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“Invisible” 2D Bar Code to Enable Machine Readability of Road Signs – Material and Software Solutions

"Invisible" 2D Bar Code to Enable Machine Readability of Road Signs – Material and Software Solutions

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Abstract

Although autonomous driving has debuted on the streets of some cities in the United States, significant challenges remain before the full potential of this next generation transportation paradigm is realized. Automakers, sensor developers and transportation authorities are forging ahead with the technology changes necessary to support autonomous driving. Infrastructure developers are also exploring and developing next generation infrastructure solutions that will enable autonomous driving to realize the promise of safer, more efficient highway transportation. This paper describes potential solutions in road signing that convey sign messaging to sensors efficiently and with digital certainty, provide clarification and confirmation of other digitally available information (e.g. mapping), provide robust fiducial for localization, and deliver data to the car and driver dynamically. These capabilities are enabled via material solutions that perform for the human driver while adding a machine-targeted message in a different light spectrum, allowing for a single signing solution that meets the needs of current human drivers and next generation machine-vision systems. The novel 2D barcode format has been tested on the road; field data and proof-of-concept designs are presented.

KEY WORDS: 2D bar code, road signs, machine vision, retroreflectivity, localization, infrastructure, V2I

Introduction

For over 100 years, traffic signs have evolved to improve the delivery of critical and concise information needed for drivers to navigate the roadways safely and knowledgeably. As technologies have improved, the visibility of these signs to human drivers has improved so as to serve road way users at night and during inclement weather. As assisted- and automated-driving technologies develop, the skills of the human drivers are being supplemented with information and additional situational awareness provided by sensors in the vehicle. These added data help the driver to navigate complex driving conditions with a more complete understanding of the environment.

Machine vision systems have been designed to capture and analyze images of street signs and classify the signs using prevailing academic and industry methods of feature extraction and matching. Most of these systems depend on the infrastructure and any associated message to be an unchangeable feature in the environment, with a message that is consistent despite the geography or the environment. To most next generation driving systems, infrastructure is regarded as an unchanging constraint to which the machine must adapt. However, if infrastructure evolves to meet the needs of automated driving, the idea of upgrading the sophistication of existing signage to create information optimized for automotive machine vision systems is reasonable, logical and necessary. Just as the development of road signs became more sophisticated over the past several decades to increase readability of signs at night, the road signs of tomorrow need to be optimized for a digital environment and for the multitude of sensors that will be required to "visualize" the environment.

That said, current market analysis suggests that in 15 years, only 15% of the vehicles on the roadway will have at least Level 2 automation. While the pace of technological innovation is fast and furious, the average lifetime of a vehicle in the US is approximately 15 years. Traffic authorities will need to develop and maintain roadways that meet the needs of today's human drivers as well as current- and next generation automated driving systems.

Safe navigation of autonomous vehicles requires sensor redundancy. As in the aerospace industry, automated driving will likely follow a "belt and suspenders" approach to assessing the environment around the vehicle: more than one type of sensor (e.g. ultrasonic, camera, Lidar, RADAR) will be required to sense and evaluate the environment so the vehicle can selfvalidate the information collected. With this redundancy in mind, it will be critical that infrastructure provide unambiguous data to the vehicle that can be read with certainty even when road or weather conditions stress the environment.

Current premium sheeting materials for roadway signage are retroreflective and return approximately 50% of the light to the driver during nighttime driving. Sheeting is designed to be readable over a range of angles as well as in inclement weather including rain and fog. Any new signing solutions need to respect these performance standards as well as be able to maintain the life expectancy of a road sign.

We have developed a 2 dimensional (2D) bar code over lay that can be incorporated into the construction of a road sign. The size of the code can be changed to meet the needs of the roadway user but generally is approximately 65% of the surface area of the sign. The 2D bar code is made with optically transparent materials and thus does not change the look of the sign to the human driver. A vehicle outfitted with an IR light source and camera can read the 2D barcode at distance similar to that at which a human driver can read a traditional road sign. The barcode can convey a significant data payload including the message of the sign, precision GPS coordinates, date of sign installation and maintenance, and additional data about the specific environment relevant to the sign. Signs with the embedded 2D barcode were placed on roadway environment for up to 2 months with no loss of visibility of the sign to the human driver nor to the machine readability of the barcode.

