Using Bluetooth Low Energy Technology to Trigger In-Vehicle Messages at Work Zones

Chen-Fu Liao1*, Max Donath2, Nichole Morris3

1. Department of Civil, Environmental, and Geo Engineering, University of Minnesota, USA
   500 Pillsbury Drive, SE, Minneapolis, MN 55455, (O) 612-626-1697, cliao@umn.edu
2. Department of Mechanical Engineering, University of Minnesota, USA
3. HumanFIRST Laboratory, Department of Mechanical Engineering, University of Minnesota, USA

Abstract

In order to reduce risky behaviour around work zones, this project examines the effectiveness of using in-vehicle messages to heighten drivers’ awareness of safety-critical and pertinent work zone information. The investigation centers around an inexpensive technology based on Bluetooth Low Energy (BLE) tags that can be deployed in or ahead of the work zone. A smartphone app was developed to trigger non-distracting, auditory-visual messages in a smartphone mounted in a vehicle within range of the BLE work zone tags. Messages associated with BLE tags around the work zone can be updated remotely in real time and as such may provide significantly improved situational awareness about dynamic conditions at work zones such as: awareness of workers on site, changing traffic conditions, or hazards in the environment. Experiment results indicate that while travelling at 70 MPH (113 km/h), the smartphone app is able to successfully detect a long-range BLE tag placed over 410 feet (125 m) away on a traffic barrel on a roadway shoulder. Additional experiments are being conducted to validate the system performance under different roadway geometry, traffic, and weather conditions.

Keywords:
Bluetooth, smartphone app, work zones

Introduction

According to work zone injury and fatality data published by the U.S. Federal Highway Administration (FHWA) in 2013, there were more than 67,500 crashes in work zones, resulting in 579 deaths and 47,758 injuries. More than 20,000 workers are injured in work zones each year, with 12% of those due to traffic incidents [1, 2]. Despite a trend towards fewer work zone crashes from 2011 to 2013, the number of estimated work zone injuries actually increased in 2013 [2].
Smarter work zones is one of the initiatives promoted by the Federal Highway Administration (FHWA) in the US that uses innovative strategies to improve work zone safety and mobility. Strategies such as incident management, traffic control, work zone speed management, and use of Intelligent Transportation Systems (ITS) have been implemented by state Departments of Transportation (DOTs) to improve mobility and safety by actively managing traffic through work zones [3]. Many ITS tools and applications have been developed and implemented to effectively mitigate traffic impacts caused by construction.

In recent years, challenges to work zone safety and mobility are exacerbated by the growing issue of distracted driving. The objective of this paper is to investigate the effectiveness of using in-vehicle spoken messages to calibrate the drivers’ understanding of the work zone in order to reduce risky behaviour, associated with distraction.

**Literature Review**

Speed enforcement, speed advisory systems, or variable speed limit systems are often used for work zone speed management. For example, Mattox et al. [4] developed a speed-activated sign that informs vehicle drivers through a roadside visual cue if they were exceeding the speed limit in a work zone. They concluded that the speed-activated sign had a significant impact on lowering the speed of vehicles in work zones. Kwon et al. [5] implemented a two-stage speed reduction scheme at one of the I-494 work zone bottlenecks in the Twin Cities, Minnesota. Despite the advisory speed limit, data collected from the field operation test indicated a 25–35% reduction of the average maximum speed difference. They also observed that drivers are less likely to comply with the variable speed limit if the posted speed is significantly different from the speed they would otherwise choose.

Automated traffic information systems have been proposed to improve safety by informing motorists with timely updates on travel time, delay, and queue length [6-11]. Ibrahim et al. [6] developed a hybrid work zone information system to notify motorists travel delays and the starting location of congestion using dedicated short range communication (DSRC) technology and a portable changeable message sign. The simulation results suggested a DSRC market penetration rate ranging from 20 to 35% is needed for the system to work.

Haseman et al. [12] use Bluetooth probe data from multiple field collection sites to communicate travel delay times to the motoring public, assess drivers’ diversion rates, and develop performance metrics for a state transportation agency to evaluate work zone mobility performance. They suggested that work zone travel time information provides a mechanism for assessing the relationship between crashes and work zone delay.
In addition, Bluetooth technology has been used in recent years as an inexpensive and reliable way to collect travel time information on roadways [13-15]. Anonymous travel time monitoring is performed by matching the Media Access Control (MAC) addresses of Bluetooth devices embedded on cell phones or GPS navigation devices. Bluetooth technology does not require line of sight, however its signal attenuation may be influenced by physical obstacles. Bluetooth travel time monitoring systems typically produce a matching rate in the 1% to 6% range [16, 17]. Dunlap et al. [18] use Wi-Fi and Bluetooth signals from transit riders’ mobile devices to estimate origin and destination information, number of boarding and alighting, and passengers’ waiting time at stops. Their results suggest that the Bluetooth and Wi-Fi signal based methodology is reliable at providing a robust and detailed source of data for transit planning and operations analysis.

