Modelling longitudinal and lateral spacing between motorcycles and other vehicles with the purpose of Advanced Rider Assist Systems (ARAS) development

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Abstract

Advanced Driver Assist Systems (ADAS) use has spread considerably in the recent years. These systems promise a safer and more comfortable commute to drivers. Examples of such systems include Automatic Emergency Braking (AEB), Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA) [1][2]. In recent years, interest in Advanced Rider Assist Systems (ARAS) for motorcycles has risen. Certain safety systems, such as ABS, are already in production by motorcycle makers. In addition, limited research has been performed into ARAS systems such as frontal collision warning [3]. Nevertheless, ARAS in general is still an untapped field holding potential for improving motorcycle riders’ safety and comfort. ARAS design varies significantly from ADAS design due to differences in passenger vehicles dynamics compared to motorcycles as well as driver’s vs. rider’s perception. This paper investigates the following and passing behavior of passenger vehicles from motorcycle perspective and the vice versa. Results of this study includes longitudinal and lateral spacing between various types of motorcycles and passenger vehicles at a steady following state. Such spacing is assumed to describe the comfortable driving behavior of motorcycle riders and passenger vehicle drivers. This data can then be used to make conclusions on the comfortable design of ARAS systems.

I. Introduction

In 2017, 37133 fatalities were recorded by National Highway Traffic Safety Administration (NHTSA). Motorcyclist fatalities constitute a 14% of the total number of fatalities [4]. It can be observed that this percentage has been steady in the range of 12.5% to 14.7% for the past ten years regardless of the fluctuations in the total number of fatalities [5]. A common agreement in automotive and ITS industry is that passive/active safety systems and ADAS improve the drivers’ safety [6], while driver distraction and the increase of the number of vehicles on the road may lead to an increase in the number of motor vehicles crashes and fatalities. Such systems have been increasingly ubiquitous in cars and trucks. These systems have the potential to enhance motorcycle riders’ safety and comfort. Nevertheless, to date, safety and driver assist systems implementations in motorcycles are very limited.

Traffic modelling is usually attained through macroscopic or microscopic modelling. Macroscopic modelling describes traffic in roadways as a whole using fluid dynamics. Evidently, such method has very limited capability in aiding the design of ARAS and investigating its benefits. Microscopic traffic modelling aims to describe the interactions between individual vehicles using car following and lane changing models [7]. This type of traffic modelling is a promising tool for simulating and describing the behavior of ARAS. Nevertheless, such modelling is generally focused on maintaining particular time gaps between vehicles, that can be described as random variable using certain distributions, when performing car following and lane change maneuvers. While such modelling is very useful to simulate the traffic trends and understand effects of ADAS/ARAS on the general traffic, one cannot use these models to obtain drivers and riders headway and time gap preferences at different driving/riding conditions with the
purpose of ARAS design. In addition, majority of these models do not describe the in-lane movement of vehicles when passing other traffic. This type of movement may prove useful when designing ARAS systems. As such, a need arises for a method to investigate motorcycles and vehicles interaction with the focus of drivers comfort and spacing preferences.

Limited research can be found focusing on the following and passing behavior as well as in-lane movement behavior of motorcycles based on naturalistic data. Amini et. al. applied a data set collected from a 45 minutes video recording spread into 3 days (15 minutes per day) at an urban freeway in Tehran, Iran to a GHR (Gazis-Herman-Rothery) model [8]. The aforementioned paper mainly investigates the passenger vehicles’ behavioral change when following a motorcycle. It is observed that passenger vehicles drive more cautiously with increased headway and lower acceleration values when following a motorcycle. Authors in [9] developed an adaptive neuro-inference system (ANFIS) motorcycle following model and compared it to the motorcycle following models in a traditional stimulus-response type model by General Motors (GM). The ANFIS based model proved to be superior. Work in [10] was the first to develop a heterogeneous vehicle movement model using Cellular Automata. A three hours, 30 meters, data collected from a Taipei urban street was used in this paper and an assumption of no lanes to guide the traffic was made when developing the models. An exclusively time-based analytical car following model has been developed in [11] accounting for motorcycles. This study uses US 101 NGSIM data base, constituting a 45 minutes of data collection on 640 meters of an Urban freeway, to validate the resulting model [12].

To the best of the author knowledge, no comprehensive naturalistic study has been performed to evaluate the following and passing behavior of motorcycle from both the motorcyclist and the passenger vehicle driver perspective. In addition, the previous research investigated motorcycles as one type and did not look at the different in behavior between different motorcycle types.

