Project: Driver behavior and active safety systems in critical rear-end situations

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Introduction

The focus of this project is on a specific type of safety-critical situation called a rear-end collision. A rear-end collision occurs when a vehicle hits another vehicle from behind. This crash type, often caused by an inattentive or distracted driver, is one of the most frequently occurring world wide. Active safety systems that can warn the driver or autonomously brake the vehicle have been developed to avoid or reduce injuries and fatalities from these crashes. In this project you will 1) analyze the kinematics of a rear-end situation, 2) process and use experimental data to understand drivers' braking behavior in a critical rear-end situation, and 3) use the gained knowledge to propose a forward collision warning (FCW) and an autonomous emergency braking (AEB) system. The results need to be discussed and presented in a final report.

Learning Objectives

By the end of this project, the students should be able to:

- Use the equations of motion to predict collision outcome in a longitudinal rear-end scenario
- Process and use experimental data to describe driver braking behavior in a critical rear-end situation
- Develop simple threat-assessment and decision-making algorithms for active safety systems in MATLAB
- Put the results in a bigger context by discussing 1) driver behavior and 2) how the implemented algorithms might be limited in real traffic scenarios

Resources

All the data and documents are to be found on the course's Canvas page. The following table describes the available resources. The file `RadarData.mat` contains a structure containing the data collected from a test-track experiment.

1 A hypothetical rear-end conflict situation *(11 points)*

To illustrate a hypothetical rear-end conflict (see Figure 1), consider the following example. A driver, who is on the way home from work, is following a lead vehicle at a constant distance on the highway at a constant speed of 90 km/h. The driver is engaged in *distracted driving*: looking down on the phone reading a text message from a friend. The consequence of the distraction is that the driver does not realize that the lead vehicle is changing lane and uncovers a stationary vehicle which the driver is now approaching. The driver has a reaction time of 1.5 s and the vehicle brakes with a constant acceleration of -5 m/s^2 when the brakes are applied by the driver.

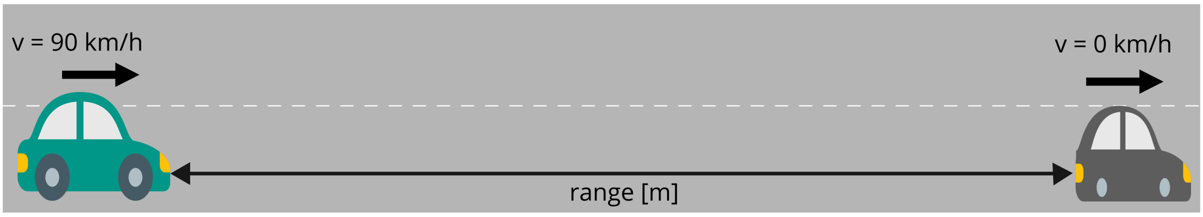

Figure 1: Scenario schema

Please answer following questions:

(a) What is the minimum range (the distance between the driver's car and the stationary vehicle) at which the driver needs to start braking to avoid a collision? *(2 points)*

(b) What is the time-to-collision (TTC) at this moment you identified in question (a)? What does this mean? *(2 points)*

(c) The driver redirects the eyes towards the forward path and identifies the approaching threat at a range of 90 meters. Taking into consideration the driver's reaction time, which distance is needed for the driver to stop the car? Will a collision be avoided? *(3 points)*

(d) Visualize (or make a simple animation of) the hypothetical rear-end conflict in a figure. At minimum, the figure should include information about the travelled distance or distance to the lead vehicle, the speed of the driver, and when a crash occurs. *(4 points)*

One way to help drivers avoid a collision or mitigate the consequences would be to equip the car with active safety systems such as an FCW or AEB system. The FCW system could issue a warning, helping the driver to redirect the attention away from the phone to the forward path and be able to identify the conflict well in time to solve the situation (i.e. brake or steer to avoid a collision). If, for some reason, the driver did not react to the warning, the AEB system could brake the car and stop it before a collision would occur or at least decrease the collision speed and hopefully mitigate the consequences. In a later part of this project, your task will be to design simple FCW and AEB systems to solve the previously analyzed situation.

