Development and Evaluation of Chip-Enabled Raised Pavement Markers for Lane Line Detection

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***Abstract*—Increased energy consumption and upfront cost of driving sensors can be seen as potential barriers for broad adoption of autonomous vehicles (AVs). For a high quality perception of the environment, incoming data from multiple sensors needs to be fused together using advanced computational algorithms which require a high compute load. As an alternative, infrastructure based sensors can be designed to facilitate perception and sensing by supporting vehicle–to–infrastructure (V2I) information exchange. This work presents an initial investigation of an energy efficient infrastructure based sensor. The sensor, a chip–enabled raised pavement marker (CERPM) is capable of wireless communications to exchange environment information with connected and autonomous vehicles (CAVs). As a test case, developed technology is tested to perform lane line and drivable region detection for an AV.**

***Index Terms*—LoRa; CERPM; GPS; CAV; RPM; Line Detection**

I. Introduction

Autonomous vehicles (AVs) use input from multiple sensors to extract information about the driving environment, such as the free drivable area and the obstacles, traffic velocities, and even predictions of their future state [1] using cameras, radio detection and ranging (RADAR), and light detection and ranging (LIDAR). Incoming data from these sensors needs to be fused and interpreted using advanced sensor fusion algorithms which typically requires an in-vehicle computer with very high operating frequencies and/or multiple processors. Power drawn from each of these different sensors and the in–vehicle computer, and subsequent computational load from fusion algorithms reduces the energy efficiency of AV driving.

Usual computer vision-based lane detection technology relies on image processing algorithms to extract lane line features, reduce image channels, extract essential features of the acquired image, and fit lane lines post extraction [2]. Recent advances in deep learning has led to neural network-based lane detection methods of higher accuracy. In most lane detection models based on deep learning, each pixel obtained through semantic segmentation is predicted to a category, which indicates whether it belongs to a lane line or not. While traditional algorithms fail in complex road scenarios such as lack of lane lines, blocked lanes, and poor light, neural network based lane detection algorithms demand higher computational power as a larger and deeper convolutional network is required to extract high–level semantic information.

Raised pavement markers (RPMs) aid drivers identify lane lines. RPMs are found on roadways throughout the United States, especially on high–volume highways and low visibility roads. Traditional RPMs include a retro–reflector, however a proposal has been made to include speed sensors and information display systems, among other things [3]. Herein a chip–enabled raised pavement marker (CERPM) is developed and tested for added functions, including capabilities for data processing and wireless data exchange to support cooperative driving automation (CDA). Given the variety of CDA applications, this research focuses on lane line and drivable region detection for AVs using CERPMs. CERPMs, when developed to transmit the Global Positioning System (GPS) coordinates of their location to the on-board vehicle computer, can help in lane line and drivable region detection for AVs.

II. Methodology

A. Raised Pavement Marker

A commercial Stimsonite RPM [4] was investigated for transmission technology integration. The RPM was 11.56 cm in length, 8.08 cm in width, and 1.68 cm in height. The plastic filling of the RPM was milled to fit the transceiver setup inside it as shown in Figure 1. Upon milling, the available volume for transmitter setup integration was about 65 cm^3 (7.62 cm in length, 5.4 cm in width, and 1.40 cm in height).

B. Selection of Communication Protocol

An energy efficient communication protocol that supports long–range communication needed to be chosen to justify the reasoning behind mass adoption of the CERPMs. Long range (LoRa) [5] is a low–power wide–area network (LPWAN) technology which enables energy efficient communication over longer distances [6]. Petajajarvi et al. [7] conducted experiments to demonstrate the coverage for LoRa when employed with long range power wide–area network (LoRaWAN) and obtained a maximum communication range of over 15 km on

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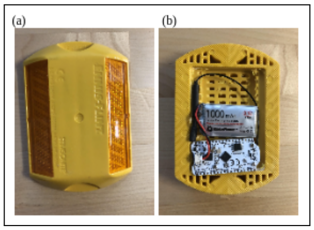

Fig. 1. (a) Chosen RPM and (b) IoT board and battery placement inside an RPM.

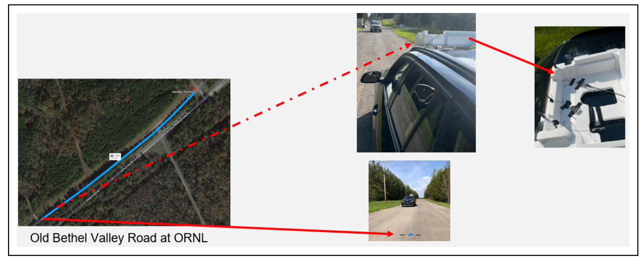

Fig. 2. Measurement Setup at ORNL for range measurements

ground and close to 30 km on water. Compared to alternative LPWAN technologies like NB–IoT, SigFox, Telensa, and Ingenu RPMA, Almuhaya et al. [8] showed LoRa as the most energy and cost efficient solution for broader adoption.