The goal of this paper is to investigate comfortable spacing, while traveling at different speeds, from both the motorcyclist’s perspective and the other vehicle driver’s perspective with the aim of future ARAS development. The contributions of this paper are twofold:

1) Characterizing motorcycles to car spacing at various speeds has been performed. This includes motorcycle to car following distance for different motorcycle types compared to car to car following distance. In addition, car to motorcycle following distance has been investigated.

2) Characterizing lateral spacing between motorcycles and other vehicles. This entails an investigation of motorcyclist in-lane maneuver when passing a car and the vice versa.

This research describes comfortable spacing, while traveling at different speeds, from both the motorcyclist’s perspective and the other vehicle driver’s perspective. Both pre-existing and newly collected data were used in this study. Data from naturalistic riding studies were used to measure the comfortable spacing exhibited by motorcycle riders, while a new data collection will be used to determine comfortable lateral and longitudinal spacing demonstrated by drivers of other vehicles.

The reminder of this paper is organized as follows. Section II details the methodology for data collection and processing. Section III describes the results obtained in this study including a discussion of the results implication on future ARAS functions. Section IV provides concluding remarks and potential future research.

II. Methodology

This section describes the existing data that has been used in this study as well as the newly collected data. Details of the collection method, location and post processing are presented.

A. Existing data sources

Two existing databases were used in this work:

1) The Strategic Highway Research Program 2 (SHRP2) naturalistic study by Virginia Tech Transportation Institute (VTTI) [13]: The data from this study was used to obtain the car to car following behavior. A total of 3542 drivers were recruited for SHRP2 at 6 different location in the U.S. (Seattle, WA; Bloomington, IN; Buffalo, NY; State College, PA; Durham, NC; and Tampa FL) resulting in over 32 million miles/1 million hours of naturalistic driving data. The vehicles involved in this study included cars, trucks and SUVs and they were instrumented with forward facing radar as well as forward, backward and driver facing cameras. Data collected included the aforementioned sensors measurements as well as continuous recording of the vehicles’ position, speed, acceleration, steering and brake status.

2) The Motorcycle Safety Foundation (MSF) naturalistic data study by Virginia Tech Transportation Institute (VTTI) [14]: The data from this study was used to obtain the motorcycle to car following distance and passing
behavior. This data collection campaign comprised 260 participants in 42 different U.S. states resulting in over 760000 miles of riding data. Participants' age range was between 21 and 79 years old. An important factor of this study, apart from the scale, is the diversity of motorcycle types that were chosen for the data collection. Three different motorcycle types were used in this study: sport, touring and cruising with engine sizes ranging from 250 cc to 1800 cc. The motorcycles were equipped with a number of sensors including machine vision lane tracker, accelerometer, gyro, forward radar, five cameras and a GPS receiver. See Error! Reference source not found. for an example of MSF equipped motorcycle.

Fig. 1. Example of equipped motorcycle in the MSF study.

B. New data collection

The previously mentioned existing databases are suitable for studying the car to car following behavior and the motorcycle to car following behavior. Nevertheless, they fall short in term of detecting car to motorcycle following distance as the motorcycles in the MSF study were not equipped with a rear range sensor. As such, a new data collection campaign was conducted in this project.

A Honda Goldwing motorcycle was used for this project. The motorcycle was equipped with a video lane tracker for lane position, full trip video data from 5 cameras, IMU, GPS and five radars (1 forward facing SMS radar with 300 meters range and 4 Continental corner radar units with 95 meters range). The radar units mounted on the motorcycle provide 360 degrees of coverage around the motorcycle. This allows the tracking of other vehicles as they overtake or are overtaken by the motorcycle. The radar, in combination with the instrumented motorcycles lane position, can be used to measure comfortable spacing selected by drivers of cars adjacent to a motorcycle. See Error! Reference source not found. These sensors are used to detect vehicles behind the motorcycle, report their longitudinal and lateral distance and track them through steady state following and passing maneuvers.

Fig. 2. Instrumented motorcycle for data collection
The motorcycle is ridden in the conditions of interest (highways at different speeds) and the collected data was analyzed to describe comfortable spacing. Approximately, 43 hours of data was collected at both urban and rural freeways in the states of Virginia and Maryland. Error! Reference source not found. provides more details of the data collection locations while Table 1 summarizes the data collection characteristics.