Role of Road Signage in Autonomous Driving

Although often overlooked in the evolution of autonomous driving, road signs can be used for a variety of tasks to improve the safety and accuracy for cars on the road. Signs can communicate warning or information directly to the driver or to the vehicle; they can describe changing conditions or obstacles; they can elucidate details surrounding local rules of the road; they can bring extra attention to high risk situations. Road signs can also be used in concert with high-definition maps as fiducial markers for localization. These stationary markers can provide important location anchors when and if mapping-based information is not available, incomplete or lacks needed resolution. Future iterations of road signs could provide dynamic information to the vehicle, changing a warning or a message as conditions change on the road ahead.

The role of signage: improved classification

In the non-autonomous world, road signs convey information, warnings or rules to a human driver. For Class 1 and 2 autonomous vehicles, road signs perform this same function but with the capability of communication both to the human driver and directly to the vehicle. Although humans are very proficient at determining the meaning of a sign (~95%), even when some part of the sign is obscured, machine vision lacks the accuracy of the human, particularly when the learned pattern is not perfectly preserved during, for example, heavy traffic or inclement weather. Although computer vision and machine learning techniques are getting better at classification of poor or incomplete images, there are still significant gaps to leap between where we are today and perfect classification [1].

For example, in 2010, the German Traffic Sign Benchmark (GTSRB), a 50000-sign image set was published in conjunction with using neural networks for sign classification [1]. Subsequent convolutional neural network implementations achieved 99.81% classification accuracy, compared to human results around 98.5% accurate [2]. The GTSRB data set included only 43 sign classifications, less than 5% of the number of different sign classifications in the US. In the United States alone, there exist over five hundred unique federal signs each with multiple different sizes. Only 23 states have standardized to the Standard Highway Signs stipulated in the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD), while the other 27 states have "largely conforming supplemental volumes" introducing many hundred more variations.

This variation and the sheer number of options put a strong burden on the machine vision / sign classification engines. Developing one ubiquitous national model is an important, unsolved challenge to-date, as readability performance drops as the number of classification choices increases.

The role of road signage: provide additional situational awareness

Besides providing the MUTCD sign classification (a limit of current technologies), signs can convey more advanced functions of navigation information. The classification performance metrics referenced above, only evaluate classification of the sign code; they do not attempt to decode of the text in the sign, for example the numerical speed limit. Citing a more recent speed limit decode challenge shows a significantly different set of results with the successful decoding of a speed limit sign at a mere 84.31%, which confirms the opportunity to deliver sign content in a more optimized fashion [3].

The role of road signage: provide fiducials for localization

In addition to improving classification and data quality of signs, next generation road signs provide an opportunity to supplement location data provided by high-definition mapping. Mapping companies are creating extremely detailed and dynamic maps to help drivers and automated vehicles plan routes and to position the vehicle appropriately on the roadways (e.g. HERE HD Live Map, Tom Tom Real Time Maps). Current HD mapping relies on continuous analysis of scale-invariant feature transformation (SIFT) to provide localization. In order to develop reliable features, an extremely dense mapping needs to take place and be accessible to the vehicle. Given that these may change over time and that dense maps can consist of large amounts of data, keeping such maps up to date, reliable, and to provide wide coverage is expensive and challenging.

Next generation signs may contain high precision GPS coordinates as well as a unique-to-the-sign identifier. Standardized layout and sizing of codes would enable accurate pose estimation for a vehicle. Combining this pose with sign position metadata, would provide a high quality signal to be used for vehicle localization, which could provide redundancy in scenarios where GPS or other systems are providing degraded performance.

The role of road signage: local information, temporary traffic events, & work zone information

Beyond the certainty provided by a unique identifier on road signs, limiting location information for vehicles to HD maps will provide incomplete, or even inaccurate data in the case of an environment that is rapidly changing, such as an active work zone. In all of these scenarios, the vehicle will be required to break from a static driving pattern as presented in an HD map. SIFT features may become unobservable or invalid. In some cases, such as lane closures, or lane shifts, the vehicle will be expected to proceed in a manner that violates the rules under normal circumstances by, for example, re-routing on to the shoulder or into a lane that under normal operation services vehicles traveling in the opposite direction.