Liao [19] previously developed a system using smartphone and Bluetooth technologies to help people with vision impairment navigate in or around a work zone. A smartphone app based on the Android operation system was developed for providing audible messages to people with vision impairment at a work zone. Global positioning system (GPS), Bluetooth technology, a text-to-speech (TTS) interface, and a digital compass already present on a smartphone were integrated with a digital map in the smartphone app. The smartphone app communicates with Bluetooth beacons installed near a work zone to help determine a user’s location and provides corresponding navigational guidance instructions.

The latest Bluetooth technology, Bluetooth Low Energy (BLE) or Bluetooth Smart, has considerably reduced power consumption as compared to earlier versions. Low-cost BLE devices have enabled many applications using BLE tags and smartphones to locate or identify personal items or alert owners when personal belongings are left behind. All newer generations of smartphones are now equipped with BLE technology. For example, iBeacon from Apple uses BLE technology to identify locations that trigger an action on the iPhone. Many articles, including Ashford [20] quoted the Bluetooth Special Interest Group (SIG) that predicts that more than 90% of Bluetooth-enabled smartphones will support the low energy standard by 2018 [21].

BLE technology typically has a wireless communication range up to 50 meters based on line of sight, according to its specifications. Commercially available BLE tags are usually configured as non-paired and discoverable Bluetooth devices. A BLE equipped smartphone app can continuously scan for BLE devices in the environment. The BLE tag can “broadcast” its service name or other information. When the smartphone app receives the wireless signal from a BLE tag, it will also receive a Received Signal Strength Indicator (RSSI) value with that broadcasted message. The RSSI can be used to evaluate distance from the tag. Whether BLE tags can be used to alert drivers of high-speed vehicles about work zones ahead is one of
Using Bluetooth Low Energy Technology to Trigger In-Vehicle Messages at Work Zones

the key questions being addressed here.

**Our Approach and System Design**

Drivers often rely on signs along the roadway to be cautious and slow down as they approach the upcoming work zone. However, most work zone crashes are caused by drivers not paying attention. Our approach aims to design and test an in-vehicle work zone alert system that announces additional messages through the driver’s smartphone. These messages would be triggered by passing near specific BLE tags in or ahead of the work zone and adjacent to the road. Our goal is to understand whether this type of additional warning message tailored to the individual driver’s behaviour can improve the situation awareness of the driver and their response to the work zone, particularly when there are workers on site and construction work is in progress.

The system architecture of the proposed in-vehicle work zone alert system is illustrated in Figure 1. The system includes a spatial database, a middleware for data transactions, a smartphone app, and BLE tags. A work zone database for BLE tags was incorporated into the system to include location, sign, message content, and other necessary information associated with BLE tags in a work zone. A subset of the BLE work zone database is accessed by the smartphone based on the vehicle’s current location. The Bluetooth scanning service on the smartphone is automatically activated as drivers approach the work zone using geo-fencing and based on direction of travel. Appropriate warning messages are referenced to each BLE tag when detected by an in-vehicle device (e.g., a smartphone app).

An Android smartphone application, called *Workzone Alert*, was developed for testing and data collection. The app was configured to run as a background service on the phone when the phone is turned on. The app constantly monitors a vehicle’s location using the GPS sensor on the smartphone and periodically updates its local work zone database (stored on the phone) within a 50 miles (80 km) radius of the current vehicle location from a work zone database server. A continuous Bluetooth scan is initiated when a vehicle enters a geo-fenced work zone. When a work zone BLE tag is detected, the app projects an audible message which is supported by a visual display associated with the tag. When multiple work zone BLE tags are sensed, messages associated with the nearest BLE tag, i.e., the tag with the strongest signal, are announced to the driver. The current app includes several features, such as vibration, alerting tone, data collection, and graphical display, for testing in our field experiments.

If the BLE tag is configured to alert based on speeding, the app will announce “*You are speeding*” in addition to the work zone message that will be provided. When the vehicle leaves the geo-fenced work zone, the Bluetooth scanning service is terminated. Current messages attached to each BLE tag were selected for functional testing only. The final
message structure and content will be determined from the results of a human factors study currently being conducted by the HumanFIRST Laboratory at the University of Minnesota.

