TerraVision

Localizing Ground Penetrating Radar for Autonomous Vehicles

Image Your World®

GSSI

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Introduction

Since 2017, GSSI has been licensed by MIT's Lincoln Laboratory to develop Localizing Ground Penetrating RADAR (LGPR) technology to help autonomous vehicles navigate by using subsurface geology. The newly created LGPR system is called TerraVision™.

Most localization methods for autonomous vehicles incorporate multiple sensors (e.g. LIDAR, cameras, and GPS) that scan features above the road and the surrounding environment. Each instrument provides various grades of accuracy, consistency and availability. Each requires the successful mapping of surface details, and each share common failure modes.

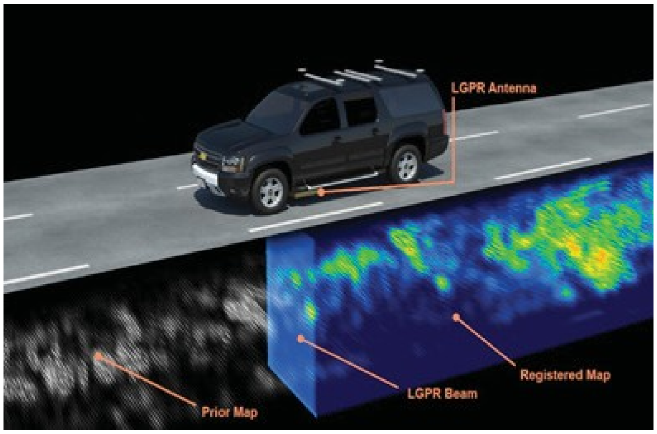
For example, each is affected by:

- Seasonal variations
- Surface feature changes
- Obscuring conditions
- Sensor blindness

Since TerraVision LGPR does not rely on any of the above-ground features on which the other sensors depend, it offers a new and truly independent sensor for localization. Changing environmental conditions that present severe challenges to the other modalities have minimal effect on LGPR localization.

Extensive testing confirms that geology is rarely boring. Scanning down into about 3m of subsurface soils and geologic features provides enough uniqueness to enable lane-keeping to within about 4 cm: at highways speeds, at night, in snow, fog, rain etc.

The thin 10cm ground penetrating radar (GPR) array achieves 2-3m depth penetration from a compact 12 antenna.

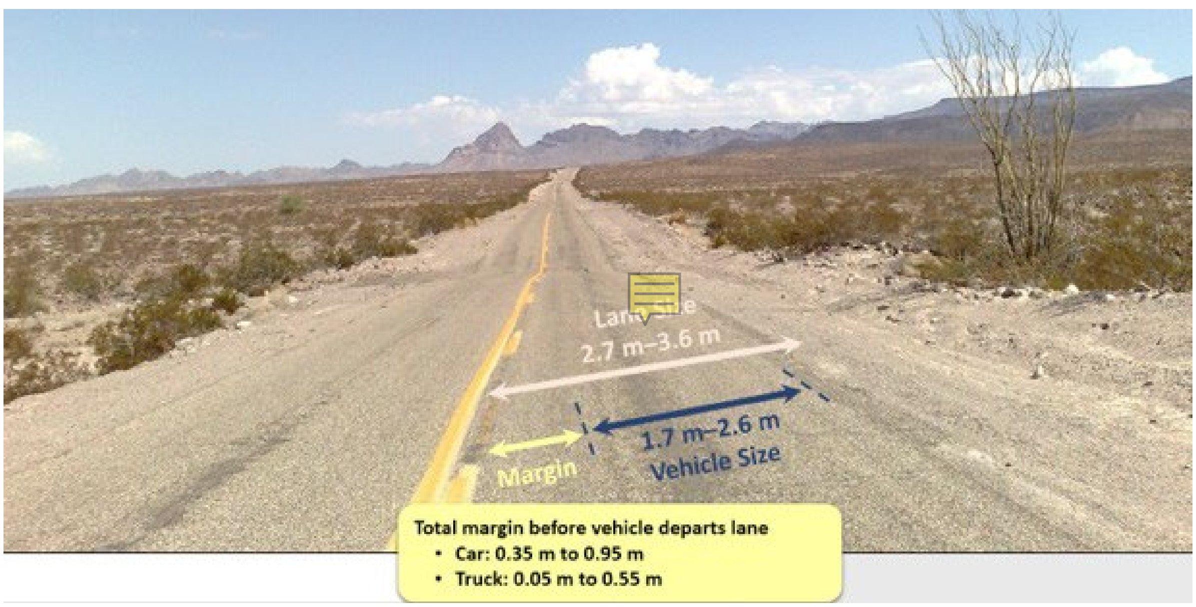


Challenges for Lane Keeping

Integrating LIDAR, RADAR and cameras into autonomous vehicles with GPS and IMUs has dramatically decreased lane keeping failure modes. Nevertheless, these sensors all localize using most of the same surface map characteristics, which make them susceptible to similar challenges:

