University, Provo, Utah, 1992. He has 17 years experience as a registered patent attorney in law firm, government, and Fortune-500 corporate settings. He is the founder of NrevTech, a start-up technology development firm focused on providing new solutions in mobility, manipulation, and actuation for mobile robotics applications.