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ENHANCING DRIVER-ASSIST SENSORS: BACKGROUND AND CONCEPTS FOR SENSOR-FRIENDLY VEHICLES AND ROADWAYS

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ABSTRACT AND SUMMARY

Autonomous Intelligent Vehicle Initiative (IVI) systems (which include in-vehicle forward- and side-looking sensors) can be supplemented by vehicle-vehicle and vehicle-highway cooperative and, if possible, passive elements to comprise a “sensor-friendly” highway environment that would enhance the operational efficiency, and ultimately, the safety benefits of emerging IVI driver-assist systems. Thus far in our research, we have identified the current limitations of autonomous sensing systems in target/background discrimination in dynamic and cluttered highway scenes. Based upon this, relatively inexpensive, passive vehicle-highway cooperative markings have been concepted to allow those limitations to be mitigated. Emphasis has been placed on 77 GHz (millimeter wave) and laser radar sensors – sensor bands which we believe will be used for products in the relatively near term. In this paper, we introduce relevant IVI systems, describe roadside signatures, and using the previous two sections as a basis, discuss various cooperative vehicle-highway concepts.

INTRODUCTION

The underlying premise of the U.S. Department of Transportation project, "Evaluation of Sensor-Friendly Vehicles and Roadways to Support Intelligent Vehicle Services" is that while autonomous Intelligent Vehicle Initiative (IVI) systems perform adequately for use in some markets, cooperative IVI systems will yield significant improvement – enough, perhaps, to facilitate widespread introduction and acceptance in the United States to accrue safety benefits. These IVI safety services will at least initially be implemented in conjunction with autonomous vehicles and not be dependent on special highway or roadside features. Hence, the intent is *not* to make sensing systems dependent on any special infrastructure; rather, the intent is to understand how to provide supplemental infrastructure as an independent measure to improve the performance of autonomous intelligent vehicle sensing systems. In that manner, the default operating mode would be with the absence of cooperative markings, but if they do exist, system effectiveness could be considerably enhanced.

In accordance with our near-term emphasis, the following Intelligent Vehicle candidate systems are primarily considered: (i) Forward Collision Warning [1,2]; (ii)

Lane Change/Merge Assistance [3,4]; and (iii) Roadway Departure Warning [5,6,7]. In each of the three systems the key design element will be the acceptable rate of false positives, false negatives, nuisance alarms, and perceived non-alarms. If the rate is low enough, users will accept and acknowledge the safety system warnings; past a threshold, the user will not accept and will ignore the warning.

RADAR SIGNATURES

In order to gain more insight to the radar signatures of roadway elements, we employed an Eaton VORAD EVT-200 24 GHz radar to obtain range and rate in a variety of driving scenarios while following a lead vehicle. Selected range results from the primary target track are plotted in Figures 1-3. Concurrent digital video data was collected to facilitate analysis of the range and rate data; these images correspond to times marked in Figures 1-3 and are denoted by Cases 1a through 3h. It should be noted that while the sources of some radar returns are easily pinpointed, high clutter and the lack of azimuth information on target tracks make it difficult to interpret the exact source of many returns. Accordingly, hypotheses on the effect of roadside clutter are only developed for returns with sources that could be readily interpreted.

The most pronounced outcome is the ambiguity and inconsistency of the radar to returns from roadside objects that might be expected to give more consistent returns (i.e., objects with high reflectance such as metal traffic signs or electroliers were sometimes tracked; at other times, they were not). Sensitivity to roadside and overhead clutter appears to be dependent on the range from the radar unit to the vehicle in front; that is, clutter at the approximate range of the lead vehicle was generally not detected, whereas clutter at ranges greater or less than that of the lead vehicle tended to cause loss of track. This behavior may be a function of the signal-to-noise ratio within the field of view (FOV), since at ranges closer than the forward vehicle, clutter returns are high, and at high range-to-clutter ratios, the target signal is relatively small. Data was collected at following distances typically between 25 and 50 meters, so it is not determined whether this sensitivity to clutter holds for much smaller or larger following distances.

From Figure 1, Cases 1a, 1c, 3c, and 3h show that even in the presence of metal guardrails, electroliers, and other clutter, the radar continues to track the forward vehicle. Overhead signs and overpasses marked with signs also failed to attract radar track the majority of the time (Cases 2a, 2b, 2e, and 2f), except in the cases where there was curvature in the road ahead, causing the lead vehicle to be at the limit of the radar's range or out of the FOV (Cases 3e and 3f). The insensitivity of the radar to the surround under these conditions is especially evident when passing through the trusses of a bridge. Cases 1e and 1h show instances of the trusses being detected at long and short ranges, respectively, but for most of the duration under the trusses, they are not detected (Cases 1f and 1g). There are also examples of metal objects that are regularly detected, such as the chain link fence in Case 3a.