Temporal Variations	Surface changes	Obscuring conditions	Sensor Blindness
Summer Rain Spring Mud Fall Leaves Winter Snow	Road work Dirt roads Old lane marks New structures	Night Fog Dust Passing trucks	Windshield dirt Headlight glare Scratching Pitting

Typical lane widths in the US vary from 2.7- 3.6m (2.5 to 3.25 in the EU), with vehicle widths typically 1.7m for cars and 2.6m for trucks. Even drivers know this leaves little margin for lane keeping.

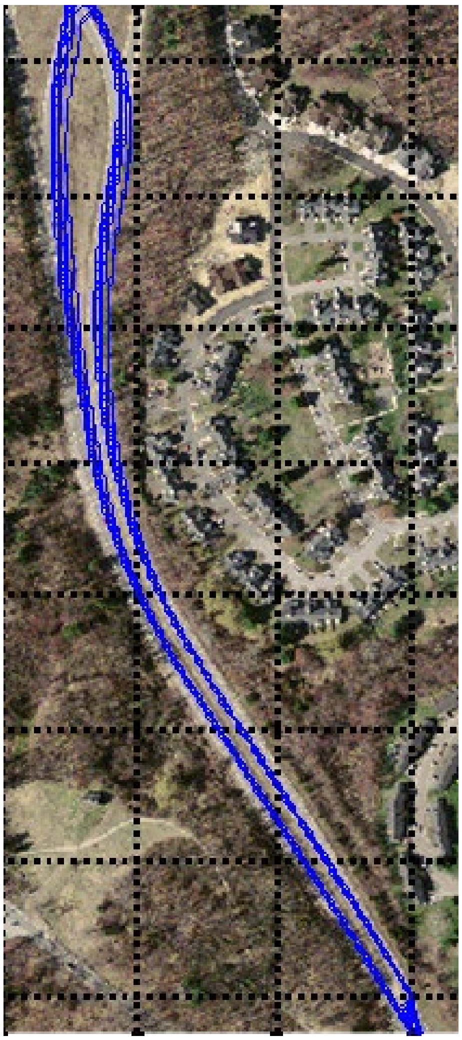


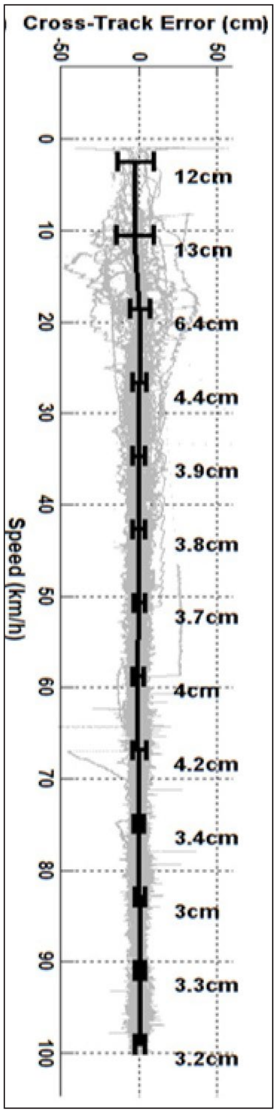
While LGPR has failure modes of its own (see below), it provides a truly independent localization data set: it creates a 'lane lock' using geologic maps rather than visual cues. LGPR improves ADAS/AV performance by multiplying tracking probabilities and by maintaining high positional accuracy in adverse conditions.

Accuracy: LGPR vs RTK GPS

LGPR works by driving once to collect a 3D LGPR "Base Map", then driving the same track again, to create the vehicle track, and comparing the difference. A few examples, from thousands, serve to illustrate performance and current limitations.

Recent hardware and software improvements are producing more accurate measurement results. But early results (compared against a 2cm (rms) GPS RTK) already indicate an LGPR cross-track error of 4.3 cm rms. These errors are skewed high, since the largest errors occurred during the low speed U-turns, where the Vehicle Track often only partially overlapped with the Base Map.