Material Solution for “Invisible” 2D Bar Coded Road Sign

Conventional sign sheeting material (e.g. 3M’s Diamond Grade Sheeting) is highly retroreflective, returning 58% of light to the source [4]. This high retroreflectivity is due, in part, to tiny “cube corner” structures in the sheeting that reflect light very efficiently back towards the source. Relative to more conventional sheeting, the high retroreflectivity makes the signs easier for humans to see, especially at night. Although, in the US, the requirement that traffic signs be retroreflective was established in 1935, a minimum standard for retroreflectivity was not established until 1993. The standards, which have continued to evolve, make many assumptions about the age and position (relative to the light source) of the driver, the size and position of the vehicle and head lamps and the vehicle orientation on the road, with the key measurement, luminance, being difficult to measure quantitatively [5].

To continue meeting the needs of human drivers as well as to provide the functionality described above for current- and next-generation automated driving systems, it was assumed that implementation of the barcode described above should be done in a way that meets current specifications and would produce no significant change in visible appearance of current signage. At the same time, the barcodes should have high contrast for accurate detection and decoding by machine vision systems comprised of readily available sensors. For those reasons, we focused on barcode materials that have high transparency in the visible spectral region, 380-780 nm, and low transparency in the near-IR spectral region, 780-1,500 nm. The barcode construction chosen used material with a left band edge (wavelength at which the transmittance is 50%) of 900 nm. At longer wavelengths (900-1070 nm) the transmittance quickly decreases to a very low value, approximately 1.5%, while at shorter wavelengths the transmittance rapidly increases to a value of 88-89%. This results in a barcode that can be applied to traditional signage sheeting that has a luminous visible transmittance (380-780 nm) of approximately 92% while providing a near-IR contrast value of approximately 90%. Both a visible image and near-IR image of a barcode with this construction, laminated to printed signage sheeting, is shown in Figure 1 below.

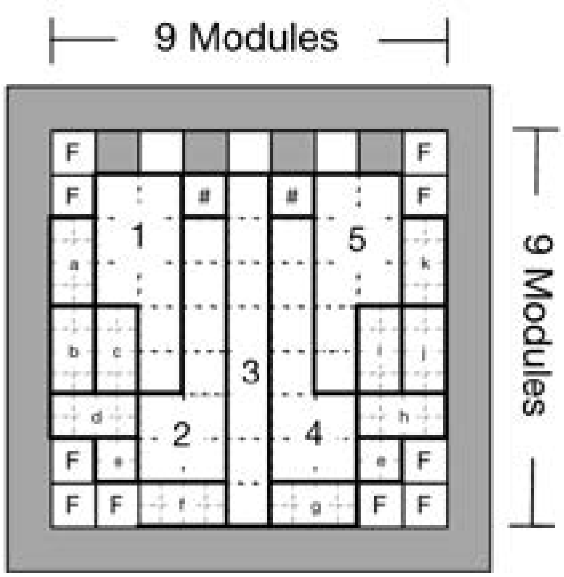
Figure 1: Visible and Near-IR View of 2D Bar Code

The visible image was captured with a typical color machine vision camera. The near-IR image was capture with a monochrome machine vision camera containing a near-IR bandpass filter centered at a wavelength of 940 nm. Because of the high visible transparency of the barcode laminate, the sign has the usual visible appearance, while at the near-IR read wavelength a high contrast image of the barcode is readily apparent.

Field test data from natural weathering conditions was collected over the course of several months in the tests described below. Accelerated weathering tests have been initiated. In these evaluations, the 2D code laminates on signage sheeting are exposed to Xe arc emission (1.3 W/m², 340 nm) with and without added moisture. After 1500 hours of accelerated weathering, no decrease in retroreflective light return has been observed.

Software Solution for "Invisible" 2D Bar Coded Road Sign

A new 2D barcode optimized for data payload efficiency, read distance, error correction, and read confidence has been developed and evaluated within a highway corridor. The optimizing metrics tend to compete so not all can be optimized simultaneously. As such, we describe one approach to balancing these metrics to deliver information salient to autonomous vehicles (see Figure 2).