Figure 2 shows that large areas of white roadway paint appear to elicit radar response. These areas include painted diamonds in transit lanes (Cases 2c, 2g), wider lines marking onramps and offramps (Case 2h), and restricted areas of the roadside (Case 2d). Although the electrical properties of the paint are unknown, it is possible that they possess a measurable radar cross section.

Traffic signals and lights (at railroad crossings, for example) represent complex geometries and can reflect a large amount of incident energy, so the large RCS return from these objects was expected, per Cases 3b and 3g. However, due to the overhead positioning of most traffic signals, they are not detected at close range and within the limited radar FOV. Railroad tracks themselves also showed no consistent return at short distances, even when steel plating was used to construct the crossing (Case 3d). Additionally, wet road conditions did not seem to cause any significant changes in the return, but there are a few instances where it is conjectured that a spray of water from the lead vehicle created considerable backscatter, causing the radar to miscalculate range and rate (see Case 1b).

We also employed a 77 GHz scanning radar on the CMU Navlab 6 vehicle for data collection. The returns from the radar signals were superimposed on a live video from the front-facing vehicle camera, and the results were recorded on video for further analysis. The RALPH video-based lane tracking system was also run, and the detected road borders were displayed on the same video image. The detected lane boundaries were used to classify the obstacle placement with respect to the driving lanes, and radar targets were color-coded as to on the travel lane, on the right, or on the left. The vehicle was driven over a course that included a wide variety of roads in the Pittsburgh area: suburban arterials, urban arterials, urban limited-access roads, suburban and rural interstates. Over five hours of data were recorded and analyzed. From the initial qualitative analysis, it was found that there is a good correlation between the radar returns and the superimposed markers on the video.

A wide variety of roadside clutter was detected: right and left guard rail; right and left Jersey barrier; utility / electric pole; overhead signs; overpasses; overpass pillar; sign boards; fence; tunnel wall; parked cars; and road surfaces. On rural interstates, the clutter mainly consisted mostly distant reflectors. On urban and suburban arterials, all the aforementioned clutter sources were detected. Almost all clutter was properly classified by the RALPH vision system and can therefore be dismissed as out of the current travel lane. The major exception is overhead signs and bridges. Since the radar has no way to measure elevation angles, it can only report is the horizontal location of the target.

The primary conclusion from these data collections is that accurate path prediction is important. However, path prediction is not sufficient. In particular, overhead structures will be detected and classified as in the vehicles travel lane. It is unlikely that automotive radar will have the vertical resolution to distinguish overhead objects from obstructions on the road. Other approaches will have to be pursued, such as stealthing or marking overhead and possibly other high-RCS roadside objects.

Case 1a. Insensitive to clutter

Case 1b. Undetermined short return (possibly spray from lead vehicle)

Case 1c. Insensitive to clutter

Case 1d. Sensitive to electrolier/shed

Case 1e. Sensitive to truss (long range)

Case 1f. Insensitive to truss (long range)

Case 1g. Insensitive to truss (short range)

Case 1h. Sensitive to truss (short range)