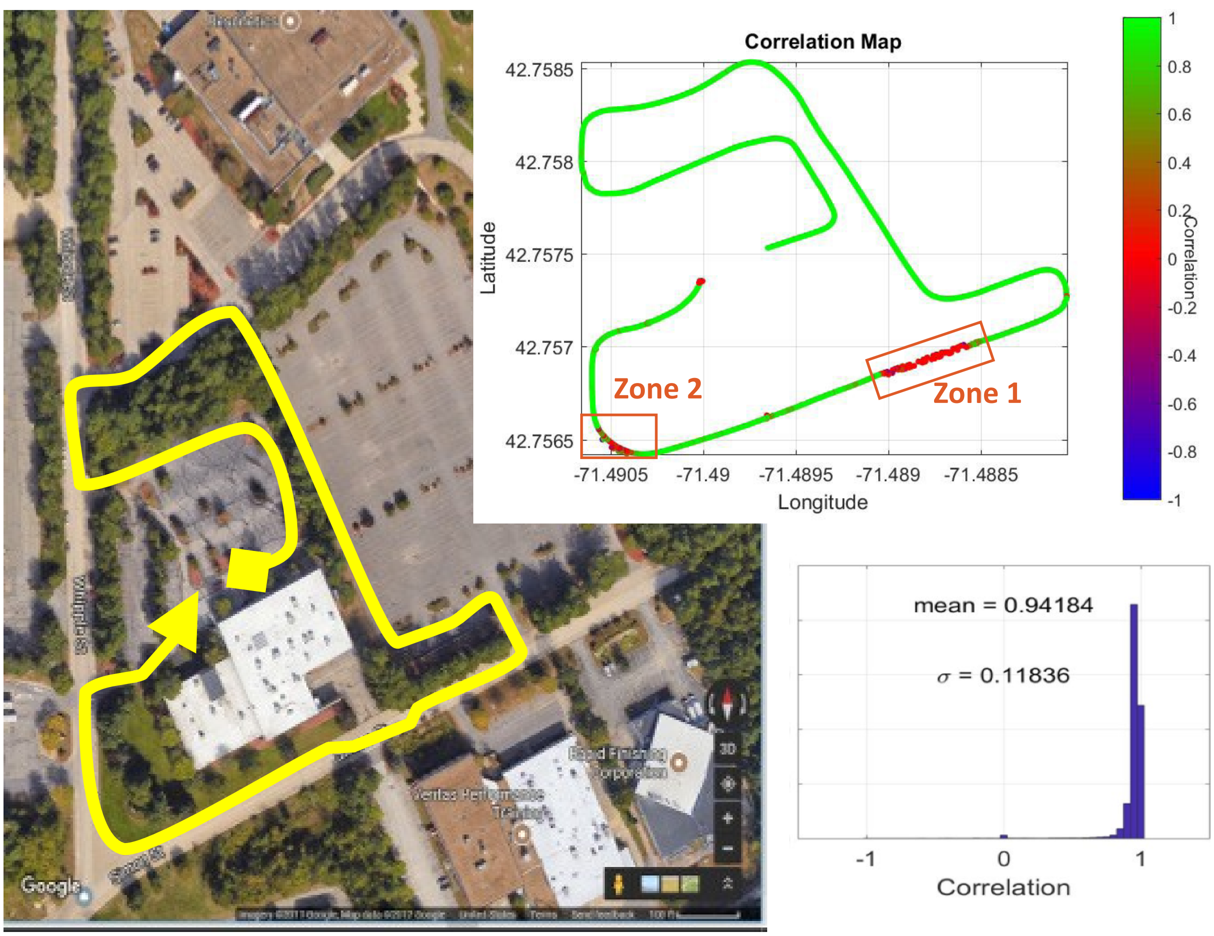




	Measured Error
LGPR	4.3 cm RMS
Differential GPS/INS (WAAS)	35.0 cm RMS

Test on Secondary Roads

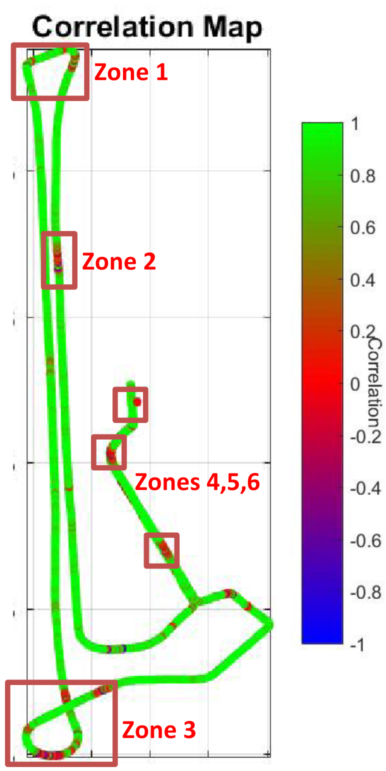
The example below shows performance on a secondary road. The track correlations are nearly perfect except in two zones. The first zero correlation Zone 1 occurred when the driver intentionally changed lanes, creating no overlap between Base Map and Vehicle Track. This failure mode is, of course, fixed with full multi-lane Base Map coverage. The second zero correlation Zone 2 represents an area where the soil lacks specificity. This soil location repeatedly gives poor correlations.

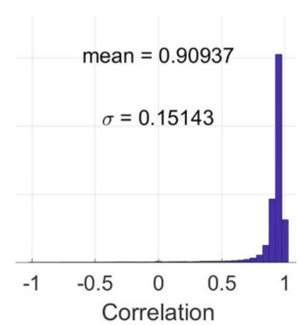


Test: Highway Speeds

This typical LGPR highway test shows high 0.91 rms correlation. While clearly demonstrating robust performance at highways speeds, the few low correlation spots help highlight areas GSSI continues to work on. For example, Zone 1 occurs over an overpass, with intermittent correlation, due to rebar patterns in the bridge concrete. Zone 2 shows zero correlation when the Vehicle Track missed the Base Map during a lane change. Zone 3 occurred during a turn (Base and Track maps must overlap by at least half). Low performance in Zones 4,5,6 we believe are due to soils conditions: i.e. boring geology with insufficient specificity.

GSSI is working with research partners to improve accuracy and to reduce or eliminate such corner cases. And as our collaboration team grows, we will continue to improve on what has already been shown to be a powerful Lane Keeping tool.





Specifications

Antenna	
Radar Type	Stepped frequency continuous wave
Frequency Range	100 - 400 MHz
Frequency Spacing	51 tones spaced by 6 MHz
Array Dimensions	157x 64 x 10 cm
Array Offset from Ground	15.24 cm +/- 10 cm
Elements in Array	12
Number of Channels (# pairs of elements)	11
Weight of Device (without cables)	21.8 kg (48 lb)
Ingress Protection	IP64
Operating Temperature	-20˚C to 50˚C
Operating Humidity	10% - 90% non-condensing
Console	
