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High Performance Robotic Traverse of Desert Terrain

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Abstract

This report presents tentative innovations to enable unmanned vehicle guidance for a class of off-road traverse at sustained speeds greater than 30 miles per hour. Analyses and field trials suggest that even greater navigation speeds might be achieved. The performance calls for innovation in mapping, perception, planning and inertial-referenced stabilization of components, hosted aboard capable locomotion.

The innovations are motivated by the challenge of autonomous ground vehicle traverse of 250 miles of desert terrain in less than 10 hours, averaging 30 miles per hour. GPS coverage is assumed to be available with localized blackouts. Terrain and vegetation are assumed to be akin to that of the Mojave Desert. This terrain is interlaced with networks of unimproved roads and trails, which are a key to achieving the high performance mapping, planning and navigation that is presented here.

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Introduction

This report presents tentative innovations to enable unmanned vehicle guidance for a class of off-road traverse at sustained speeds greater than 30 miles per hour. Analyses and field trials suggest that even greater navigation speeds might be achieved. The performance calls for innovation in mapping, perception, planning and inertial-referenced stabilization of components, hosted aboard capable locomotion. The innovations, if refined and combined, are believed to constitute a new means for high performance off-road navigation.

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Map Registration/Map Resolution

Easily accessible area maps have resolutions between 10 and 30 meters per pixel. Registration of typical features might be 10 meters. This resolution and registration are profoundly inadequate for ground vehicle navigation. Both are an order of magnitude coarser than required for successful “blind” navigation. Blind navigation refers to utilizing a map, preplanning a route, then “blindly” tracking the intended path by following position references. The need is for quality of the map, route-plan, path-tracking and safeguarding to have sufficient fidelity, resolution and registration to drive and survive. This has been achieved for pre-driven routes, improved roadways, and rigged environments, but is not yet achieved for spontaneous navigation of diverse desert terrain.

One-meter map resolution and one-meter feature registration would enable a vehicle to track unimproved roads and trails with viable fidelity, and would enable well-understood off-road route planners to succeed. An approach to augment and correct accessible maps to this standard would exploit aerial imagery for feature resolution, and ground-truth position data from field observations. Aerial images (DOQQ maps) have a resolution of 1 meter per pixel, which is better than the resolution of the elevation and feature maps that can be obtained from open sources like USGS topographical data. Aerial images are generally more recent than USGS maps.

An implementation approach for this innovation is to exploit the networks of unimproved roads and trails as features that are identifiable in both USGS and

DOQQ maps, and are amenable for ground-truthing by recording while reconnaissance driving. Though laborious, it is possible to record position data for these “roads”, then to match, morph, scale and register the elevation and aerial map data by anchoring to the “road” network. The approach yields greatest improvement and highest fidelity along paths that are explicitly recorded while driving, but it also generally improves map quality even distant from drivable paths.

Inertial-Referenced Sensing Models

The use of range sensing is well understood for safeguarding and route correction for unmanned driving, but not at high speed in rough, desert terrain. Irregular desert terrain induces erratic vehicle motion, and high speeds disperse and smear the density of sensor hits on a given projection of passing roadway. The enabling innovation is to reference perception sensors to inertial and route coordinates frames rather than the traditional approach of referencing sensor data coordinates from terrain through chassis to sensing. This work creates capable models from inertial-referenced sensor data that is only loosely coupled to gross vehicle motion.

This work deploys a laser ranging line scanner in the configuration of Fig. 1.