On account of privacy concerns [20], our system architecture includes a 3-tier implementation that improves the data security of communication between client devices and the database. We reprogramed the firmware of two commercial off-the-shelf (COTS) BLE long-range tags from two different sources that meet our application requirements. The BLE tags operate in discovery mode with minimal power consumption. The BLE tag and a battery were packaged in a NEMA enclosure for field-testing. Our app only recognizes the BLE tags that are programmed for our application. Other Bluetooth devices within the detection range are ignored.

In order to reduce the effort required in the placing the Bluetooth beacons at a work zone, another smartphone app was developed for use by the work zone deployment contractors. This app allows the staff in the field to submit a request for message update at the location where a BLE tag is installed. This app automatically determines current latitude/longitude location of the smartphone beacon, scans for Bluetooth beacons in the vicinity, and then lists identified Bluetooth tags. After the staff selects the BLE tag and an authorized security code, the smartphone app then submits the message update request to the BLE database through the wireless network. This approach allows engineers or staff who are responsible for the work zone operation to update the in-vehicle messages in a timely manner.

**Experiments and Data Analysis**

We conducted several experiments on a city street while traveling at 45 MPH (72 km/h), a county highway while traveling at 55 MPH (89 km/h), and at the MnROAD facility while
traveling from 30 to 70 MPH (48 to 113 km/h) by placing the BLE device on a traffic barrel on the shoulder of the roadway or mounting the BLE device on a lamp post. The MnROAD facility is a test track owned and operated by Minnesota Department of Transportation (MnDOT) for conducting research on pavement and material performance.

Experiment at MnROAD
For experiments conducted at the MnROAD facility, the BLE tag was placed on top of a traffic barrel with its antenna facing toward the incoming traffic. The results indicated that the smartphone app is able to successfully detect the long-range BLE tag placed on the roadside. As illustrated in Figure 2, a test vehicle (a sedan) travelled at 70 MPH (113 km/h) on the MnROAD test facility in Albertville, MN. It travelled on the inner loop (in the northwest direction) towards a BLE tag placed on a traffic barrel on the shoulder. The smartphone app recorded the GPS latitude and longitude coordinates (dots in Figure 2) when the BLE tag was detected. The plot in Figure 3 shows the speed profile of the test vehicle passing by the BLE tag around 9:37:51 am. The estimated Bluetooth detection range at 70 MPH (113 km/h) was about 410 feet (125 meters) ahead of the traffic barrel.

![Figure 2 Field Experiment with a Test Vehicle Traveling at 70 MPH (113 km/h)](image)

![Figure 3 Speed Profile of a Test Vehicle Traveling at 70 MPH (113 km/h)](image)
Using Bluetooth Low Energy Technology to Trigger In-Vehicle Messages at Work Zones

**Experiment on a local street**

Another experiment was conducted on a city street using a smartphone with the *Workzone Alert* app running as a service in the background. The smartphone was mounted below the dashboard using the cup holder of a minivan as shown on the left of Figure 4. Figure 4 illustrates the optional graphical display that is triggered and an audible warning message associated with the sensed BLE tag. In the field experiment, it is expected that the smartphone will be mounted below the dashboard. When the smartphone is paired with a vehicle’s audio system through Bluetooth, the warning message will be announced through the vehicle’s audio system. As illustrated in Figure 5, the minivan travelled at 50 MPH (80 km/h) on the city street northbound from a starting point toward the BLE tag with geo-fencing implementation. The Bluetooth scanning service on the smartphone was activated immediately after the test vehicle entering the geo-fence zone (the dash-lined polygon in Figure 5). The app performs a geo-fence check whenever a GPS location update (every second) on the smartphone is available. The app starts recording the GPS coordinates when the vehicle enters the geo-fenced zone. The speed profile plot, as displayed in Figure 6, shows that the test vehicle passed by the BLE module at 10:17:05 am. The estimated range of Bluetooth detection at 50 MPH (80 km/h) is about 922 feet (281 meters). Figure 6 shows the vehicle showing down after the message is played.

