Towards a Connected Bicycle to Communicate with Vehicles and Infrastructure

Multimodel Alerting Interface with Networked Short-Range Transmissions (MAIN-ST)

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***Abstract*—The Connected Vehicles program is a multimodal US Department of Transportation (USDOT) initiative that enables safer, smarter, and greener surface transportation using dedicated wireless communication technology. Although significant efforts are being made to bring motor vehicles and transportation infrastructure onto this connected network, bicycles have been largely overlooked. Bringing cyclists onto this network will enable other connected vehicles and infrastructure to be aware of their presence, and allow cyclists to take advantage of the safety and transportation benefits of receiving information from other connected entities. To connect bicycles, we are designing a prototype Multimodal Alerting Interface with Networked Short-Range Transmissions (MAIN-ST). MAIN-ST brings cyclists onto the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) networks to enable a suite of safe cycling capabilities. This paper describes our progress accomplished over a 6-month period, and documents the feasibility of the MAIN-ST technology approach.**

Keywords*— *Connected Vehicles; Connected Infrastructure; Bicycles; Vehicle-to-vehicle; Vehicle-to-infrastructure

I. Introdoction

As of 2012, over 48% of bicycle trips were taken on paved roads vs. sidewalks (13.6%), bicycle paths (13.1%), or dedicated bicycle lanes (5.2%) [1]. These shared roadway trips resulted in 743 cyclist fatalities and an estimated 48,000 injured in 2013 as a result of bicycle-motor vehicle accidents; 68% of these incidents occurred in urban settings. Although advances in technologies such as object detection [2], lane recognition [3], and collision detection and avoidance [4] are helping motorists better detect and react to cyclists on shared roadways, these systems may not warn motorists or respond early enough to prevent an accident, and may fail altogether if the cyclist is hidden from these systems' vision-based sensors due to obstructions or inclement weather.

Significant R&D has been conducted into vehicle V2V and V2I communications, collectively V2X. The USDOT recently proposed a rule that mandates V2V communications in all new light-duty vehicles to enable crash-avoidant technologies [5]. Currently, dedicated short-range communications (DSRC) for wireless access in vehicular environments (WAVE) is the only way to provide V2X communications with high reliability and low latency. DSRC WAVE can provide basic safety messages (BSM) to help support vehicle safety [6], but the collision-avoidant vision-based technologies are not available for cyclists, bicycles are not on the DSRC WAVE networks, and the current DSRC BSM message set supports only limited bicycle-specific capabilities (e.g., bike lane localization) [7].

This paper describes an ongoing USDOT FWHA-funded effort to overcome these limitations by developing a connected bicycle solution—Multimodal Alerting Interface with Networked Short-Range Transmissions (MAIN-ST). MAIN-ST aims to provide cyclists with a low cost DSRC WAVE solution that significantly advances bicycle (and motor vehicle) safety by providing cyclists with enhanced hazard awareness. It delivers early warnings in a format that helps a cyclist apply safe cycling techniques in hazardous situations.

II. Approach

Figure 1 shows the MAIN-ST system architecture. The Application Framework is MAIN-ST's core. It integrates a commercially available DSRC radio linked to the framework via a custom API. Within the framework, this API acquires BSM data on other connected entities. This data is the primary input for a suite of features, including hazard reporting and safe route planning. The Hazard Assessment Engine uses the data to detect potential hazards using custom, proximity-based algorithms and models of cycling hazards. When hazards are identified, they are passed to an alerting queue, where alerting priorities determine which alert type and modalities should be used to deliver the alert via the Multimodal Alerting Symbology. The framework can be packaged for deployment on any hardware platform—we have developed an Android smartphone app, and are currently deploying an embeddable Raspberry Pi module.

A. DSRC]API

We developed API components that enable a smartphone app to send and receive BSMs on the DSRC WAVE network using a DSRC radio. We used Arada System's Libwave software library to create a generic interface that supports message sourcing, compiling, transmission queuing, and message receipt, decryption, and parsing for the API. We used

