VSI Labs

Why Lane Markings Matter: Where ADAS and Infrastructure Meet

Markings make a Difference

Lane markings are the ultimate ground truth for automated driving systems. Any compromise in the contrast and/or placement of markings directly compromises the safety and performance of the automated driving system. VSI has been studying this for years having logged thousands of miles in the pursuit of understanding the limitations of automated driving systems.

This paper examines common causes of poor lane detection that can compromise the safety of ADAS and/or automated driving systems. This is largely the detection of lane markings but often within the context of other factors such as lighting, weather, geometry, merges, exits, interchanges, and more.

Why are Lane Markings so Important?

Lane markings are the positioning rails for automated driving systems and the guard rails for ADAS systems. Passive systems that warn the driver are less critical because those are under the full control of the driver. Active LKA (Lane Keep Assist) systems maintain full lateral control of the vehicle. This is the basis of Level 2 automation.

Lane markings are highly detectable by cameras, particularly when markings offer adequate contrast. No other sensor could possibly do this. Radar does not get a return, and lidar results are mixed depending on the type of Lidar being used.

Supplemental LKA Methods

In cases where lane markings are inadequate to support LKA systems, it is possible for an automated driving system to use high-definition (HD) maps. Accurate coordinates provided by the virtual lane markings in these maps can be used to guide vehicle trajectory. The adoption of HD maps for this use is not widespread, however, because licensing costs are high, and maintenance of the maps is challenging.

A trained LKA algorithm sees and interprets lane markings much like humans do. Even if markings are not perfect, most ML-trained algorithms can accurately detect them. However, these ML algorithms may also misinterpret something, especially within the context of ramps, blend areas, slopes, or curves. Other factors can also cause misdetection such as expansion joints, cracks, or the presence of ghost markings.

How to Automate When There are no Lane Markings at all?

Localization against lane markings is reasonably straight forward if you have properly placed markings. But what do you do when your automated vehicle is operating where no markings exist? For example, unpaved rural roads are tough and likely outside the ODD of most automated driving systems. Shuttles, however, are designed to operate on tarmac with no markings whatsoever.

It is possible to create a laneless algorithm that mimics humans. In theory, this is possible but not practical for all roads and in all conditions. The software decision making infers everything from how humans tend to behave in similar scenarios. This is only made possible from massive data collection efforts and would struggle on roadway conditions that the software was not trained on.

A couple of methods don't rely on markings at all, like lidar point cloud matching or prerecorded path following. Some methods may be preferred to vision-based lane detection depending on the type of vehicle being automated and the environment in which the vehicle will be operating.

Lidar Point Cloud Method (Relative Localization)

The requires a prerecorded Lidar point cloud, whereby in playback mode, the vehicle matches what it sees in real time versus the recorded point cloud. The path of the vehicle is prerecorded and geocoded against the points from the lidar. This method relays on relative localization and can only be done in dense areas where there is enough infrastructure within 50 meters or so of the vehicle. This method also requires a full 360-degree scanning so a rotating lidar is necessary, ideally one with a resolution of at least 64 channels.

This method of localization and path planning is often the primary method used by Level 4 Robo-taxis. In urban environments, the density of surrounding infrastructure makes this method very suitable. Furthermore, absolute localization using GNSS may be compromised in dense urban areas where satellite blocking from trees or tall buildings may become a factor.

Pre-Recorded Route (Absolute Localization)

Another way to automate a vehicle on a road is through GNSS. With this method, you are relying on high performance location data coming through satellite and augmented with terrestrial correction services. Ideally you want centimeter level accuracy for this method. Precision location hardware can be expensive, but companies are working to bring down the cost of this.

Absolute localization is applied to a pre-recorded path. This method is like the Lidar point cloud method but relies instead on GNSS. The vehicle must first record its path in advance and then it is able to follow that path with precision. Shuttles may rely on this as their primary method. Multiple routes can be recorded to accommodate several optional routes.

The MUTC

The Manual on Uniform Traffic Control Devices (MUTCD) is the bible for specifications related to roads, signals, and signs. Some critical elements include Vehicle to Infrastructure (V2I) communications and corridor consistency to facilitate machine vision.