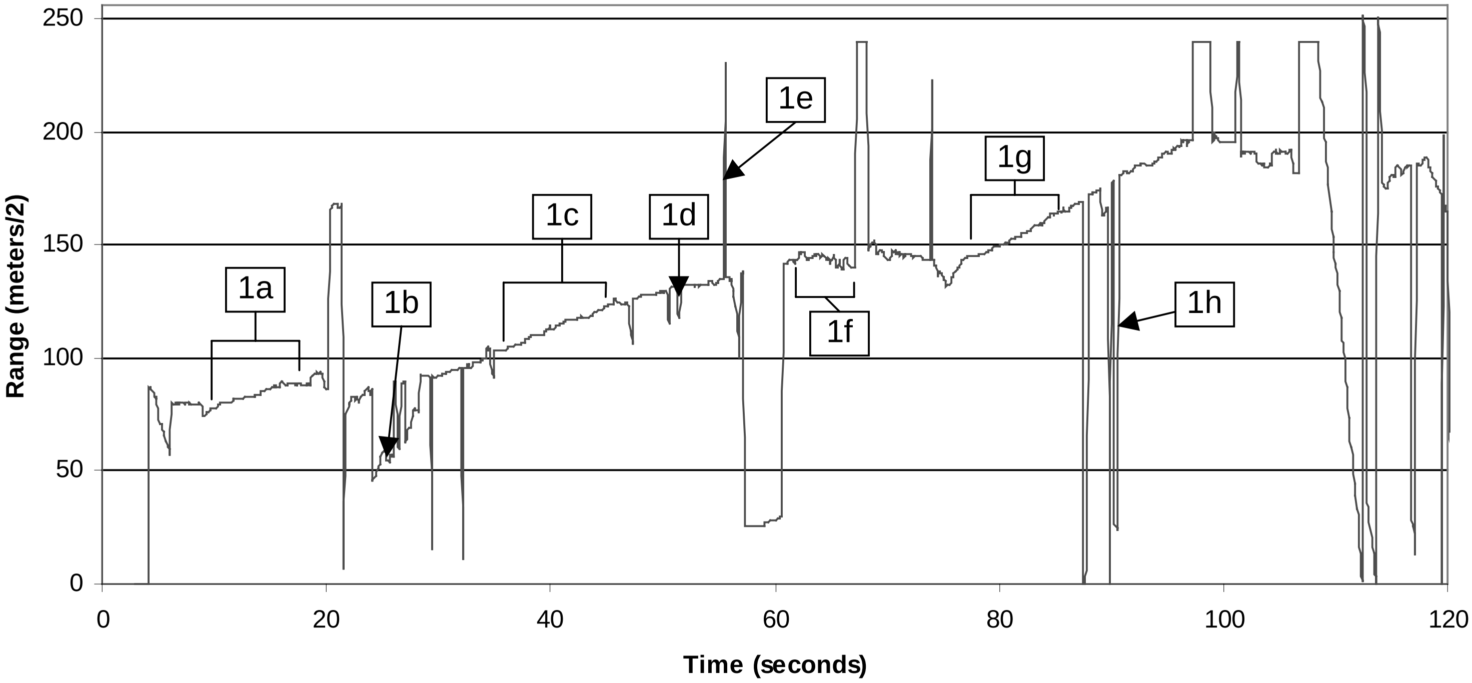

Figure 1. EVT-200 Radar Data – Case 1

Case 2a. Insensitive to overpass

Case 2b. Insensitive to overhead sign

Case 2c. Sensitive to painted diamond

Case 2d. Sensitive to painted area

Case 2e. Insensitive to overpass

Case 2f. Insensitive to overhead sign

Case 2g. Sensitive to painted diamond

Case 2h. Sensitive to wide painted lines

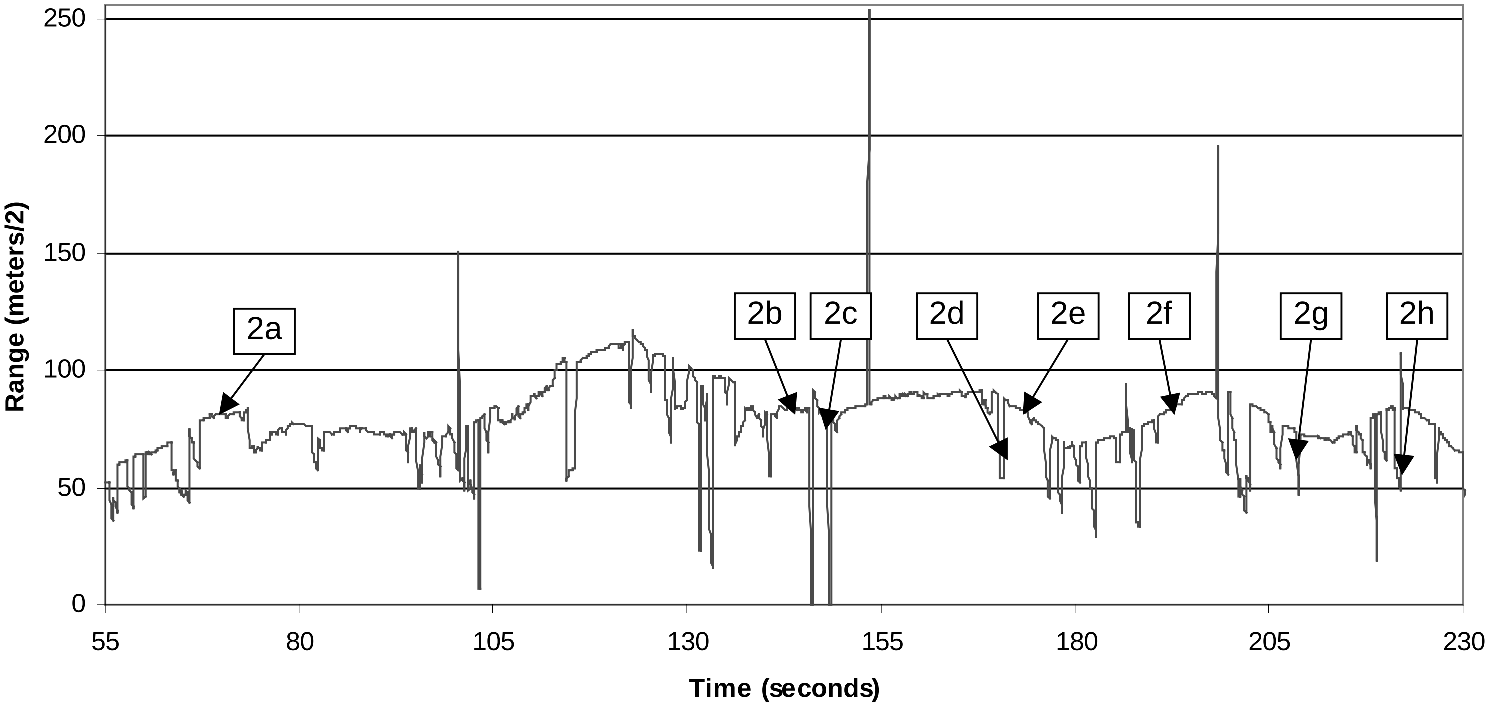

Figure 2. EVT-200 Radar Data – Case 2

Case 3a. Sensitive to Chainlink Fence

Case 3b. Sensitive to R/R crossing

Case 3c. Insensitive to clutter

Case 3d. Insensitive to R/R tracks

Case 3e. Sensitive to overpass on curve

Case 3f. Sensitive to overhead sign

Case 3g. Sensitive to traffic lights

Case 3h. Insensitive to clutter

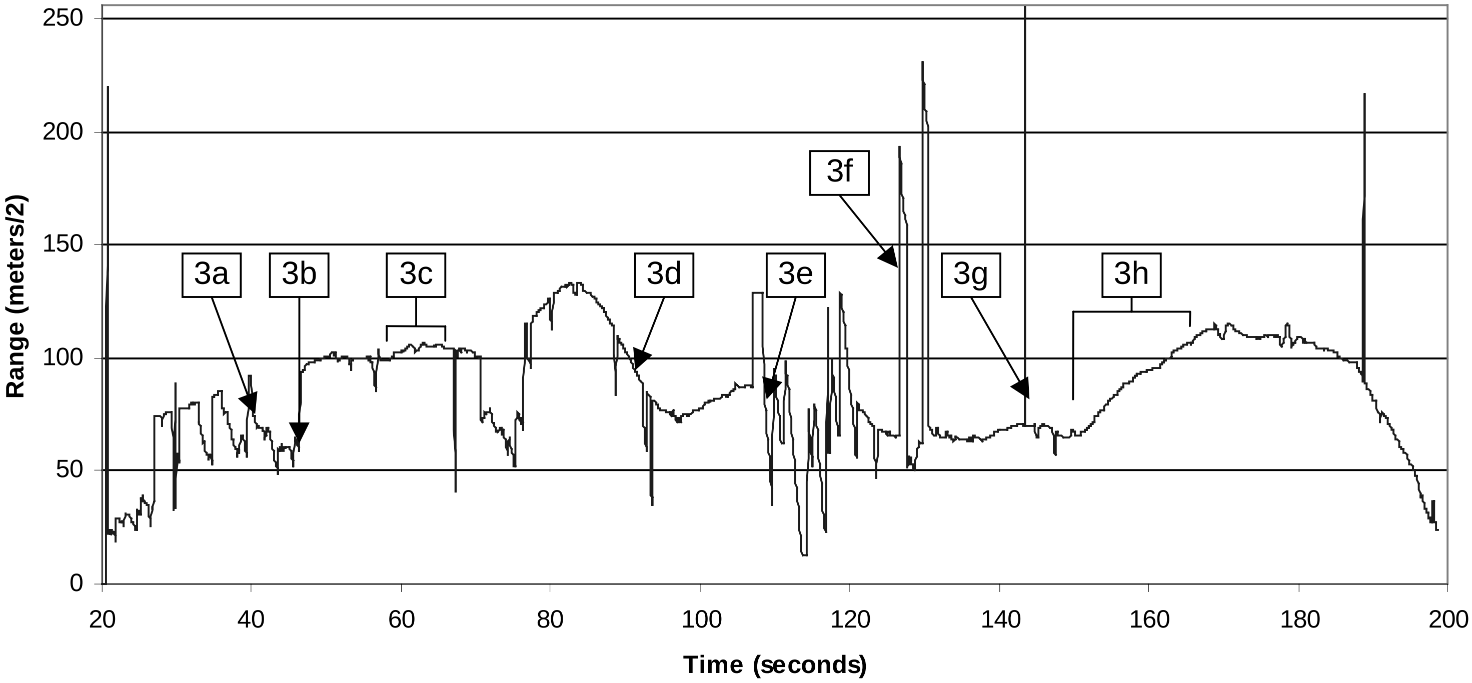

Figure 3. EVT-200 Radar Data – Case 3

SENSOR-FRIENDLY CONCEPTS, APPROACHES AND MODIFICATIONS

We have progressed from characterizing the operating environment to identifying candidate cooperative devices and systems. A number of concepts deal with 77 GHz automotive radar, where we consider vehicles that can be equipped with radar reflectors, either passive, to increase their radar cross-section, or actively modulated, to provide some communication. Roadside infrastructure can be similarly treated in order to make their radar profile distinctive and recognizably different from a vehicle. In addition, some roadside elements can have their RCS deliberately reduced, for instance by replacing steel signs with signs made of composite materials.

