Dynamic Risk Assessment in Autonomous Vehicle Motion Planning

Andrzej Wardziński
Gdańsk University of Technology
Andrzej.Wardzinski@eti.pg.gda.pl

Abstract

Arguing that an autonomous mobile system is sufficiently safe to operate in presence of other vehicles and objects is an important element in development of such systems. Traditional approach to assure safety is to distinguish between safe and unsafe area and prevent the autonomous vehicle from entering the unsafe area. The paper presents a model of autonomous vehicle control system which uses risk assessment of the current and foreseen situations to plan its movement. The approach is discussed for two examples of simulation scenarios. The problem of risk assessment uncertainty and the need for cooperation between vehicles is addressed.

1. Introduction

Nowadays we can observe an increasing level of autonomy in transport systems or its components. As safety is a critical issue in transportation this raises a question how to assure that an autonomous mobile system is sufficiently safe to operate in presence of other vehicles and objects. Traditional approach to assure safety is to distinguish between safe and unsafe area and prevent the autonomous vehicle from entering the unsafe area. The boundary is often specified on the basis of calculation of the vehicle coordinates and distance from other objects. We discuss the problem of autonomous vehicles safety in Section 2.

The paper presents a model of autonomous vehicle control system which uses risk assessment of the current and foreseen situations to plan its movement. The concept of a situation risk level and the approach to vehicle motion planning is described in Section 3.

In Section 4 we present two example scenarios to discuss the approach features and problems with its application. The summary of the risk-based approach for autonomous vehicle motion planning is presented in Section 5.

2. Autonomous Vehicles Safety

Autonomy relates to an individual or collective ability to make decisions and act without outside control or intervention. *Autonomous vehicle* is a vehicle able to perform action planning and control without human interaction in order to accomplish its long-term mission goals. Autonomous vehicles operate in an open (i.e. non-controlled) environment.

We will define *open environment* as an environment in which many vehicles can operate and can have different mission goals and strategies. Some regulations can be defined for the environment and vehicles should follow them however it cannot be guarantied that every vehicle would always act in accordance with the regulations. A vehicle cannot assume that all other vehicles will cooperate and preserve safety.

The essential feature of an autonomous vehicle control system is its ability to plan actions and achieve long-term mission goals. Usually the objective of an autonomous vehicle is to:

- accomplish its mission (a long-term goal),
- comply with the regulations if such rules are defined,
- preserve safety (avoid hazardous events).

An example of a hazard is a collision – when a vehicle collides with another vehicle or an object. There may be many different causes for such an event. It can be a sensor or actuator failure, wrong route planning, unexpected events in the environment or maneuvers of other vehicles.

The main approach for preserving safety for mobile systems is to implement barriers to separate safe from potentially unsafe area so that the vehicle will stay within the specified boundaries. There are many forms of barriers. Hollnagel [1] classified barriers as:

- *material* barriers, e.g. a fence which can be detected using bumper sensors or distance sensors,
- *functional* barriers, when a specific precondition is defined which have to be fulfilled before an action can be carried out,

– *symbolic* barriers, e.g. signs and signals that have to be perceived and interpreted,
– *immaterial* barriers – using the knowledge to follow the rules of allowed behaviour (e.g. Highway Code).

An example of a symbolic barrier application is an autonomous vehicle which operates near to airport runways and uses GPS coordinates to ensure operation in allowed areas only [2]. The vehicle is not allowed to enter the airport runways. The system is using complex technologies because it is not possible to build fences (material barriers) near airport runways.

The concept of a barrier can also be used for a vehicle operating in presence of other vehicles. Robertson in [3] presents kinematic motion study for a vehicle operating in an urban environment and competing in DARPA Urban Challenge. The goal of the kinematic model analysis was to define safety regions for situations like crossing a road. The safety region is an area that is required to be free from other vehicles in order to continue driving. The size of the safety region can vary depending on current situation. If the safety region is occupied by any vehicle the system should stop and wait until the safe region is clear. The control system decision is binary: go or do not go. The idea of the barrier is based on the binary condition that activates the barrier. In reality safety is not a binary attribute however this simplification makes system design and proving its safety easier.