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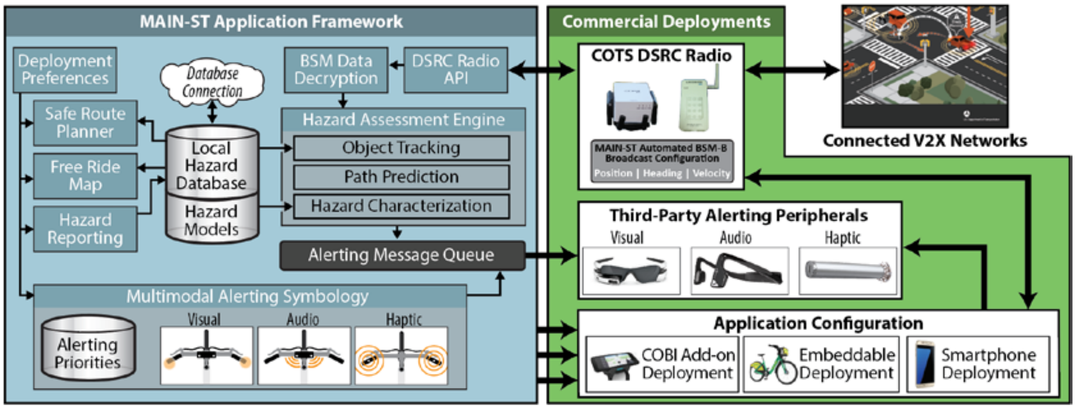

Fig. 1 MAIN-ST system architecture

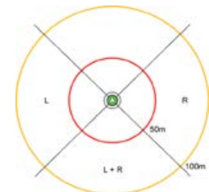

Fig. 2 Hazard proximity range and alerting pattern. Different alerts were generated when hazard entities breeched the various zones surrounding the cyclists.

the Arada System's LocoMate Mini radio hardware to broadcast and receive BSMs from other connected vehicles and infrastructure.

B. *Hazard Assessment Engine*

Once BSM data has been collected and decrypted via the API protocols, MAIN-ST assesses the potential for hazards based on this data to provide timely notifications, warnings, and alerts from V2X networks. Our prototype Hazard Assessment Engine geospatially maps BSM message sources and treats them as hazards, since colliding with any transmitting entity can cause a cycling accident. Once an entity is within a specified warning distance, its position is calculated relative to the position and heading of the bicyclist and trigger the appropriate alert. Figure 2 shows how we designed alerting distances. The outer ring is a warning threshold, and the inner ring is a hazard threshold. This proximity-based hazard identifier tracks the position of connected entities. Figure 3 shows the cyclist's location (in green) and an approaching entity (in red). To complement the V2X hazard source, MAIN-ST uses a crowd-sourced Hazard Database, accessed through Amazon Web Services. Using a voice command, a cyclist can report a hazard (such as a pothole or construction work), which is then saved to the database to provide hazard alerts to other cyclists. Crowd-sourced hazards are placed with GPS location information and are used to calculate safe routes with the Safe Route Planner.

C. *Multimodal Cyclist Alerting Symbology*

Presenting hazard information to cyclists without distracting them from a potentially hazardous situation is paramount to the success and safety of a connected vehicle system. Unlike automotive solutions that can provide control inputs (e.g., automatic braking), it is not feasible to introduce these capabilities on a bicycle. Bicycles are also limited because they do not have dashboards or speakers to serve as information displays.

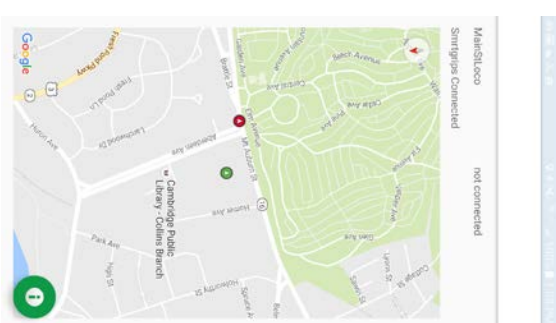

Fig. 3 Preliminary MAIN-ST application screen

To create a safe cyclist alerting symbology, we first characterized the hazards encountered by cyclists operating on public roadways, bike paths, or other shared infrastructure. We then sent surveys to safe cycling instructors available through our partnerships with MassBike and the League of American Bicyclists, and compiled the results to create five, high-level hazard categories (Figure 4) based on the appropriate response to a hazard. Hazards are first classified as collisions or hazards, and range in response severity from awareness to immediate action required to avoid collision. A standard symbology was developed of audio and haptic alerts based on empirical evidence of the efficacy of alerts using these modalities for similar transportation applications (e.g., aviation cockpit alerting standards). We intentionally excluded visual alerts because the only visual display available to cyclists is their smartphone, which requires risky, heads-down cycling to view information. By varying signal durations, frequency, intensity, and other parameters, MAIN-ST provides a unique vocabulary of distinguishable audio and haptic symbols that cyclists can learn (similar to smartphones' different vibrations for email and text messages). Haptic and audio alerting were tested using a smartphone speaker to deliver audio alerts and Boreal Bikes' haptic smrtGRiPs to provide tactile feedback.

