Poster: Helping Autonomous Vehicles Maneuver Traffic Anomalies using UWB

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Figure 1: Traffic anomalies occur when a self driving car is confronted with unusual situations: (a) a semi-truck carrying a mobile home [11], (b) a car towed with its front facing the back [5], (c) a truck carrying a tree confuses a Waymo car [6], (d) a Waymo car having difficulties following police hand signals [10], (e) multiple driverless Waymo cars all stuck because of each other creating an artificial traffic jam [12].

ABSTRACT

This paper proposes a UWB beacon to be installed on trucks carrying unusual loads to warn approaching autonomous vehicles (AVs) of unconventional cargo. We propose several approaches, including one where the AV only receives UWB messages. We plan to use a QR code to provide secure communication between the AV and the cargo. The proposed system generalizes to static and dynamic traffic anomalies.

CCS CONCEPTS

• **Networks** → **Sensor networks**; • **Applied computing** → **Transportation**; • **Computer systems organization** → **Sensor networks**.

KEYWORDS

UWB, Autonomous Vehicles, Vehicle-to-Infrastructure (V2I) Communication, QR Code

1 INTRODUCTION

Vision-based processing of surroundings remains a vital and crucial component of self-driving vehicles, with substantial "knowledge" used for machine learning and training coming from recorded driving videos, either with human drivers or from autonomous driving. These large datasets and live map data aim to prepare the vehicle for all possible scenarios. Yet, one-off events remain challenging for AVs. Examples (Figure 1) include AVs confused by trucks carrying trees or mobile homes. Perhaps even more importantly, AVs have trouble responding to law enforcement officers trying to communicate with the AV through hand gestures; instead AVs might attempt to go around the officer, mistaking the officer to be a pedestrian. All of these one-off events which we call *anomalies*, are controlled situations where responsible individuals such as the truck drivers or law enforcement officers are involved. It is important to recognize that while AVs are equipped with advanced vision and sensor systems, they can still be prone to misinterpretations in dynamic and complex traffic environments.

This project proposes to lend a helping hand to autonomous vehicles to understand and navigate such anomalies a little better. We plan to install a wireless beacon on vehicles carrying unconventional cargo (fallen trees and portable houses, for example) similar to how red blinking lights or caution signs are attached to such oversized loads today to help human drivers. Such a wireless beacon will readily allow measuring distance from the cargo, and provide information about the 3D structure of the truck's cargo. Similarly, a police officer who expects to encounter autonomous vehicles may wear wireless beacons which help the AV disambiguate between a police officer and a pedestrian, and understand

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hand gestures using wireless communication [2]. Such an approach is in sharp contrast to using computer vision techniques for first determining that the person on the road is actually a police officer, and that their hand gestures are specific instructions that must be followed.

We expect two important features from such a wireless beacon: (1) a means for securely broadcasting information about the cargo to other vehicles on the road, and (2) a means for the AV to estimate its distance from the beacon(s). By obtaining distance measurements from the beacon(s) attached to the extremities of the cargo, the dimensions of the cargo can be estimated without having to rely on visual cues which can be sometimes misleading (for example a metal rebar jutting out of a truck might easily go unnoticed by cameras and lidar scans). Since obtaining distance measurements and dimensions of the cargo are important properties of the system, we propose to use ultra-wideband (UWB) radios, which readily provide ranging capabilities. UWB transceivers can be installed on the oversized cargo and worn by police officers.

Both QR codes and UWB tags are used together to ensure secure communication, with the QR code providing a key to authenticate the UWB signal. While camera-based systems can estimate distance, they lack the ability to provide detailed structural information. A multi-UWB system is preferred for its precise distance measurements providing 3D structural data, simplifying navigating around complex cargo.

While UWB could potentially provide clues about the dimensions of the cargo, an important question remains: *how to ensure that the wireless beacon signals being received by the AV are indeed coming from the truck in front of the AV*, and not from some malicious transmitter at the side of the road? Angle of arrival of the signal and the localization of the transmitters based on multiple UWB anchors could be obvious solutions. However, with metallic reflections, limited aperture for the AV's receivers and because of the dynamic nature of the anomaly, in this work, we propose an orthogonal but simple approach. We plan to display a QR code on the oversize cargo that can be read by the AV following behind. This QR code will contain a key to communicate with the UWB devices on the truck, assuring the AV that it is indeed receiving data from the truck's UWB beacons.

2 RELATED WORKS

The literature in this field tries to reduce the chances of encountering an unusual situation (anomalies) by focusing on large data collection efforts [16]. Of course, visual inputs alone are not sufficient and hence several works propose multi-sensor fusion approaches. For example, [17] proposed a multi-sensor data fusion system that integrates data from cameras, laser range finders, radar, and ultrasonic sensors to create a comprehensive perception system for off-road autonomous vehicles, where unusual situations is the norm.