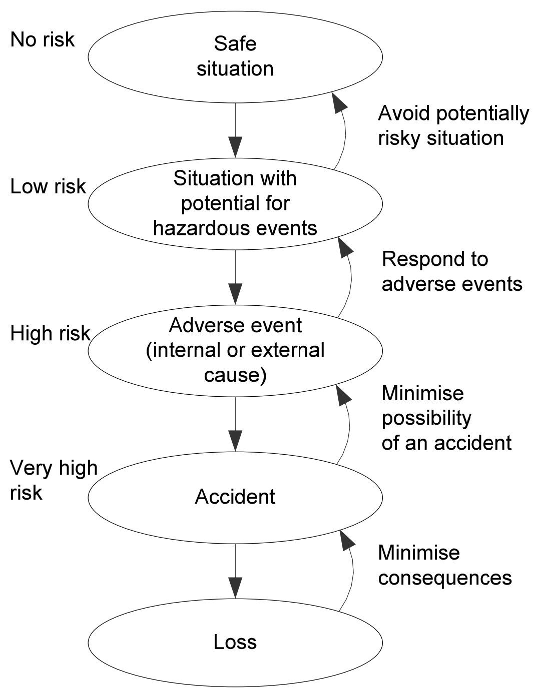

Figure 1. Accident model

To understand how vehicle safety can be assured have to use a conceptual model that incorporates a vehicle motion model and an accident model. The accident model should represent mechanisms of accident occurrence and accident prevention. Most of the accident models base on the assumption that an accident is followed by a sequence of events as shown in Figure 1. The objective is to break the event chain that leads to an accident. A barrier prevents transitions from one state (e.g. safe situation) to a more risky (unsafe) state. For one system we can define many barriers and each will prevent a specific state type of transition from occurrence. Each barrier can be implemented independently in the control system.

One of the vehicle control system tasks is to plan the route. That is to decide on the vehicle speed and course. Current situation is to be continuously monitored to accordingly adjust the route. At any moment of time the vehicle control system can choose from a set of possible vehicle actions (drive on, turn left or right, accelerate or slow down).

3. Situation Risk Assessment

The concept of the risk-based autonomous vehicle safety assurance is based on the assumptions that the vehicle control system can:
– identify possible actions for a given current situation,
– foresee probable changes in the environment and actions of other vehicles,
– predict possible future situations,
– assess the risk level for predicted situations.

The key issue of the approach is situation awareness. Situation awareness is, generally speaking, the knowledge of what is going around. Situation awareness is an area of research in domains of philosophy, psychology, artificial intelligence, computer science (human-computer interface). The research goal in psychology is to examine how a human maintains situation awareness, while in robotics the aim is to create machine situation awareness. Assessment if a situation is safe or dangerous is one of the situation awareness functions.

The general concept of situation awareness is well known however there is no one agreed definition. Endsley introduces three levels of human situation awareness [4]:
1. *Perception*: basic perception of cues based on direct observation.
2. *Reasoning*: the ability to comprehend or to integrate multiple pieces of information and determine the relevance to the goals the human wants to achieve.

3. *Predicting*: ability to forecast future situation events and dynamics based on the perception and comprehension of the present situation.

This conceptual model can be applied to robots however we are aware that we cannot compare today's limited intelligence of robots to immense human capabilities. Our objective is to search for applicable and effective ways to allow the autonomous vehicle to *perceive* current situation, *predict* possible scenarios and *reason* which action scenario is acceptably safe.

First we have to agree on the meaning of the risk level. Human risk assessment is usually subjective and there are no established methods for risk assessment interpretation. Another problem is that we cannot guarante the complete knowledge of the situation and all relevant risk factors. In fact the vehicle should keep safe operation even when the situation awareness knowledge is incomplete. We use the Dempster-Shafer logic [5] to represent uncertainty in risk assessment [6].

In our approach we assume that four risk level (RL) values are to be defined as the risk scale:

RL-A. no risk – the lowest risk level (e.g. no other vehicle in a specified distance),

RL-B. acceptable safe (a limited set of specific risk factors can be perceived, e.g. vehicles in some distance),

RL-C. hazardous situation (serious threats to system safety can be identified),

RL-D. accident – the highest risk level.

The objective of the vehicle control system is to keep within the limits of A and B risk levels, that is preserve from causing higher risk level then B. If the risk level rises above the B level then the objective will be to lower the risk level.

We should be aware that the exact meaning of a risk level is a subject to interpretation and can be questioned as there are no measurable values in real world that could be compared and verified. For our experiments we use the scale from 0 (A risk level) to 1 (D risk level) and values 0,2 for B and 0,8 for C risk levels. For a given risk factor it is really difficult to justify why the resulting risk level is 0,65 and not 0,64. What we can do is to compare two situations, judge which one is more risky and then check if calculated risk level is higher or lower. We also analyze vehicle motion scenarios to check how the risk level rises or is reduced in time.

From the point of view of system safety it is important to assure that any threat (represented as a risk factor) is detected early enough in order to avoid the risk of the accident. We should note that the risk assessment is not the only factor used to plan the route. The vehicle control system objective is to plan the route that gives an optimal combination of:

– mission progress,
– compliance with formal rules (regulations),
– safety assurance (risk minimization).

Depending on the vehicle strategy and the method of risk level calculation we can achieve different vehicle behaviour:

– aggressive when the mission goal has higher priority,
– balanced or
– defensive when the priority is risk minimization.

4. Simulation experiments

We expect that risk-based approach will improve system performance in comparison with the barrier-based approach while still assuring safety. To verify this approach we have conducted a set of simulation experiments. The main objective of the experiments was to analyze variants of situation risk assessment methods and compare system performance with the barrier-based approach. We used a simplified vehicle kinematic model and vehicle failures were excluded from the simulation. The simulation does not take into account weather conditions or road surface characteristics but only basic physical characteristics of the vehicle like inertia.