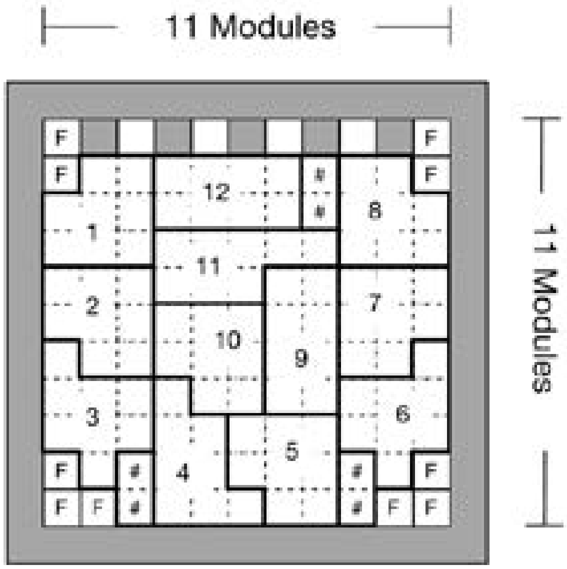


Finder Modules (F) – 17 modules around the edge

Far Modules (1-5) – 5 8-bit blocks. 1 payload block (1, 256 classes) and 4 RS correction blocks (2-5, corrects up to 2 block errors)

Near Modules (a-k) – 11 8-bit blocks. 5 payload blocks (a-e, 1.09 trillion codes) and 6 RS correction blocks (f-k, corrects up to 3 block errors)

Figure 2: Proposed 2D Code and Module Key



Finder Modules (F) – 19 modules around the edge

Modules (1-12) – 12 8-bit blocks. 6 payload blocks (1-6, 281 trillion codes) and 6 RS correction blocks (7-12, corrects up to 3 block errors)

Figure 3: Proposed Single Resolution 2D Code and Module Key

Figure 2 depicts the encoding locations of one proposed arrangement of data and overhead modules and their allocations into blocks. The text box to the right of the figure contains the module label key. Besides the Finder modules, two additional module types are defined: Far modules and Near modules. The Far modules are designed to contain data blocks which can be decoded from a longer distance; they contain error correction optimization likely to be encountered in a longer range roadway obstruction. The payload of these Far modules is intended to be data to aid in safe driving decisions and localization. In contrast, the Near modules are smaller module sizes and will have somewhat less of a read range based on their decreased size. This proposed layout places the Near modules at ¼ the size of the Far modules and arranges them at locations in the code that are more likely to be obscured. This tradeoff was chosen due to the lower relative likelihood of an obscuring situation at the shorter read range, and the criticality of the information conveyed at the farther distance. In this example, localization information could be conveyed in the Near modules. If the localization information is not decoded properly, it can be discarded and obtained from the next sign, since a positive read from every sign will not be necessary to maintain accurate localization. Other information unique to the road sign, such as installation details or maintenance information, or a database link to dynamic content, could also be conveyed in this payload.

Figure 3 depicts an alternate single resolution bar code. If constructed with the same maximum dimensions as the code in Figure 2, the full payload would become available at a distance between the range at which the Near and Far payloads are available for the first code style. This layout and error correction are also optimized for long range occlusions.

2D Barcodes: Payload efficiency through reduction of finder modules

As discussed above, there are two main classes of modules in a code: overhead and payload. The overhead section is used for several functions including position, alignment, timing, version, and format. The payload consists of data and error correction information.

Maximizing data density is extremely important to enable the long read distances for a fixed physical code size compatible with a road sign. To this, a reduction in overhead is proposed by tailoring overhead code functionality to be optimized for implementation on a road sign.

2D Barcodes: Read range

Read range, or the distance at which a sensor can perceive data, is a critical concern for autonomous vehicles. High-speed driving on freeways is an early goal for Level 4 and 5 automation, but increased vehicle speed requires that salient data be available from further away to allow for sufficient reaction time. Where information delivered 50 meters from a target may be sufficient for surface streets, longer range driving goals suggest 150 meters of read range is desired for vehicles operating at highway speed. The read range for the 2D barcode is determined by sensor geometry and pixel density, lens and other optics, and the size of the modules that make up the code. Read range is theoretically limited by the Nyquist limit, where 2 pixels along each axis correspond to the size of a module of the code. This is a minimum, increasing the pixels per module leaves headroom for sensor noise, lens imperfections, demosaicing, and other factors that may limit effective resolution.