![Figure 4 Placement of a Smartphone in a Test Vehicle (Prototype for Testing)](image)

![Figure 5 Experiment at a City Street Test Site](image)
Using Bluetooth Low Energy Technology to Trigger In-Vehicle Messages at Work Zones

Experiment at a Highway Work Zone

Another experiment was conducted on I-35E NB near County Road E East in Vadnais Heights, MN using a passenger vehicle. A long-range Bluetooth tag was mounted on a speed limit sign as shown in Figure 7. As illustrated in Figure 8, the test vehicle travelled at 50 MPH (80 km/h) on I-35E NB from downtown St Paul toward the BLE tag with a geo-fencing technique implementation. The Bluetooth scanning service on the smartphone was activated immediately after the test vehicle entered the geo-fence zone (dash-lined polygon on the left of map in Figure 8). The speed profile plot, as displayed in Figure 8, shows that the test vehicle passed by the BLE module at 10:51:44 am. The estimated range of Bluetooth detection at 50 MPH (80 km/h) is about 525 feet (160 meters) ahead of this work zone.

Figure 6 Speed Profile of a Test Vehicle Traveling at 50 MPH (80 km/h)

Figure 7 Installation of a Bluetooth Beacon at a Highway Work Zone
Using Bluetooth Low Energy Technology to Trigger In-Vehicle Messages at Work Zones

**Figure 8 Speed Profile of a Test Vehicle at I-35E & County Road E East Work Zone**

**Power Consumption**

We used a DC inline watt meter and power analyser [22], to measure the smartphone battery power consumption rate. As shown in Figure 9, our test smartphone (a Samsung S6 model) draws 196 mA per hour without running the *Workzone Alert* app. This battery power consumption rate is used as a baseline. The test phone consumes 209 mA per hour when the work zone app is running without Bluetooth scanning. When the Bluetooth scanning is running continuously, the test phone will draw 325 mA per hour. For a smartphone with 3000 mAh battery capacity, for example, the smartphone with a fully charged battery will respectively last 15, 14, and 9 hours for the baseline, work zone app without Bluetooth scanning, and work zone app with continuous Bluetooth scanning scenarios.

**Figure 9 Comparison of Smartphone Battery Consumption**
The BLE tag consumes about 10, 33, and 36 mA while idling, receiving (RX), and transmitting (TX) modes, respectively. Currently, the BLE tag is powered by a 2700 mAh portable charger. It will last about 3 to 3.5 days if BLE module is in TX/RX mode continuously. A commercially available solar panel can be integrated into the existing rechargeable battery system to power the BLE tags.

**Potential Impact**

The objective of this study is to investigate the feasibility of using inexpensive Bluetooth low energy technology to trigger in-vehicle messages for motorists in work zones. We believe the proposed approach could establish an alternative to automatic speed enforcement to change behaviour in work zones by providing dynamic work zone information. The research findings of this study will help to understand the communication performance (latency, scanning rate, power consumption, etc.) of long-range BLE tags in a work zone. Based on the proposed approach, the experiment results indicated that communication between a smartphone and BLE tags at high speed is feasible. It is anticipated that this project will provide guidelines for engineers and operational staff to determine the placement of tagged landmarks at work zones for triggering in-vehicle messages. The app can potentially be integrated with a 511 system or other navigation apps to dynamically receive relevant work zone information.

**Summary and Ongoing Work**

We have developed a Bluetooth Low Energy (BLE) system that can be placed in a work zone or at key locations to provide in-vehicle warning messages to a driver. A smartphone app was developed to perform Bluetooth scanning and announce corresponding message with a Bluetooth tag when it is detected. A continuous Bluetooth scan is initiated when a vehicle enters a geo-fenced work zone. Current messages attached to each BLE tag were selected for functional testing only. The final message structure and content will be determined from the results of a human factors study.

In addition, another smartphone app was developed for work zone deployment contractors to request message updates. This approach allows work zone staff to easily reconfigure any changes in a work zone by submitting message update through the smartphone app. After receiving message update request, engineers or staff who manage the work zone operation can update the audible messages in a timely manner.

The current system demonstrated that it is capable of providing in-vehicle messages for motorists approaching a work zone using the Bluetooth low energy technology. Our experiment results indicated that communication between a smartphone and BLE tags at high speed is feasible. Our future effort will focus on validation of the proposed system in a real work zone environment under different traffic conditions.
Using Bluetooth Low Energy Technology to Trigger In-Vehicle Messages at Work Zones

Acknowledgement
The authors would like to thank the Roadway Safety Institute (RSI) at the University of Minnesota (UMN) and the Minnesota Department of Transportation (MnDOT) for supporting this project. The RSI is the University Transportation Center (UTC) for the United States Department of Transportation (USDOT) Region 5, which includes Minnesota, Illinois, Indiana, Michigan, Ohio, and Wisconsin. Financial support from RSI was provided by the USDOT administered through the Office of the Assistant Secretary for Research and Technology (OST–R).

References