Instructions for the report:

- Add your explanations and solutions for the questions above
- Add all equations that you used

2 Study critical braking behavior with experimental data *(30 points)*

When designing active safety systems, it is important that these systems will be accepted by the users. Therefore, it is essential that the systems do not issue warnings or brake the car in situations not perceived critical by the drivers. In order to understand drivers' braking preferences in a critical rear-end situation, an experiment was performed. Nine drivers participated in the study which took place on a test track. Each participant was told to keep a certain speed (10, 20, 30, 50 or 60 km/h) when driving towards a stationary "balloon vehicle" (a conflict object often used in experiments). The participants were asked to brake as late as possible to avoid a collision. During the experiment, vehicle kinematics and radar data were recorded. These data are provided to you in the file `RadarData.mat` which can be downloaded from Canvas. The file contains the following signals:

- Kinematics data
  - Vehicle speed in *m/s*
  - Vehicle yaw rate in *rad/s*
  - Vehicle time (Time vector for the above vectors) in *s*
- Radar data
  - Radar range in *m*
  - Radar range rate (speed) in *m/s*
  - Radar acceleration in m/s^2
  - Radar time (Time vector for the above vectors) in *s*

In this task, you are asked to identify the braking maneuvers (i.e. when the participants braked to avoid a collision) in the experimental data. Experimental data often requires processing before they can be analyzed. The reason for this can be e.g. missing data due to sensor failure, participants who did not follow instructions or that the format of the data is not the right one for the analyses at hand. There are different ways to characterize drivers' critical braking behavior. In this project we will use a set of numbers, referred to as "safety metrics", that are relevant for braking. To extract these metrics, you first need to obtain a cleaned data set.

Instructions for MATLAB *(18 points)*:

Perform the steps below to import and process the experimental data, not necessarily in the given order (**do not forget to comment your code!**):

- Import the data into MATLAB
- Investigate the structure containing the data and make sure you understand what it contains and how to extract the data (it could be helpful to plot the signals)
- It might be helpful to create a new structure in which you can save the results after the data manipulation
- Remove empty test runs (Hint: find runs with only NaNs in the radar range data)
- Synchronize the radar and vehicle kinematics time. The radar time is 200 ms delayed compared to the vehicle time. (Hint: use the minus operator.)
- Determine if there are runs with too little information to be useful and remove these runs (and motivate clearly in the report why you removed test runs)
- Identify braking maneuvers. Note that for this step there is no single correct answer. To get full points for this step you should at minimum: (a) include 55 of the initial test runs, (b) develop an algorithm that automatically identifies the braking maneuvers (it is okay to remove 1-3 test runs manually if needed).
- Make sure to plot each test run and mark the start and end of the braking maneuvers. By doing so you can evaluate how your automatic algorithm works. In addition, the teaching assistants will use this information for the midterm evaluation.
- Once the braking maneuvers are identified, the safety metrics can be calculated
  - Extract the speed at the start of the braking maneuver ("brake onset")
  - Extract the range at the start of the braking maneuver. If data is missing, fill the gaps in the data (hint: use kinematics or numerical interpolation to derive missing data)
  - Extract the mean acceleration and minimum acceleration (maximum deceleration, check for correct sign) for each braking maneuver
  - Calculate TTC at the start of the braking maneuver
- Store all the results into a table as described in Table 1
- Save this table into a .mat file

Participant	Mean acceleration [m/s^2]	Minimum acceleration [m/s^2]	Speed at brake onset [m/s]	Range at brake onset [m]	TTC at brake onset [s]
1	...	...	...	...	...
2	...	...	...	...	...
...	...	...	...	...	...

Table 1: Save the safety metrics following this structure

Instructions for the report *(12 points)*:

- Describe the steps used to process the data (this should be the most extensive part in the report of this task)
- Explain which data were discarded and why
- Describe the obtained values from the table: do the values make sense?
- Add at minimum one figure/image showing an example of a brake maneuver
- Add the full safety metrics table in the appendix

Note: The MATLAB code (in a .zip file) and table from Task 2 (a single .mat file) need to be handed in by October 3, 2021 (23:59) the latest for a mid-term evaluation. See below for more details.