![Image of data collection locations](image)

**Table 1: Summary of new collected data**

<table>
<thead>
<tr>
<th>Region</th>
<th>Status</th>
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| Urban Data Collection | • 25 Hours of Data Collection  
• 2,3 and 3+ lane roadways  
• Left and Right travel lanes  
• Different traffic densities  
• Northern Virginia and Maryland |
| Rural Data Collection | • 18 hours of Data Collection  
• 2,3 and 3+ lane roadways  
• Left and Right travel lanes  
• Different traffic densities  
• Virginia |

C. Data processing

This section describes the data processing methods employed to obtain the longitudinal and lateral spacing between vehicles of interest. Notably, the same methods was used for processing both existing and newly collected data, unless otherwise mentioned in this section.

**Longitudinal spacing**

The goals of this data processing activity is twofold: 1) Identify comfortable spacing between cars when following a lead vehicle (car to car); 2) Identify comfortable spacing between motorcycles and passenger vehicles (car to motorcycle and motorcycle to car). The longitudinal spacing selected by the motorcycle rider, or the car driver, were measured using the forward mounted radar in the existing data or the 360 degrees radar system in the new data. Then, these measures were summarized to provide an average spacing for each epoch of interest in the data. In addition to the base measure of spatial distance, some measures that include relative speed and headway are also explored to potentially assist in explaining the distance based measures.

To achieve this task, epoch of interest with the following restrictions were chosen:

- Motorcycle or a car traveling in a lane for a particular length of time
- Following a Lead Vehicle for a particular length of time
- Controlled access roadway
- Straight roadway segments

First, a steady following state is identified by detecting both the following vehicle approach to the leading vehicle and the following state termination. The range time series in-between is considered to be the steady state following. See Fig. 4. Second, the steady state following is subdivided into multiple fixed length, 60 seconds, segments to be able to obtain stable following distance statistics. This method of steady state vehicle following detection adheres to [15]. Third, as illustrated in Fig. 5, vehicle following measures are calculated form the segments including minimum
and mean following distance, minimum and mean headway, and speed.

**Fig. 4. Steady state following**

**Fig. 5. Epochs segmentation and selection**

**Lateral spacing**
The goal of this activity is to identify any adjustments in lane position that occur when a motorcycle passes a car or the vice versa, see Fig. 6. These adjustments are likely preformed based for the comfort of the passing vehicle rider or driver.

**Fig. 6. Example of lane position adjustment during an overtaking maneuver**

An onboard machine vision lane tracker will provide information on the lane width and lateral position of the motorcyclist in the lane. Changes in this lane position as the motorcyclist overtakes other vehicles was be measured to show how the motorcyclists are adjusting lateral spacing due to the influence of the other vehicle.

To achieve the goal of tracking the target vehicle in the adjacent lane, a motion model was implemented to track the vehicle being passed. While the target vehicle is within the front radar field of view, the radar measured speed,
lateral distance and longitudinal distance are used. Whenever the target vehicle leaves the radar field of view, the target vehicle’s speed and location in its own lane are held constant. However, its longitudinal position is propagated assuming a constant speed model using (1):

\[ x_t = \int v \, dt + x \]  

(1)

Where; \( x_t \) is the position at time \( t \), \( v \) is the last observed speed and \( x \) is the last observed longitudinal position.

Notably, this motion model pertains only to the exiting data, being used to calculate the spacing from the motorcyclist point of view. For the new data collection, being used to calculate the spacing from the driver point of view, the motorcycle is equipped with five radars providing a 360 degrees field of view. As such, real-time measurements are reported during the maneuver of a vehicle passing the equipped motorcycle.

III. Results

This section conveys the results observed in this study as well as a discussion on their potential impacts on ARAS design. The results are divided into longitudinal and lateral spacing and then further segmented into motorcycle rider perspective and car driver perspective.

A. Longitudinal spacing

Headway from the perspective of motorcycle rider was measured and compared to the car to car following distance. Fig. 7 (a) depicts the mean following distance as detected from the steady state epochs. The headways of cruiser and touring motorcycle types are slightly smaller than that of the car. However, the sport type motorcycle headway is considerably smaller than the car headway, up to 30% in certain cases. This may be attributed to several reasons including: 1) a more responsive control in the sports motorcycle; 2) “sporty” riding style of this motorcycle type riders; and 3) riding posture of the sports bike which provides a better ground view in front of the motorcycle compared to the other motorcycle types. Fig. 7 (b) shows the minimum time headway for the same types of vehicles. The minimum headway follows a similar trend to the mean. However, it can be seen that the minimum headway drops to risky levels, sometimes reaching below 0.5 seconds at 75 mph for sport motorcycles. Notably, this is a steady state following condition, and not passing or slowing condition, emphasizing the need for certain ARAS features to improve the safety and provide assistive maneuvers in case of an emergency and/or providing the rider with an advisory of the following headway during the steady state riding condition.

