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TITLE: Stochastic decision-making method for autonomous driving system that minimizes collision probability

Subject: Vehicle Safety

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ABSTRACT:

This paper describes a new stochastic decision-making method for use in an autonomous driving system that minimizes the probability of a collision.

In a previous work, Broadhurts *et. al* [1], discussed a reasoning framework for analyzing the safety of complex road scenes, each of them consisting of multiple objects, and defined a collision probability. However the probability is defined for a scene with all objects, not for a particular path of a particular object (autonomous vehicle), therefore it cannot be applied to a decision making of an autonomous driving system directly.

This paper defines a collision probability for a particular path of a particular object in consideration of all possible paths of other objects. This probability is used to find the best path for the object.

The collision probability is computed in 3-dimensional spacetime, where the car's (x,y) position at time t is the point (t,x,y) in 3D spacetime. Similarly, the movement of the car during t=0 to t=T is represented as a trajectory in 3D spacetime (figure 1).

When the movement is only known statistically (e.g. when computing a set of possible future trajectories), it is represented as a set of trajectories with their probabilities (figure 2). The probability of a trajectory is computed as a product of operation's probabilities of each time step (figure 3), where an operation is defined as (α, γ) (acceleration 'α' and steering angle velocity 'γ' for tire angle) when using the 2-wheeled (bicycle) vehicle model (figure 4)[2]. If there is no knowledge about operation's probabilities in advance, the uniform probability is assumed because it represents the most unpredictable case.

To compute the collision probability between an autonomous vehicle with a single trajectory and another car with multiple possible trajectories, we sum the probabilities of the other car's trajectories that intersect with the autonomous vehicle's trajectory. If there are multiple cars, they are each represented as sets of trajectories (figure 5), and the probability that an autonomous vehicle will collide with at least one car is used as the collision probability for each autonomous vehicle's trajectory.

The safest trajectory for an autonomous vehicle is the trajectory that minimizes the collision probability with any other car (figure 6).

This approach has been tested in a scenario where the autonomous vehicle is merging onto an expressway. Even without any knowledge of other car's behavior (assuming uniform probability), these tests show that the autonomous vehicle will choose appropriate actions as follows (figure 7):

1) accelerate its speed up to the speed of other cars in the cruising lane (100km/h),
2) merge onto the cruising lane, keeping appropriate distance from other cars,
3) merge onto the passing lane and go forward while keeping appropriate distance from other cars.

These results indicate that the collision probability measure introduced here is well suited for this application, and minimizing this probability is very effective for collision avoidance. This measure should be considered in the design of autonomous driving systems.

References

[1] Adrian Broadhurst, et al., (2005) "Monte Carlo Road Safety Reasoning".

[2] Stephan Petti & Thierry Fraichard, Proc. of the IFAC/AAAI Int. Conf. on Informatics in Control, Automation and Robotics (2005). "Partial motion planning framework for reactive planning within dynamic environments".

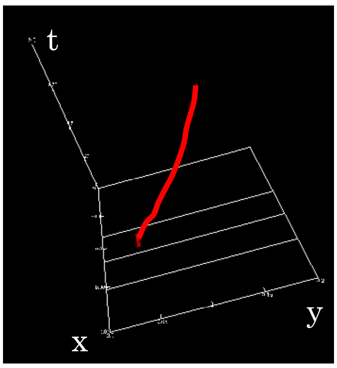


Figure 1: Trajectory that represents the movement of the car

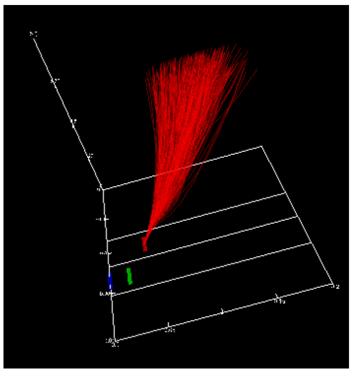


Figure 2: Trajectories that represent the possible movements of the car

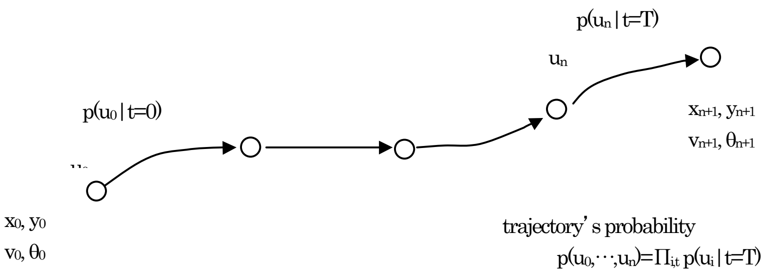
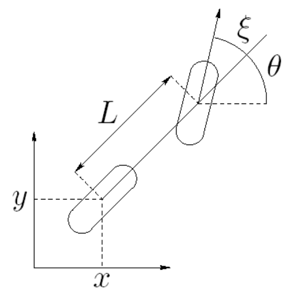