Up until now, little has been said about optimizing roadways and markings to better suit vision based ADAS and AV technologies. However, there is a new section (Part 5) for Automated Vehicles including general considerations for agencies to assess their infrastructure needs and prepare their roadways for safe AV deployment. Here are the most relevant items to MUTCD that impacts automated vehicle technologies as it relates to lane markings:

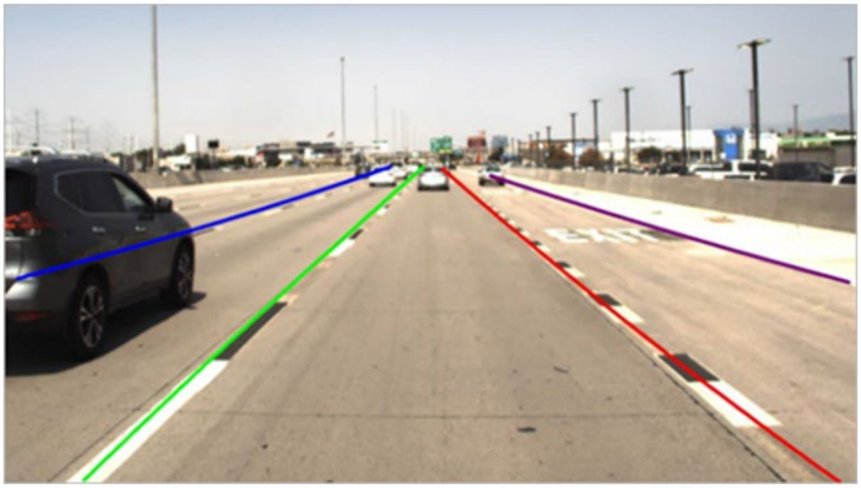
- Normal-width longitudinal lines of at least 6" wide on conventional roadways.
- Edge lines of at least 6" in width on conventional roadways with posted speeds of 40 mph or less.
- Dotted edge line extensions along all entrance and exit ramps, all auxiliary lanes, and all tapers where a deceleration or auxiliary lane is added.
- Chevron markings in neutral areas of exit gores to distinguish from travel lanes.
- Continuous markings at the beginning of work zones and in all lane transitions.
- Raised pavement markers as a supplement to lane markings.
- Uniform contrast markings on light-colored pavement to create contrast.
- Broken lines of at least 10' in length with a maximum gap of 30'.

Best Practices – VSI Observations

Lane marking width is vital to lane detection simply because the added marker width provides more points onto which raw detections can attach. This is particularly useful for highway applications where speeds are greater. Marker width is also a factor in low contrast situations, particularly when coupled with high contrast materials.

High Contrast Materials

We find two kinds of high contrast applications. One method provides a black border around the white markings. Another method alternates a white marking with a black marking. Both methods are particularly beneficial to vision-based lane detection. High contrast markings are often used on concrete surfaces that are much lighter than bituminous surfaces.



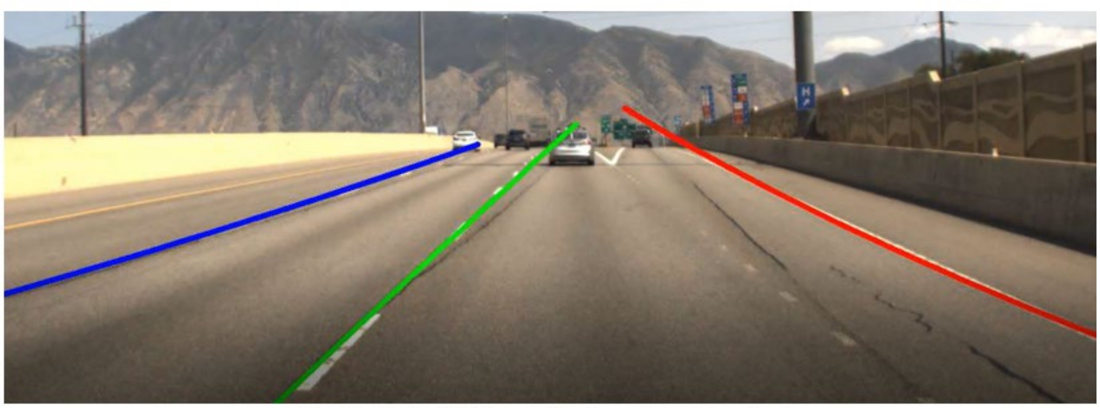
High Contrast 6- and 8-inch Markings

Dotted Edge Lines at Ramps

The MUTCD has recognized continuous edge markers at ramps to be important enough to cite in the manual. We discovered this some time ago as most LKA systems will struggle with large gaps.

For example, blend areas for on-ramps and off-ramps are often lacking a dotted line and this causes boundary conditions for the automated vehicle which is trying to center itself within the expanded lane. For on-ramp scenarios, this results in little more than a wiggle, but for an off-ramp, the lack of a dotted line in the channeling area may cause the vehicle to inadvertently exit the roadway.