3 Driver behavior analysis *(15 points)*

From now on, use the safety metrics table from Task 2 (received from the teaching assistants after the mid-term evaluation) to answer Tasks 3 and 4. Before designing your safety systems, you will need to dive deeper into your data set to analyze driver behavior. Please answer the following questions (include equations where you deem applicable):

(a) Plot speed at brake onset (x-axis) vs. TTC at brake onset (y-axis) for each participant. *(2 points)*

(b) Use the graph to describe if the different drivers have both high and low TTC values or are there clusters in the data? *(3 points)*

(c) Plot a histogram showing the TTC data for all drivers. Which type of statistical distribution would you say best decribes your data (e.g. normal, skewed)? What are the 5th and 95th percentiles? *(3 points)*

(d) Assume that you are asked to design an active safety system (e.g. a warning or intervention system) that uses TTC to assess the criticality of the situation. Which TTC would you use to design such a system? What happens if you design your system only for the average person and/or only for the most careful (i.e. a more conservative system) or sensation-seeking drivers (i.e. a more aggressive system)? *(4 points)*

(e) Plot distributions for mean and minimum acceleration (results from Table 1). What information about driver behavior can you obtain from these? *(3 points)*

Instructions for the report:

- Add your explanations and solutions to the questions

- Add the graphs you created
- Add all equations that you used

4 Active safety system design *(29 points)*

The calculated safety metrics can be used to estimate upper and lower limits of driver braking behavior in critical rear-end situations. Your task is now to propose simple FCW and AEB systems. The proposed systems should be tested on the hypothetical scenario described in Task 1 to see if they can help avoiding the collision.

(a) Propose (i.e. write some pseudocode and provide numerical thresholds) two FCW systems (a conservative and an aggressive one) based on the obtained knowledge from the driver behavior analysis (Task 3) that could be used for the scenario in Task 1. Describe your systems in terms of what the “threat-assessment” and what the “decision-making” is? *(4 points)*

(b) Test both systems in the situation from Task 1. How do both systems perform (i.e. at what distance to the lead vehicle do the systems activate and can they help avoid a crash)? Is any of the two systems better? *(4 points)*

(c) What are the limitations of an FCW system? Can an FCW system alone avoid a collision (please explain your answer)? *(2 points)*

(d) Now, propose (i.e. write some pseudocode and provide numerical thresholds) an AEB system that uses the required acceleration to stop the car as the “threat-assessment” metric. To do so, you will need to assume a maximum braking capability (i.e. the required acceleration needed to stop the car cannot exceed this value) of the car. The value selected needs to be motivated. Describe your system in terms of what the “threat-assessment” and what the “decision-making” is. *(4 points)*

(e) How does this AEB perform in the situation in Task 1? Assuming the determined maximum braking capability, at which minimum TTC (and which distance to the lead vehicle) does the AEB need to intervene to avoid a collision? *(4 points)*

(f) Another way of designing the AEB is to use TTC as the “threat-assessment” metric. Propose (i.e. write some pseudocode and provide numerical thresholds) such an AEB system, by defining a TTC at which your system would trigger an AEB intervention (and motivate your value). How does such a system perform in the situation in Task 1? At what distance to the lead vehicle does the system activate? At what distance to the lead vehicle does the car come to a full stop, what is the benefit or drawback? *(4 points)*

(g) These simple AEB systems (i.e. that only consider one threat-assessment metric) may not always brake the car in situations perceived critical by the driver. Please explain one scenario in which such simple AEB system may brake the car unexpectedly to the driver. Provide at least one additional piece of information the system would need to better assess the situation and make the correct decision. *(2 points)*

(h) In the visualization (or simulation) you created in Task 1 (d), add information about when your four systems (two FCW and two AEB systems) would warn the driver or start to autonomously brake the car. You can assume the driver to not act (e.g. starting to brake). *(5 points)*

Instructions for the report:

- Add your explanations and solutions for the questions
- Add the graphs you created
- Add all equations that you used

Assignment report *(15 points)*

The results from the project need to be summarized in a final report. Use International System of Units (SI) as primary units. Define abbreviations and acronyms the first time they are used in the text. Include all values and equations (including derivations). Insert labels and a legend in each figure. Make sure the font size in each figure is large enough. Proofread spelling and grammar. Your report should be in PDF or Word format. The report should not exceed **10 pages**, excluding cover page, references and appendix.