C. Transceiver Selection

The Transmitter–Receiver (Tx–Rx) setup needed for effective LoRa communication was to be selected. Besides effective communication, Tx setup had to be compact enough to fit in the available space of $65\,\text{cm}^3$ inside the RPM described in Section II-A. An internet of things (IoT) development board called WiFi LoRa 32 [9] designed by Heltec Automation was used as Tx as it is integrated with SX1276 LoRa modem which supports data transmission in frequency ranges from 137 MHz to 1.02 GHz. The integrated CP2102 USB to serial power chip allows for programming the IoT board using Arduino library. 3.7 V Lithium rechargeable battery [10] of 1000 mAh battery capacity was chosen to power the IoT board. The chosen IoT board, battery, and the originally supplied antenna fit in the application. The internal volume would be potted while making sure the antenna is as close to the external surface as possible.

Similar to the Tx setup, the same IoT development board was used for the Rx setup as well. However, the originally supplied antenna with the transceiver module for the IoT board (Rx) was replaced with a AEACAQ190012–S915 [11] antenna for increased antenna gain of 0.5 dBi.

D. Communication Range Measurements

The selected Tx–Rx setup was experimentally tested to determine the feasibility of the CERPM in terms of providing a successful wireless communication. Received signal strength indicator (RSSI) of a radio signal can be determined using:

$$P_R = P_0 - 10\eta \log_{10}\left(\frac{d}{d_0}\right) \tag{1}$$

where P_R is the received power in dBm, η denotes the path loss exponent, P_0 stands for the free–space path loss, d and d_0 are the distance between Tx–Rx and the reference distance for path loss measurements, respectively.

Tests were carried out at Oak Ridge National Laboratory (ORNL) with a roadside CERPM and capturing the RSSI, signal–to–noise ratio (SNR), CERPM id, and GPS coordinates by Rx. Measurements were taken over a 10 m–410 m Tx–Rx distance at 20 m intervals. Rx was mounted on top of 2015 BMW X1 at an height of 1.55 m above Tx.

E. Data Message Transmission and Reception

With the incoming data from Tx LoRa nodes, LoRa Gateway forwards all the radio packets to the Rx LoRa node after adding metadata such as SNR and RSSI [12]. Data messages to be transmitted from the CERPMs must be properly defined. The required data for lane and drivable region detection were identified as the GPS coordinates (latitude, longitude, and altitude) of the CERPM location and a unique CERPM id for each CERPM. The GPS coordinates of the CERPM location were measured using a high–precision GPS sensor, Trimble Catalyst [13] and each CERPM was programmed using Heltec Arduino LoRa Library [14] to transmit the GPS coordinates, CERPM id, SNR, and RSSI in packets. Average packet size of the messages sent from one CERPM was around 47 bytes. In–vehicle Rx–setup placed at the top of the ego vehicle was programmed to receive packets sent by the CERPMs. In–vehicle Rx and CERPMs were programmed to operate in the United States unlicensed industrial, scientific and medical (ISM) radio frequency band of 915 MHz.

F. Data Routing

With the integrated CP2102 USB to serial chip, a serial communication was established which enabled communication between the Rx–setup and the in–vehicle PC of an autonomous research vehicle (Kia Niro Hybrid 2016) operated out of Western Michigan University (WMU) Energy Efficient and Autonomous Vehicle (EEAV) lab. A Python program was written to read in the data coming in through the serial port. Sensor communication to the EEAV Lab's research vehicle is facilitated via Robot Operating System (ROS). A ROS node was created which reads in the data output from the developed Python program. The creation of a ROS node also helps in making sure that CERPM data is available to AV control system for sense and perception. The entire data routing flowchart can be seen in Figure 3.