Increasing read range for a given sensor resolution comes at the cost of field of view. Maximizing read range is done by maximizing sensor resolution and minimizing the required field of view. With a narrow field of view, the camera may not be pointed at the sign and thus the sign might not be sensed. Assuming noise increases aren't significant, increasing sensor pixel density, where everything else is fixed, increases the range at which features can be resolved.

Field Results

I-75 Corridor, Detroit, MI

During the summer of 2017, 15 traffic signs bearing the 2D barcode were installed in a construction zone along Highway I-75 outside of Detroit, MI. The test corridor includes a ~4km stretch of roadway that is part of Phase 2 of the Michigan Department of Transportation's (MDOT) 10year construction plan. Testing occurred between May and September 2017. Fifteen signs of 3 different designs with 2D barcodes were erected within the corridor. A suitable camera and sensor system was developed and installed in the test vehicle; data were collected on a laptop computer in the test vehicle. A variety of different signs were printed on different color backgrounds. Examples are shown in Figure 4, below.

Figure 4. Examples of Road Signs with 2D bar codes installed on I-75 Corridor in Michigan, USA.

Read distance was recorded from the moving vehicle with data collected from either the center or right lane of traffic at speeds of 35-90kph. Some differences in read distance were noted depending on which lane the car was driving in relative to the sign. After preliminary analysis of the data for the first iteration of the system (POC-1), both the software and materials set were optimized and read distance was measured again for the optimized system (POC-2). Both systems utilized a monochrome CMOS camera with a 29.6 degree horizontal field of view corresponding to 2448 pixels. The camera was configured with a 940 nm bandpass filter and a 940 nm light source was collocated with the camera. Code layouts on signs were 0.56m x 0.56m using the 11×11 layout (Figure 3). Results are summarized in Table 1.

Table 1. Summary of Read Distance Associated with 2D Bar Code, I-75 Corridor in Detroit, MI

Version	Conditions	Read Distance	Samples
POC-1	Day Time	36 +/- 20 m	n = 106
POC-1	Night Time	37 +/- 18 m	n= 42
POC-2	Day Time	95 +/- 16 m	n= 48
POC-2	Night Time	86 +/- 17 m	n= 46

This was the first test of the 2D bar code and associated sensors on a public highway; subsequent work will focus on increasing the read distance or on increasing the information density readable at highway speeds.

Watch test video

Clearly the optimization, of both codes and materials, was successful in increasing the read distance on the I-75 corridor. Both day time and night time values for POC-2 are statistically different from (higher than) those collected for POC-1. In addition, the relative variation associated with the read distance was reduced when POC-2 was tested.

In neither POC-1 nor POC-2 were read distances statistically different in daytime (10AM-6PM) versus night time (6PM-12AM). We expected that night time read distance may have exceeded day time given that there is reduced visual background, but in these data sets, no difference was observed.

Read distance was also measured for different signs in the POC-2 configuration; no statistically different read distance data were collected for signs of white or orange background during either day time or night time conditions.

Conclusion

As vehicles, sensor systems, and data collection move roadway transportation towards next generation solutions that improve safety, reduce travel time and reduce automobile emissions, next generation infrastructure should be regarded as an important contributor to an ecosystem solution. Road signs readable by both human drivers and autonomous driving systems can be optimized to help with several important tasks including providing greater situational awareness, offering improved localization and providing a means of conveying dynamic information about changing roadway conditions, all tasks that provide redundancy to other sensor systems engaged in the vehicle. Road signs that serve the needs of both humans and machines may be especially valuable in the next 2 decades as the fleet of private vehicles transition from Level 0 to > Level 2 automation. These prototypes embody a specially designed 2D barcode that can be laminated to a road sign such that it is essentially invisible to a human driver. The code is optimized both with respect to payload and error correction, providing opportunities for Far and Near read modules to make sure that critical information is conveyed to the vehicle even if the sign is partially obscured. The prototypes tested here were constructed with premium sheeting materials that maximize the readability of the code with no adverse effect on the visibility of the signs to human drivers. Measured retroreflectivity of signs with the 2D code meet retroreflectivity specifications even after 1500 hours of accelerated weathering. Optimized software and material configurations have demonstrated a read distance of approximately 90 meters measured on the highway while traveling at posted speeds.

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