	• 12 switch matrix module • Custom VHF stepped frequency continuous wave (SFCW) GPR • One single-board computer (SBC)
Power Requirements	320W = 27A @ 12V.
Total Radiated Power	40 µW continuous (one element at a time)
Leakage Power (above ground)	4 µW
Max Sweep Rate (all 11 Channels)	126 Hz (7.8 ms)
Depth of Penetration	2-3 m (New England soil)
Radar Range Resolution	20 - 30 cm
Software Components	
Registration Algorithm	Heuristic Search
Optimization Method	Particle Swarm Optimization (PSO)
Maximizing Correlation	5 DOF.
Interface	ROS

GSSI Overview

Our Company

GSSI, builds products that solve problems in the geophysical, archaeological, forensics, infrastructure, public works and transportation industries.

49 years of technical excellence has given GSSI international respect and recognition as the world leader in ground penetrating radar (GPR). We love to create innovative products people cannot live without. And we love to support our equipment with speedy turn-around times and expert training both at our facilities and globally as well.

Our Team

To date, GSSI team is 87 strong and manages several external agencies and consultants.

Our engineering groups' Innovation Lab is directed by David Cist, a Ph.D. in geophysics. The LGPR team is led by Babak Memarzadeh, a Ph.D. in electromagnetics. Steve Berry, Hardware Engineering Manager, is our expert electronics engineer; Ross Frushour and Jeremy Lund have over 60 years of experience in mechanical engineering; and Rafiou Oketokoun brings 20 years of geophysics and medical software knowledge.

Our Process

Our Innovation Lab works in a series of phases:

Imagine:	Match real-world problems to solutions within our skill-sets.
Investigate:	Explore those solutions with targeted industry research.
Implement:	Prototype,test, re-evaluate our assumptions.
Impact:	Quantify real-world impact, then re-imagine something even better.

Additional Information

Introductory Video

https://www.youtube.com/watch?v=rZq5FMwl8D4

Paper

http://onlinelibrary.wiley.com/doi/10.1002/rob.21605/epdf

Patent

https://www.google.com/patents/US20140121964