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An on-road evaluation of connected motorcycle crash warning interface with different motorcycle types

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ABSTRACT

Crash warning systems have been deployed in the high-end vehicle market segment for some time and are trickling down to additional motor vehicle industry segments each year. The motorcycle segment, however, has no deployed crash warning system to date. With the active development of next generation crash warning systems based on connected vehicle technologies, this study explored possible interface designs for motorcycle crash warning systems and evaluated their rider acceptance and effectiveness in a connected vehicle context. Four prototype warning interface displays covering three warning mode alternatives (auditory, visual, and haptic) were designed and developed for motorcycles. They were tested on-road with three connected vehicle safety applications - intersection movement assist, forward collision warning, and lane departure warning - which were selected according to the most impactful crash types identified for motorcycles. Combined auditory and haptic displays showed considerable promise for implementation. Auditory display is easily implemented given the adoption rate of in-helmet auditory systems. Its weakness of presenting directional information in this study may be remedied by using simple speech or with the help of haptic design, which performed well at providing such information and was also found to be attractive to riders. The findings revealed both opportunities and challenges of visual displays for motorcycle crash warning systems. More importantly, differences among riders of three major motorcycle types (cruiser, sport, and touring) in terms of rider acceptance of a motorcycle crash warning system were revealed. Based on the results, recommendations were provided for an appropriate crash warning interface design for motorcycles and riders in a connected vehicle environment.

1. Introduction

A crash warning system (CWS) is an automobile safety system designed to reduce the frequency or severity of automobile crashes by detecting imminent crashes using various sensors and/or machine vision and delivering timely warnings to users. As a result of the warning, users are able to respond quickly to potential threats, permitting sufficient time to execute evasive maneuvers and avoid crashes. There are various systems for mitigating different crash types: forward collision warning (FCW), lane change warning (LCW), intersection movement assist (IMA), etc. Built on a foundation of robust research and development conducted over the last couple of decades, CWSs are now deployed within the high-end vehicle market and

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are steadily spreading to additional motor vehicle industry segments each year. However, there is much less research on these systems for application to motorcycles and no systems have been released in the motorcycle market to date.

Traditional CWSs are based on relatively costly sensors such as RADAR, LIDAR, and camera with machine vision support to monitor objects on the roadway and, usually, multiple systems are needed to cover various directions for different crash types or to function effectively during all weather conditions. Today, CWSs based on Connected Vehicle Technologies (CVT) are being actively developed. By utilizing dedicated short-range communications (DSRC), which are fast, secure, and reliable, connected vehicles ranging from cars to trucks and buses to motorcycles would be able to talk to each other (vehicle-to-vehicle communication [V2V]) and to different types of roadway infrastructure (vehicle-to-infrastructure communication [V2I]), continuously sharing important safety and mobility information (Fact Sheet). CWS will likely be among the first applications deployed that capitalize on the advantages of both V2V and V2I communications. By continuously monitoring and sharing information with surrounding traffic and infrastructure, one connected vehicle system could potentially prevent numerous types of crashes. CVTs provide expanded capabilities with all-weather 360-degree coverage, are small, lightweight, and inexpensive relative to traditional sensors, thus making them attractive for application to motorcycles.

As with any system, there are a number of objectives that must be met for successful implementation. A CWS interface must rapidly direct attention to the pertinent threat. The interface must also avoid unintended consequences, and be acceptable (if not desirable) to the target user. To balance these goals, it is then important to conduct evaluations and collect responses and feedback from end users. By nature, CWS studies should aim to put participants in crash or near-crash situations. Indeed, researchers often develop safe protocols (e.g. passenger side brakes, soft targets, bailout procedures, etc.) for conducting CWS experiments in passenger vehicles. However, many of the traditional safety assurance techniques cannot be applied to motorcycles and the rider is at a higher risk of injury should a crash inadvertently occur.

Thus, most previous CWS motorcycle studies were conducted in simulated environments where risk was well controlled. However, compared to other drivers, motorcycle riders are riding in a relatively exposed and dynamic environment where motorcycle noise, wind impacts, vibration, etc. are present, which increases the difficulties of reproducing a realistic riding environment in a simulator. This study was designed to evaluate a prototype motorcycle crash warning interface (CWI) and collect measures of user acceptance and input within realistic on-road riding scenarios in a connected vehicle environment.

2. Background

2.1. Motorcycle crash types

Motorcyclists are among the most vulnerable road-user groups. Per vehicle mile traveled in 2012, motorcyclists were over 26 times more likely than passenger car occupants to die in motor vehicle traffic crashes and 5 times more likely to be injured (National Center for Statistics and Analysis, 2014). Although motorcycles made up only 3% of all registered vehicles in the U.S. in 2012, they accounted for 15% of all traffic fatalities and 18% of all occupant fatalities.

The most common motorcycle accidents are single-vehicle accidents, and crashes where another vehicle violates the motorcycle's right-of-way (ROW) at an intersection (Hurt et al., 1981; Molinero et al., 2008; ACEM, 2004). The motorcycle ROW violation crashes indicate a motorcycle conspicuity problem in both daytime and nighttime conditions (Hurt et al., 1984) that leads to poor speed-spacing judgment and detection failure (also called "looked but failed to see" error (Hills, 1980; Herslund and Jørgensen, 2003). This may be because motorists rely on visual cues to judge the speed and space of approaching traffic as part of their judgment in accepting gaps to cross the intersections, and due to the insufficient frontal surfaces of motorcycles, the visual cue for motorists is sometimes too weak to detect or use to adequately judge the speed and space-gap of motorcycles (Pai, 2011). Rear-end and side-side crashes are the next most frequent crash types (Molinero et al., 2008; Clarke et al., 2004). The latter may be related to overtaking behaviors some riders are more likely to perform (Clarke et al., 2004). Among motorcyclist fatal crashes in which the motorcycle collided with other motor vehicles in transport, almost 90% are two-vehicle crashes and in 75% of two-vehicle crashes, motorcycles collided with the vehicles in front of them (National Center for Statistics and Analysis, 2014).

It was found that in many cases, a rider did not have time to complete crash-avoidance maneuver (Biral et al., 2010). This suggests that warning riders of a potential threat ahead of time would help them complete evasive maneuvers and thus avoid crashes. Therefore, it is reasonable to believe that motorcyclists could benefit greatly from CWSs (or applications in a CVT-based CWS) such as FCW, LCW, and IMA.

2.2. Warning modalities on motorcycles

Many CWS studies exist, but the majority pertain to the automotive domain (Fancher et al., 2001; Horowitz and Dingus, 1992; LeBlanc et al., 2006). Due to differences between four-wheel vehicles and motorcycles, and the lack of relevant studies for the latter, this study focused on the development and evaluation of a prototype CWI specifically for motorcycles and riders.

A SAFERIDER project was recently implemented in the EU, and some traditional crash warning systems for motorcycles were studied (Biral et al., 2010; Huth et al., 2012; Pieve et al., 2009). The SAFERIDER project aims at introducing advanced driver assistance systems specifically designed for motorcycles, called Advanced Rider Assistance Systems (ARAS). The pro-