III. Preliminary Results

A. *Informal Lab Testing*

During the prototyping process, we conducted frequent, informal tests to determine the feasibility of our approach. Our testing focused on the reliability and accuracy of our DSRC messages and GPS devices. We identified the Arada LocoMate Mini and ME as the DSRC radios to demonstrate the feasibility of our MAIN-ST approach. We connected the

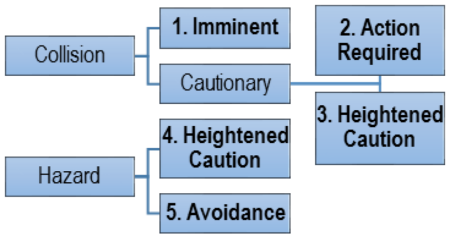

Fig. 4 High-level cycling hazard categories

Arada devices to a smartphone application over Bluetooth and parsed the DSRC messages to confirm that our devices were both sending and receiving DSRC messages correctly. Informal testing was promising and showed that our application was feasible, but highlighted some concerns with the reliability of the Arada devices' internal GPS modules. To augment our smartphone efforts, we also created a custom MAIN-ST prototype using a Raspberry Pi with a GPS module. Based on several test trips by train, we reviewed the recorded position and position error values reported by the GPS module. GPS was frequently accurate to within 3-4 meters despite an average reported error of 17.5 meters. The hazard detection was accurate (with an alert at 10m) on our custom embedded solution using static hazards in a parking lot.

B. Informal Road Test

We performed an informal road test to evaluate the ability of the DSRC radio to acquire and transmit BSM high priority elements (location, speed, and heading) in a real-world setting with the MAIN-ST system. To support this event, we equipped a ride-share bicycle with the MAIN-ST system, a ground truth GPS device (Garmin Backtrack), a decibel meter to record ambient sound (to support alert design), a video camera, and a smartphone running MAIN-ST. The goals of this informal testing were to evaluate the accuracy of the Locomate's GPS, heading, and course estimates; evaluate the performance of the MAIN-ST hazard reporting system; acquire ambient noise readings as a reference for the alerting symbology; ensure BSM broadcasts were being transmitted at acceptable rates; and test the DSRC radio mounts.

C. Live Test Event at USDOT Connected Road Test Site

In November 2016, we conducted a live test of the MAIN-ST prototype at the USDOT Connected Road Test Site at the Turner-Fairbank Highway Research Center (TFHRC), a facility that includes static DSRC transmitters and a connected vehicles test fleet. Our live test consisted of four scenarios: (1) the cyclist rode through a connected intersection with no hazards to demonstrate BSM transmission and reception; (2) the cyclist rode on a path for a perpendicular collision with an approaching vehicle; (3) the cyclist traveled while a vehicle overtook the cyclist on the left; (4) the cyclist approached a reported pothole. Scenarios 1-3 were intended to highlight the feasibility of the DSRC component of the MAIN-ST solution, while Scenario 4 was designed to demonstrate the crowd-sourced hazard reporting feature of the smartphone app.

The results of this test were promising for MAIN-ST's situation awareness features, but highlighted some technical weaknesses. Because it was difficult to maintain a stable GPS signal with the Arada devices and we could not reliably pinpoint the connected vehicle's location, alerts were triggered at incorrect locations. The DSRC radio transmitter also encountered errors (e.g., resolving and maintaining accurate position), which prevented it from transmitting correct locations to our mobile devices. We expect DSRC technologies to improve as the DSRC standard is adopted. Our live test provided promising results; MAIN-ST consistently provided warnings through auditory, visual, and haptic modes for stationary hazards and cyclist alerts.

IV. Conclusions and Next Steps

This paper describes the approach and preliminary results of our effort to bring a bicycle onto a connected vehicle network and provide novel safety features using this connectivity. The work performed to date demonstrates the feasibility of accomplishing this goal. The next steps are to refine the system design and conduct pilot testing to evaluate system functionality (e.g., whether the DSRC radio can perform in an urban environment during valid riding conditions) and system usability (e.g., whether the alerts facilitate safer cycling decisions). We will develop a full-scope MAIN-ST system that can be embedded within a bicycle frame. We will also perform pilot testing in a target urban environment by collecting logs of transmitted and received data and comparing them to ground truth. (The cyclist will not be affected by this testing.) Usability assessments will be conducted in a controlled riding environment to validate MAIN-ST's alerting symbology, which notifies cyclists of potential hazards and hazardous situations.

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