Conclusions on the project

The last part of your report should be conclusions on the project itself. Write a paragraph on the workload and the way you have divided your work in your group. Add a table where you indicate which group member did which work[1]. Write a reflection on which features of the project and its instructions were helping your learning process. Which features of the project and its instructions were hindering your learning process? This part of the report will not be graded and not influence your final score, although only complete reports containing all points above can be considered for grading.

[1] This part is important for us to judge the individual contributions to the outcome of the project. If possible rule infringements are identified (e.g. plagiarism), this will help us to identify the involved persons and avoids bringing innocent persons in uncomfortable situations.

Deadlines

Midterm evaluation

The deadline for the midterm submission is **October 3, 2021 (23:59)**. If your midterm submission is accepted, you will receive a `TableTask2.mat` file from us, with which you should continue to answer questions 3 and 4. This way, we will be quicker to correct your final project submission, as every group works with the same data set.

Final submission

The final project deadline is **October 24, 2021 (23:59)**. All your files (see below) should be uploaded to Canvas before the deadline. An upload after the deadline will not be possible and final submissions by mail are not accepted.

Hand-in documents

For the **midterm** submission, you need to hand in the files specified below that should be uploaded on Canvas in “Project: Midterm results”:

- One .zip file containing (1) your MATLAB code for Task 2, and (2) your safety metrics table (one .mat file)

For the **final** submission, you need to hand in the files specified below that should be uploaded on Canvas in “Project: Final results”:

- Your report (one separate file) in .pdf format (including all your answers to all tasks)
- One .zip file containing (1) your MATLAB code with the solutions for all tasks, and (2) your own safety metrics table (same as for midterm submission, one .mat file)

Grading

A minimum grade 3 in the project is required to pass the TME192 course. The final course grade will depend on the project grade and the final exam grade (check the introduction lecture to the course for more details).
The project will be graded as follows:

Fail < 55 points

3 ≥ 55 points and all tasks completed

4 ≥ 70 points and all tasks completed

5 ≥ 85 points and all tasks completed

If you fail the project after the first final submission, you have the possibility for one re-submission to score a grade 3. You will have about one week time to address all comments from the correction and re-submit your project. All re-submissions need to be submitted before the end of the study period (October 31, 2021).

Final remarks

Programming

If you do not have your own computer available, all computers in the M-building are equipped with the necessary software to complete this assignment. Due to the limited amount of time, it will not be possible for the teaching assistants to help you with the use of MATLAB—if you are not familiar with programming, you are expected to learn this as self-studies (check out the MathWorks training courses, e.g. the “Onramp course”). You can always check the software’s internal helping tool, Google or YouTube.

Support

If you have questions, make sure to attend the support sessions (check Canvas for the Zoom links, and TimeEdit for the times and reserved rooms), and ask your questions there. This may be easier for you than trying to explain your problem in a message. Support sessions will be held online via Zoom by default. Support on campus may be given, too, depending on the availability of the TAs. We encourage you to use the online Discussions forum (“Project: Questions and answers”) on Canvas to seek for help, there you may get help from other students or the teaching assistants. If there are urgent problems, for instance, with your group mates, please contact the teaching assistants immediately by mail to facilitate a quick solution.

Plagiarism

All groups are supposed to work independently of each other. Copying text, code or results from others, but also from the literature or other sources is plagiarism and is not tolerated at Chalmers. All submitted documents will be checked for plagiarism. If you have doubts, check the provided documents or contact the teaching assistants. Please also make sure that you do not leave your report or results open to the public (e.g. by uploading them publicly available to GitHub).

Time management

Finally, start working on the assignment as soon as possible. By doing so, you will not get stressed with the deadline coming closer and you have the chance to ask questions and seek for support. The deadline is fixed for everyone, and if you realize that you are stuck somewhere, a day before the deadline is too late to seek help. When the deadline has passed, you will not be able to upload your results to Canvas any longer, so make sure that you upload everything in time! Submissions by mail will not be accepted.