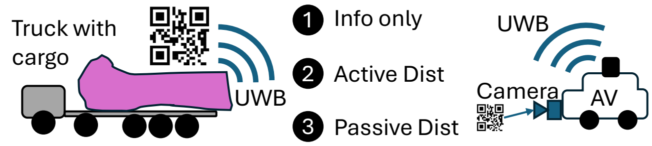

Figure 2: Our system design: the truck attaches UWB beacons choosing between three alternatives. AV following the truck uses camera to obtain the QR code with encoding key for UWB followed by UWB communication, based on the selected mode of operation.

Millimeter-waves (mmWave) can easily work in poor visibility conditions and detect car bounding boxes [7, 14].

Infrastructure support has been explored in several infrastructure to vehicle communication works including the BESAFE system [8] based on DSRC with roadside beacons providing vital information about the road. However roadside beacons cannot help navigating around unconventional cargo and communication between police officers signaling to traffic and the AVs. Traffic signs augmented with QR codes have been explored in [9] at a limited scale.

Anomaly detection has itself been a subject of interest in the past with primary focus on visual sensing. Survey papers such as [1, 15] conducted comprehensive surveys on anomaly detection techniques in connected and autonomous vehicles. However, the focus is primarily on improvements to the AV algorithms instead of attempting to extend help to the AVs using modified rules and regulations about how unconventional loads must be carried on the road.

We take motivation from the fact that such rules and regulations already exist to aid human drivers. For example, the yellow "oversize load" banners and red cloths hanging at the end of rebars jutting out of trucks, and even police uniforms all help human drivers make better judgment calls. In this work, we are re-imagining these rules to accommodate autonomous vehicles as well. We believe we are the first to introduce a secure UWB communication distributing distance information and structural dimensions from an unconventional cargo to a following vehicle.

3 SYSTEM DESIGN

We develop a UWB-QR code system attached to unconventional cargo or worn by police officers, with the UWB transmitting distance information and the QR code providing the UWB encryption key. An autonomous vehicle following such a cargo would capture the QR-code using its camera and then use the information in the QR code to either actively range with the UWB transceiver or passively listen to the encrypted information broadcast by the UWB beacon. Similarly, body-worn UWB sensors will be used by police officers to transmit gesture inferences to the AV using encoded UWB messages. We enable three modes of operation:

(1) **Informational Data No Ranging Mode:** The UWB beacon installed on the unconventional cargo only broadcasts information about the load without facilitating ranging. Such information is immediately useful since it can be parameterized to influence decisions on the autonomous vehicle. For example, unambiguously knowing the dimensions of a mobile home being carried by a truck can help an AV pass the truck safely. The QR code is used to decrypt UWB messages for trustworthiness.
(2) **Informational Data and Active Ranging Mode:** In addition to broadcasting informational data, a UWB device can also enable encrypted active ranging. Note that the QR code protects against malicious entities who are not immediately behind the trucks from requesting unnecessary distance measurements.
(3) **Informational Data and Passive Ranging with multiple UWBs Mode:** Multiple UWB devices attached to the unconventional cargo can perform continuous distance measurements among themselves. Any nearby vehicles overhearing this communication can deduce their own distance from the beacons as well as the dimensions of the structure using techniques in PnPLoc [3]. Once again, the QR code allows only a small set of vehicles directly behind the truck to use this information. The police-officer use-case will work in this mode allowing any number of vehicles to receive instructions together.

4 EVALUATION PLAN

Developing a full-fledged system for the AV industry is quite challenging due to a high barrier for entry. We plan to partition the evaluation of our system into two phases.

Determining UWB and QR-code range: We first plan to study the range of UWB devices using non-autonomous vehicles to determine whether in real-world conditions of the road, UWB will indeed be a feasible technology to explore. Next, we plan to use cameras on one car to detect and read QR codes on the back of another car. Challenges like image stabilization and QR code sizes will be explored.

A key part of the evaluation is testing UWB communication robustness in environments with multiple transmitters and assessing QR code readability under different lighting. We will run experiments to measure the effects of interference, occlusion, and varying illumination on UWB performance and QR code visibility to ensure real-world reliability.

Encoding UWB messages using a code displayed on the QR-code: We plan to use standard symmetric encryption algorithms to encode data being sent by the truck's UWB devices. We plan to also explore asymmetric cryptography so that multiple on-cargo UWB devices will communicate using one key but AVs will decipher using another.

5 POLICY CONSIDERATIONS

Oversize load permits are a complex process even today. Every state has laws governing oversize loads (GA Chapter 672-2 [13]) as well as federally defined laws for transport of such goods on interstate highways [4]. Our work with UWB and QR codes could result in additional rules incorporated in such policy handbooks in states where autonomous vehicles are allowed. We hope to arrive at standardization efforts for UWB communication for such use-cases.

A comprehensive policy framework is crucial for the adoption of this technology. It must address technical, safety, legal, and regulatory requirements for integrating UWB and QR codes into traffic systems. Collaboration with policymakers and industry is needed to create standardized protocols that comply with laws while ensuring driver safety and comfort.

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