G. Lane Line and Drivable Region Detection

The GPS points coming in from the CERPMs were overlaid onto the camera feed of the research vehicle to show lane line and drivable region detection. GPS coordinates transmitted by CERPMs were converted from WGS84 (World Geodetic System 1984) form to global North East Down (NED). Zed 2i [15] was the camera used and points were projected into the camera feed using the *projectPoints* function from the Python OpenCV image processing library. Lane lines were modeled

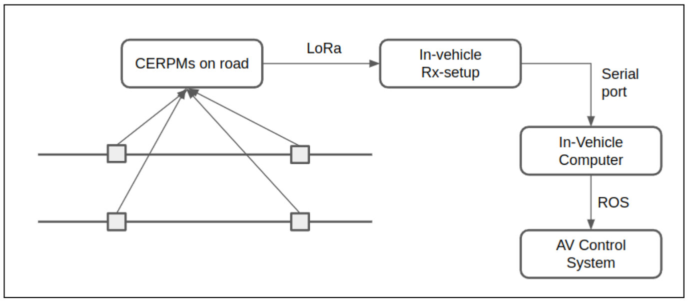

Fig. 3. Flowchart showing CERPM data routing plan

Fig. 4. Road section around WMU campus for lane line and drivable region detection testing

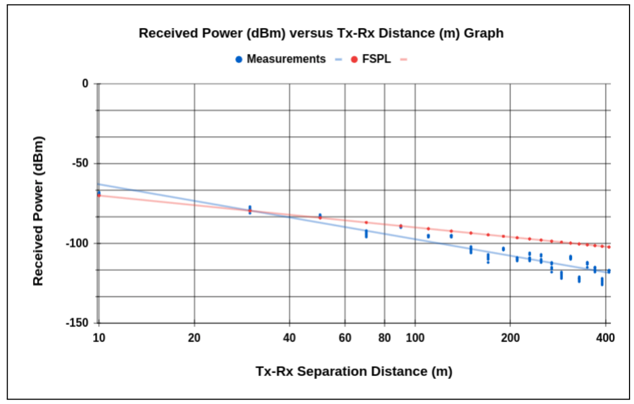

Fig. 5. Comparison of Received Power in dBm with Tx–Rx separation distance (m) for measurements taken and FSPL model (Equation 1)

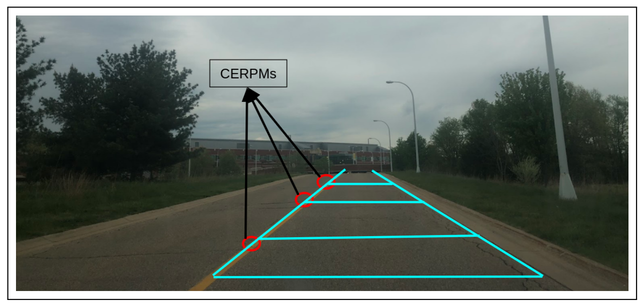

Fig. 6. Real–time lane line and drivable region detection using CERPMs

by fitting a cubic function on the CERPM points. For this experiment, six CERPMs were placed on a straight section of a WMU Parkview campus road. CERPMs were placed exactly in the middle yellow lane line in the road section shown in Figure 4. The distance between two consecutive CERPMs were kept at 10 m for this initial investigation as Department of Transportation (DoT) guidelines suggest that the spacing between conventional RPMs used on lane boundaries on straight tangents should be less than 24.40 m [16].

III. Results

A. Communication Range Measurement

The received power from the CERPM at d_0 and subsequent points was taken as the mean of five measurements, displayed in Figure 5. The received power using a free–space path loss (FSPL) model with $\eta = 2$ is also shown in Figure 5.

FSPL model and measured data show similar trend as the measurement environment as the ego–vehicle was always in line of sight of the CERPM. Antenna being inside the CERPM is the main reason for slight differences in received power for higher distances (100 m and above). Range measurements need to be further verified by taking measurements at different road and traffic conditions but the results from initial investigation made a case for an appropriate CERPM range.

B. Lane Line and Drivable region detection

Output of the developed program for lane line and drivable region detection for region shown in Figure 4 is shown in Figure 6. Lane line and drivable region detections made when CERPMs were 10 m apart have supported the claim for wireless exchange of high–quality perception data from CERPMs. These initial results have paved the way for finding optimal CERPM distance as a function of road curvature.

IV. Conclusions and Future Work

This work presented initial development of CERPMs as an infrastructure–based perception aid for AVs. In this direction, prototype CERPM was developed to transmit GPS coordinates of their location. Results show a successful wireless communication between CERPM and the in–vehicle PC at a distance upto 410 m. CERPM application for a major AV perception task, lane line and drivable region detection was shown. Developed technology, being an initial investigation, has a large scope for future work. In the near future, CERPMs will be tested at different conditions like inclement weather conditions, urban, and rural scenarios. CERPMs can be programmed to add other functionalities to aid CDA like speed sensing, and triangulation to name a few.

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