Off ramp boundary conditions can lead to hazardous situations for autonomous systems because they can lead to an inadvertent exit at highway speed. Unless the system was equipped with Intelligent Speed Assist (ISA), the velocity of the vehicle on the ramp would lead to a hazardous situation.



Poorly Marked Off Ramp Confuses Lane Keep Assist

Temporary Markings

Work zones are another vulnerable domain for LKA and automated vehicle technologies because it is arguably outside of safe operational domains. Although it depends on the type of work being done and the presence of workers, relying on temporary markings is risky and must require close human monitoring.

The MUTCD has strict guidance on the removal of ghost markings and use of masking material, but VSI observes them frequently in our data collection.

Temporary Markings and Ghost Markings

Common Problems – VSI Observations

Longitudinal Misdetections

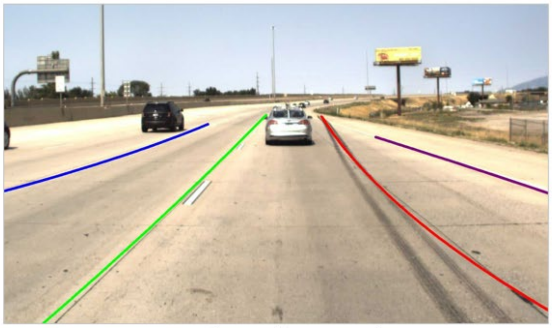
Longitudinal tire marks on a highway can confuse lane detectors into thinking there is a lane. Lane detectors largely look for contrast in a long continuous way. We see a lot of this on interstate highways, and unfortunately, most maintenance departments do not prioritize the removal of these marks.

Ghost Markings

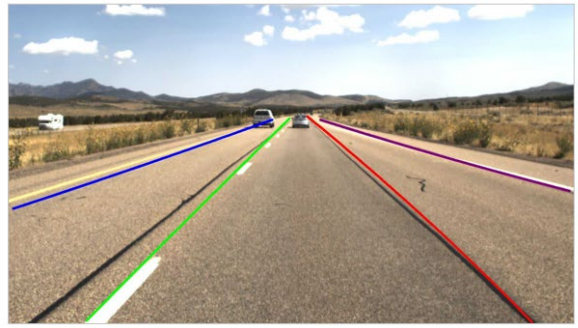
Ghost markings are those left behind from a construction area that required temporary markings to adjust lane boundaries. The MUTCD address this without much guidance other than you cannot attempt to mask them. Often, we see masking applied to a temporary marking and this is often interpreted by the computer to be an actual lane line. Best practices require proper removal with the blasting gun or high-powered power washer.

Crack Sealers and Joints

Cracks in asphalt or concrete surfaces are filled with a sealer compound that is typically black. Often joints are filled with sealer as well. In either case, an extended longitudinal placement of sealer material can incorrectly be interpreted as a lane line. Often there is a natural joint where two adjacent lanes are present, and filler placed in these joints are often in the same place as the lane line. In this case nothing is misinterpreted.



Misdetection from Tire Marks



Misdetection from Expansion Filler

Missing Markings – Outages

It is not uncommon for bridge asphalt repair to be resurfaced periodically, and in many cases, it may be some time before the maintenance department gets new markings laid down.

If the outage is not more than a couple of seconds (at normal speeds) than the LKA or automated driving system can see far enough ahead to bridge this gap and nothing bad happens. If more than a couple of seconds, the computer vision system can not see far enough ahead to maintain safe operation and a disengagement may happen.

Missing Marking on Resurfaced Overpass

Conclusion

It is estimated that more than half the new cars sold today have some level of LKA and/or automated driving technologies. Mostly these are vision-based solutions because it is cost effective for production vehicles. And while lidar, or high definition maps could be used for lane keeping and localization, it is not common for series production, largely due to cost.

Active safety and automated driving systems rely on lane markings as the highest priority in terms of confidence. Even when advanced algorithms are applied or when HD map data is available, the lane markings determine the final trajectory. Therefore, in the era of automated driving technologies, it behooves government agencies to examine their roadways for compatibility with the latest technologies.

About VSI Labs

VSI Labs is the leading researcher of active safety and automated vehicle technologies. VSI offers various research and testing services to clients that want to get their technologies tested or demonstrated. VSI Labs also serves the ITS community with its AV Readiness Survey designed to help agencies access the readiness of their infrastructure. Learn more about VSI Labs at https://vsi-labs.com/.

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