It can also be observed that the headway decreases with distance speed for all vehicle types being investigated. This may seem counter intuitive at first. Nevertheless, drivers, and riders as can be observed in this study, perceive distance rather than time during the following maneuver. As such, they tend to maintain a relatively constant distance regardless of the speed when driving/riding on freeways in a steady following state. This can be observed in Fig. 8 (a) and (b) showing the mean and minimum following distance respectively.

From an ARAS design point of view, the aforementioned results highlight the usefulness of ARAS systems with varying performance based on the motorcycle type. In addition, motorcycle rider generally seem to accept shorter headways compared to car drivers which may be an influencing factor in certain ARAS features design (such as ACC systems). However, further evaluation needs to be performed from safety perspective to understand the impact of shorter headways compared to car ACC.

![Fig. 7 Comparison between car to car and motorcycle to car time headway vs. speed (a) Mean (b) Minimum](image_url)
Fig. 8 Comparison between car to car and motorcycle to car following distance vs. speed (a) Mean (b) Minimum

Fig. 9 and Fig. 10 show the car to motorcycle mean time headway and mean following distance respectively. As depicted in these figures, the car to motorcycle mean headway and following distance follows the same trend of decreasing time headway with increasing speed. However, in comparison to the car to car and motorcycle to car time headway, car drivers seem to keep a higher time headway. This indicates a more conservative behavior observed from passenger vehicle drivers when following motorcycles, compared to all other combinations. Interestingly, the discrepancy between the car to motorcycle time headway and that of the other combinations vanishes at higher speeds.

Fig. 9 Comparison between car to motorcycle to other combinations mean time headway vs. speed
B. Lateral spacing

This subsection presents the lateral spacing results from both the motorcycle rider and the car driver perspective. Fig. 11 shows the motorcycle change in lane position when overtaking, or being overtaken by, a vehicle. It can be observed that, as a trend, motorcycles shift in lane away from the vehicle by an average of approximately 7 centimeters. Clearly, such a change in lane position is minor.

To further investigate this result, the change in lane position as a function of motorcycle initial position in lane and the relative velocity between the car and the motorcycle were plotted. Fig. 12 shows the lane position of motorcycle when passing a vehicle, segmented in three initial lane position corresponding to the lane’s right, center and left thirds. The riders in the third closer to vehicle being passed exhibit the highest shift in lane position with average values of up to 19 centimeter. The other two thirds demonstrate a lower shift in lane position.

Fig. 13 shows the passing maneuver, divided by relative speed between the motorcycle and the car: 1) negative values indicate cases when the motorcycle is faster that the car and this it is the one performing the passing maneuver; 2) positive values indicate cases when the motorcycle is slower than the car and it is being overtaken. It can be observed that the motorcycle shifts its lane position in cases where it is overtaking a car. However, it generally does not exhibit a similar behavior when being overtaken by a car. The lateral spacing results from the motorcycle rider perspective demonstrate that the motorcycle riders are more comfortable in moving away from the car during a passing maneuver. This is especially the case when the motorcycle speed is much higher than the car’s speed and when the motorcycle is closer to the car being passed.

The impact of such result on ARAS may be limited given that the shift in lane position is relatively small.
Nevertheless, it may be taken into account when designing a lane keeping systems for motorcycles. It is noteworthy that the design of such system comes with its own set of challenges given the vast difference between cars and motorcycles dynamics and the effect of the rider body movement on the motorcycle lateral motion.

![Lateral Spacing: Motorcycle Passing Cars](image1.png)

**Fig. 12** Lateral spacing during the passing maneuver divided by the motorcycle initial position in lane.

![Lateral Spacing: Motorcycle Passing Cars](image2.png)

**Fig. 13**. Lateral spacing during the passing maneuver divided by relative speed between the motorcycle and the car.

The authors did not observe a change in car’s lane position when passing a motorcycle.

**IV. Conclusion**

In this paper, we presented a study evaluating the car to motorcycle, and motorcycle to car, longitudinal and lateral spacing. This investigation was performed using naturalistic data in which motorcycles and cars equipped with various sensors where used. The results demonstrated a shared trend between motorcycle and cars of shorter time headways with increased speed during steady state following. However, motorcycle where observed to follow vehicles at shorter time headways compared to cars. This difference was more pronounced for sport motorcycles type. With respect to lateral spacing, the motorcycles tends to shift their position in lane when passing a car, moving away from the car. Nonetheless, the shift in lane position is small. A discussion on the impact of this study’s results on ARAS design was provided as well. Potential future work includes researching the potential safety implication of certain following behaviors identified in this work and the possible ARAS features that may mitigate such safety concerns.

**References**