In addition to our primary focus on 77 GHz radar, we have begun investigating a number of other technologies. Light emitting diodes (LEDs) can be used in signals or taillights, and their signal modulated for low-cost communications. Additionally, LEDs in headlights can be used to trigger fluorescence in special markings on the road, vehicles, or signs. Our concepts are summarized in Table 1.

FURTHER WORK

We have begun evaluating the efficacy of these concepts in the following sequence:

- Determining the most promising sensor-friendly vehicle and roadway methods.
- Assessing potential implementation barriers and identify successful methods to overcome these barriers.
- Determining costs and benefits of specific sensor-friendly vehicle and roadway options.
- Conducting economic trade-off analyses and select sensor-friendly vehicle and roadway options for potential deployment.

After completion of these steps, we will be able to identify the most promising potential candidates from Table 1. Subsequently, we will build prototypes and begin testing on roadways.

Table 1. Status of Technologies

Technology	Function	Comments	Cost	Development Status
Candidate Vehicle Markings				
1. LED (Light Emitting Diodes)	LED Headlights:	Tie to fluorescent paint (see below) or use with colored reflectors		Still in laboratory
	LED Taillights:	+: Potential low-cost Implementation of near-term product feature (LED CHMSL already exists) -: Current range is short; may be susceptible to visual/NIR clutter	TBD "Special receiver" may be highest cost item @~$40	Messaging capability still in laboratory
	LED Messaging Traffic Signals	+: Red LED traffic signals already exist -: similar to LED taillights	~$100 for red; may be 3X higher for other colors	
2. Active License Plates	Signature enhancement of vehicles in front	+: No impact to production cars -: Potential side lobe clutter may be introduced unless edge-card beam shaping employed with automotive radars	~$1/plate in large quantities; $100/radar to suppress side lobes ***if necessary***	Still in laboratory