One of the examples of a risky situation is when the routes of two vehicles cross each other. Each of the vehicles is driving to its destination point and their routes cross as shown in Figure 2.a.

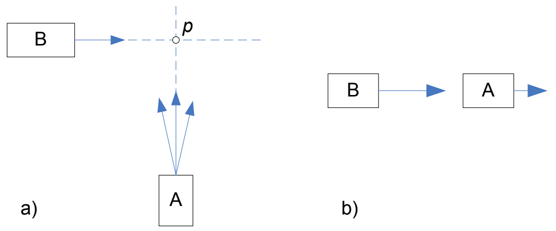

Figure 2. Examples of simulated scenarios: crossing routes (a) and chase (b)

A simple risk factor that worked quite well was predicted minimal distance (*md*) between vehicles assuming that the other vehicle will not change its speed and direction. The accident (risk level RL-D) happens then the minimal distance is less then l, where l denotes the length of the vehicle. We have defined the hazardous situation (RL-C) as $md = 2l$. We have assumed that the vehicle is acceptably safe (RL-B) when $mb = 50l$ and there is no risk (RL-A) when $mb > 100l$.

For a situation presented in Figure 2.a the control system of vehicle A can calculate the risk level for a set of possible actions (such as driving on, turning left or right, moving faster or slower). The risk assessment is precise when the other vehicle does not change rapidly its route. Unexpected changes in the behaviour of other vehicles causes that the risk assessment differs from consequent real situation. That relates to the weakness of the situation awareness function to predict future situations. One way to cope with the problem is to allow vehicles to communicate their planned routes to other vehicles and cooperate in route planning. Otherwise the prediction of the other vehicle route is uncertain and we have to represent this uncertainty in risk assessment. As it was mentioned in Section 3 we use Dempster-Shafer logic to represent uncertain risk assessment results [6]. For the presented scenario we have defined the risk factor in such a way that uncertainty level is higher when the other vehicle drives faster and when the current distance is small. Uncertainty has to be used as an element of the situation awareness model however the objective of the situation awareness is to reduce the uncertainty and precisely assess the risk.

The vehicle route is planned so that the vehicle takes a minimal risk according to the current perception of a situation, however some simulated scenarios ended with accidents depending on the other vehicle behaviour. We have tried a few different risk factors definitions but the main effective way to assure safety was to increase the distance between the vehicles when the prediction is uncertain. Our main experience is that achieving high performance and safety is possible when vehicles communicate and cooperate to make their behaviour more predictable.

The key feature of the approach is that the vehicle will always try to follow the route perceived as optimally safe for a given situation. This can be demonstrated on the example of a chase scenario. Let us consider a situation presented in Figure 2.b. Vehicle A is driving eastwards while the vehicle B is chasing him. Vehicle B is driving along the same route with higher speed. To minimize the risk of an accident vehicle A has to turn or accelerate. When vehicle A tries to change its route and for example turns left then the chasing vehicle follows him. Turning is not an effective way for avoiding an accident and vehicle A is forced to accelerate. That example shows that situation risk assessment gives us the possibility of active vehicle safety assurance.

5. Summary

The presented approach to vehicle route planning allows for achieving optimal system performance at acceptable risk level. The approach requires vehicle situation awareness which is complex and difficult to achieve. The simulation experiments demonstrate that the approach works for a simplified model of the vehicle. The results achieved in the experiments depend a lot on the used situation awareness model and risk assessment method. The main problem is completeness and accuracy of the situation model to adequately represent possible situations and allow for precise risk assessment.

The main advantage of the approach is that it gives the possibility for a vehicle to actively react to changes in the environment. That property is especially important in an open environment where other vehicles can operate and cause threats for safety. The risk-based approach is more complex then the use of barriers however it can offer features that are required for autonomous vehicles operating in an open environment.

6. References

[1] E. Hollnagel, “Barriers and Accident Prevention”, Ashgate, 2004

[2] J. Spriggs, Motion Safety for an Autonomous Vehicle Race in an Urban Environment, In: F. Redmill, T. Anderson (Ed.), *Current Issues in Safety-critical Systems*, Springer-Verlag London, 2003

[3] S.W.H. Robertson, “Motion Safety for an Autonomous Vehicle Race in an Urban Environment”, In: *2006 Australasian Conference on Robotics & Automation*, 2006

[4] M.R. Endsley, “Direct Measurement of Situation Awareness: Validity and Use of SAGAT”, In: M.R. Endsley and D.J. Garland (Ed.), *Situation Awareness Analysis and Measurement*, 2000

[5] J. Górski, M. Zagórski, “Using Dempster-Shafer approach to support reasoning about trust in IT infrastructures”, In: *Warsaw International Seminar on Intelligent Systems* (WISIS 2004), Warsaw, 2004, pp. 39-57

[6] A. Wardziński, “The Role of Situation Awareness in Assuring Safety of Autonomous Vehicles”, In J. Górski (Ed.), *Computer Safety, Reliability, and Security, 25th International Conference*, SAFECOMP 2006, Springer-Verlag, 2006, pp. 205-218