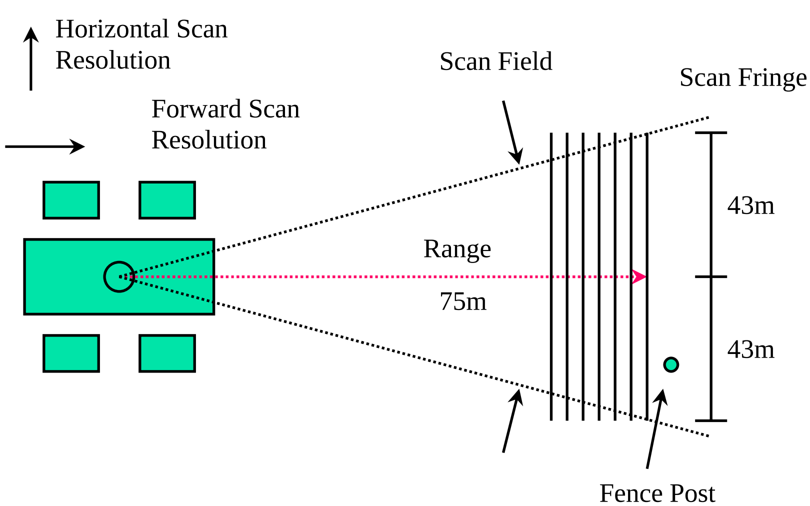

Figure 1. Range of Laser Scanner

Closed-Loop Constant Range Vector Pitch Pointing

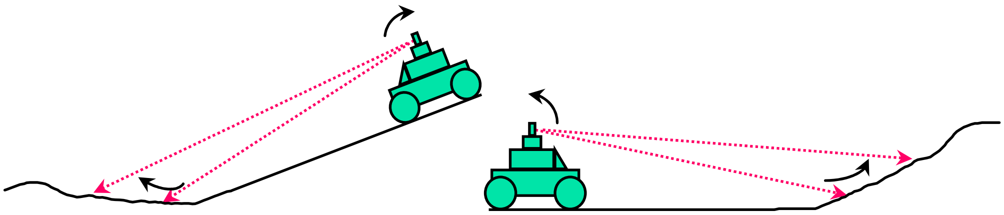

Figure 2. Closed-Loop Pitch Pointing

Closed-Loop System processes line-scan laser range data-set for range-to-target vector magnitude. The laser range finder or (LIDAR) platform pitch-angle is adjusted to maintain constant range vector magnitude. This provides reference for stabilized platform pitch angle. As a result, the robot has dynamic vertical-topology following capability and positions LIDAR for best possible vertical topology anticipation.

This produced an inertial-referenced model of terrain at high streaming data rates. A snapshot of this model is illustrated in Fig. 3. This model proved sufficient for safeguard and reaction planning at moderate driving speed. Although field tests exhibit a static sensing range of 75 meters, models were not attempted under high-speed driving conditions or rugged terrain at that horizon, so that performance is unknown. It is not yet apparent that modeling will succeed with that horizon, speed and terrain. Means for GPS-corrected inertial sensing was shown to be within commercial capability for the illustrated near-horizon models.

Figure 3. Laser Scan Field from an Off-Road Field Test

A correlation of sensing range and braking distance suggest that with improved stabilization and inertial referencing, that speeds above 30 mph might be achievable.

Vehicle Speed	Risk Assessment	Safe Stopping Distance
■ 26.8m/s (60mph)	Low	75m
■ 15.6m/s (35mph)	Mod	30m
■ 4.5m/s (10mph)	High	4m

Radar is commonly advocated over LIDAR for penetrating dust and rain, and radar utility is understood for slower navigation. However, radar does not yet achieve the fast data rate, scan rate and small footprint required for high-speed navigation of rugged desert terrain. Therefore, in a long-distance, high-speed desert traverse scenario, radar cannot yet function as a primary safeguard and navigation sensor.

Dynamic-predicated Planning

Traditional planning techniques consider terrain geometry. Better planners might consider dynamic heuristics such as speed settings that relate to path geometry and terrain type, but these are insufficient for speeds where vehicle dynamics govern performance. At some speed threshold, heuristic and quasi-static techniques become unreliable, and 3-D maneuvering and serial control actions are essential for driving success. An innovation of this work incorporates vehicle dynamics into the inner control loop. This is a new technique that performs dynamic simulation of each of the planning hypotheses. The algorithm insures that intended actions are within dynamic performance bounds.

Pragmatic Considerations for Implementing High Performance Off-Road Navigation

GPS signal is generally available across barren desert relative to availability experienced in urban environment. Multi-pathing (multiple return points for the GPS Signal) is uncommon. Integrated devices that now incorporate GPS-inertial-and-odometry sensing achieve superb six-axis pose estimation that is remarkably immune to intermittent drop-out. Hence there is realistic prospect for implementing the GPS-based trajectory tracking that is essential for blind navigation.

Technical aspects of the mapping ambition were discussed earlier, but the programmatic scope for implementing the proposed technique over state-wide scale is immense. Sampling of maps and ground-truth surveys indicate that roads and trails do not exist where maps indicate, and that trails exist where maps do not indicate. This impresses the need for an immense program of regional data gathering in addition to exploitation of available mapping sources.

Pulsed, time-of-flight radar is able to sense at ranges beyond the ability of continuous wave LIDAR. Field testing in this work exhibited reliable ranging to 75 meters+ meters This LIDAR was able to “see” through some dust to high-reflectivity terrain using well-understood “last-return” technique. However, for low incidence angles and at ranges needed for high speed, LIDAR is unable to receive enough signals to accurately characterize terrain. Dust is the bane of desert terrain in wind conditions, or in the presence of disturbance such as other vehicles. Hence, viability is contingent on wind and solitary presence, which are variables that are generally uncontrollable, but favorably pertain in specific circumstances.

Soft soil provides for short stopping distances. Specifically, off-road tires plow into soil when braking, and this “bulldozing” is an effective stopping mechanism. Hence it is possible to drive at ambitious speeds relative to customary sensing horizons.

Conclusion

This report conveys innovations of mapping, sensor referencing and planning that suggest the viability of a class of high performance navigation. Rudiments of the innovations are implemented and exhibited with promising results. If refined and combined, the innovations could guide capable desert locomotion in the near term.

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