3. Passive Amplifiers on License Plates	Change character of incoming 77 Ghz radar return to provide information	+: Could communicate considerable state information -: May require special receiver (e.g. 77GHz signal in; 5.8 GHz signal out)		

Candidate Roadway Markings and Infrastructure Improvements				
4. Fluorescent Paint	Coded reflections from road markings, signs, vehicles			Works in Laboratory settings
5. Radio Beacons	Roadside to vehicle communications	Works with current radar detectors		In commercial deployment
6. Passive Reflectors: STAR (Spatial Tetrahedral Arrays of Reflectors)				
7. Active Roadside Reflector System (ARRS)	Based on cellular phone device characterization			Untried.
8. Traffic Striping	Radar cross section can be modified to provide path determination, for both painted and thermoplastic stripes	+: Notch or polarization signatures may be an effective low-cost lane delineation preview -: Untried.	TBD for new materials. Current cost of 4" (10cm) thermoplastic stripe is ~$3.50 per meter.	Untried in application, although similar radar cross section modification with paint pigments and binders have been successfully applied in military environments
9. Composite Materials	"Stealth" roadside signs	Can be very effective with right material, geometry, coatings.: if applied, recommend that it be done only to "trouble spots" with high background radar clutter	Varies widely, but will likely be expensive: $2-4 sq. ft; moreover, will require high tolerance installation	Wide military use

ACKNOWLEDGEMENTS

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