Figure 3: Probability of a trajectory



$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{v}_r \\ \dot{\xi} \end{bmatrix} = \begin{bmatrix} v_r \cos\theta \\ v_r \sin\theta \\ \frac{\tan\xi v_r}{L} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} \alpha + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \gamma$$

Figure 4: 2-wheeled (bicycle) vehicle model

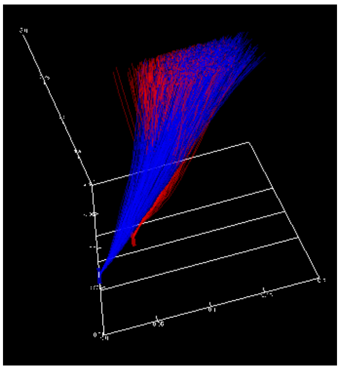


Figure 5: Trajectories that represent the possible movements of multiple cars

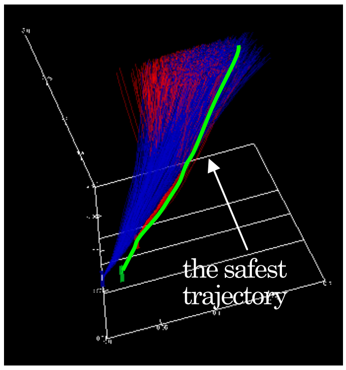


Figure 6: The safest trajectory that minimized the collision probability

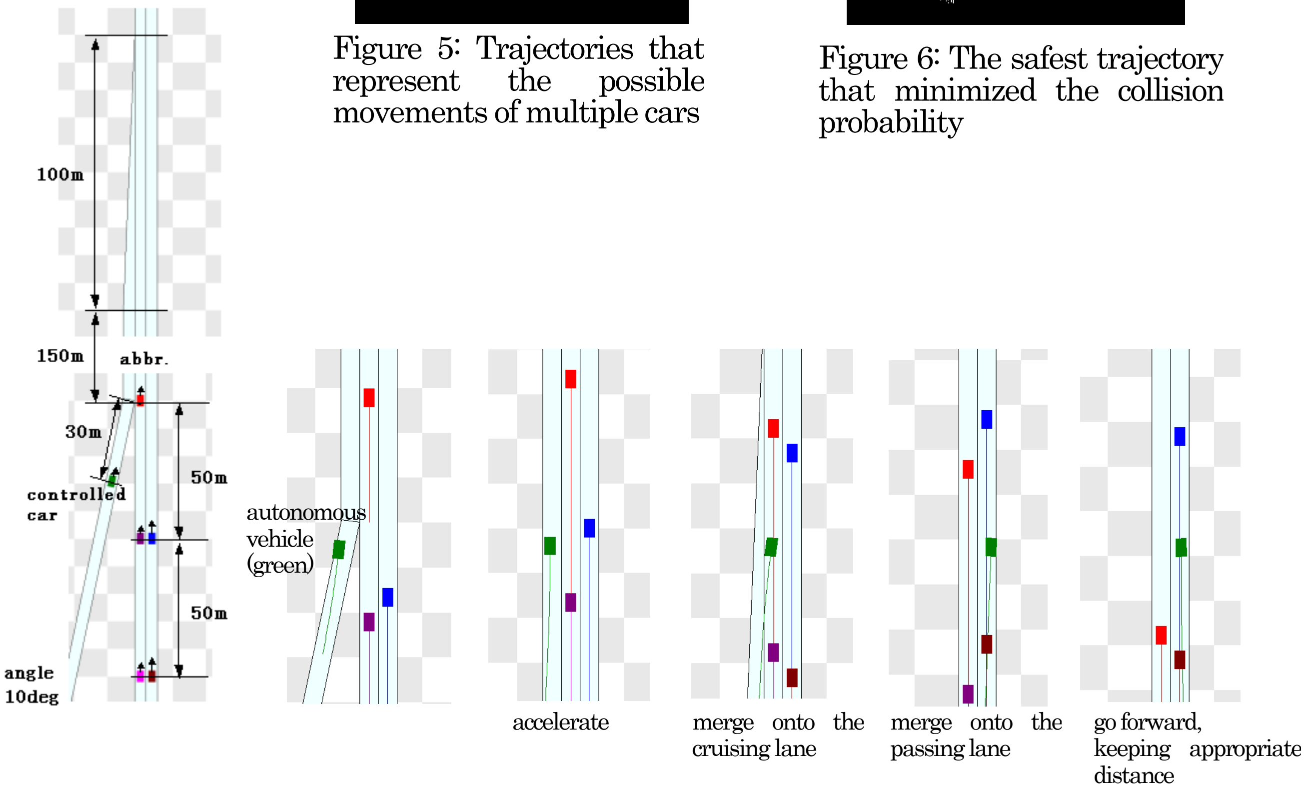


Figure 7: Result of merging onto an expressway