A Unified View on Probabilistic Tracking and Situation Assessment

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Abstract—In-vehicle Advanced Driver Assistance Systems are based on the perception and interpretation of the vehicle’s environment. These tasks are often based on probabilistic tracking algorithms such as the Bayes filter and situation assessment algorithms, e.g., Bayesian networks. However, while these techniques are subject to intensive research, the interface between them has not yet been sufficiently addressed. Thus, the main research objective of this work is to provide a generic, bidirectional, probabilistic interface between tracking and situation assessment in order to allow a unified view on these tasks. For that, it is firstly analyzed how uncertainties from the probabilistic perception of the vehicle’s surrounding can be entered into a Bayesian network in order to directly influence the situation assessment. In addition, it is investigated how uncertain knowledge about the current situation can be used in order to support the tracking performance. For that, an extension of the Interacting Multiple Model (IMM) is proposed which is called the Meta Model Filter. This technique models possible maneuvers of vehicles inside a Bayesian network in order to adaptively adjust the transition probabilities of the IMM according to the current situation. With this approach, a situation-dependent multiple model filtering can be achieved.

I. MOTIVATION & RESEARCH OBJECTIVES

One of the main goals of the ongoing research on Advanced Driver Assistance Systems (ADASs) is to contribute to safer, more comfortable, and more efficient road vehicles. Though current studies show that the deployment of current systems such as Adaptive Cruise Control (ACC) or Lane Keeping (LK) is indeed influencing road safety in a positive way [1], there are still significant challenges to meet.

In-vehicle ADASs are based on the perception of the vehicle’s environment—usually using a set of several complementary sensors which depends on the application. In future systems, those sensor data may be enhanced or even partly replaced by communication between vehicles and road infrastructure [2]. Thus, the amount of data which is available to a vehicle is likely to increase.

On the other hand, also the action possibilities of ADASs are increasing. While the first systems were limited to pure warnings, state-of-the-art applications are also capable of intervening into the driving process. Current research (for instance in the research projects HAVEit [3] or SPARC [4]) is even focusing on highly automated driving which allows to automatically execute certain maneuvers under the supervision and control of the driver and to pass the control back to the driver in situations which cannot be handled automatically.

Due to these developments, the importance of situation assessment techniques is significantly increasing in current ADASs. The aim of these algorithms is to interpret the perceived vehicle environment and evaluate the relations between the detected entities in the current context in order to derive appropriate system reactions (e.g., warnings or driving interventions). Furthermore, the increasing severity of automatic driving tasks such as braking or steering is posing additional requirements on the self-assessment capabilities of assistance systems in order to avoid inappropriate and dangerous maneuvers.

Sensor data about the vehicle’s environment are usually incomplete, imprecise and uncertain. The data may for instance be subject to false alarms, missed detections, sensor biases, or measurement noise. In order to account for this limited data quality, nearly all perception modules are using a probabilistic description of the vehicle environment, including stochastic models of the system dynamics and the sensor properties. With such as model-based description, an estimation of the existence and the state of all relevant entities in the surrounding of the vehicle can be obtained using an implementation of the general Bayes filter (for instance the Kalman, histogram, or particle filter). The process of recursively estimating the state of a moving entity is also called tracking [5].

In many applications (for instance in [6], [7]), situation assessment is done using rule-based expert systems which do not explicitly model uncertainties in their input data. For the handling of uncertainties, different approaches have been proposed which are, e.g., based on fuzzy logic [8] or Bayesian networks [9]. While the general performance of those techniques in combining uncertain evidence itself is subject to controversial discussions [10], a major limitation of the proposed techniques is the interface between tracking and situation assessment.

As the tracking modules usually provide probability density functions for the relevant entities, using alternative uncertainty representations such as fuzzy logic requires a translation of uncertainties from one domain to another. Though this approach has been successfully applied in different applications, the translation process may be criticized for its partly heuristic nature. However, even in applications which use a probabilistic approach for situation assessment, guidelines for directly linking the tracking and assessment modules are rarely available. In [9], the tracking output is for instance first translated into a fuzzy representation and subsequently translated back into a probabilistic network.

The main research objective of this work is to provide a generic, bidirectional, probabilistic interface between the perception and the situation assessment stage in order to allow a unified view on these tasks. For that, it is firstly
analyzed how uncertainties from the probabilistic perception of the vehicle’s surrounding can be entered into a Bayesian network in order to directly influence the situation assessment. The main idea is that for instance a higher uncertainty of a tracked vehicle directly leads to a lower confidence in a possible maneuver decision provided by a Bayesian network.

In addition, it is also investigated how uncertain knowledge about the current situation can then again be used in order to support the perception task – in particular in order to increase the tracking performance. For that, an extension of the Interacting Multiple Model (IMM) is proposed which is called the Meta Model Filter. This technique models possible maneuvers of vehicles (or more general, modes of different entities) inside a Bayesian network in order to adaptively adjust the transition probabilities of the IMM according to the current situation. With this approach, a situation-dependent multiple model filtering can be achieved.

II. CONTRIBUTIONS

In order to enter perception uncertainties into a Bayesian network, two new approaches are proposed and analyzed. One possibility is to define dynamic likelihood nodes inside the Bayesian network whose conditional probability tables depend on the uncertainties of the tracking modules. This approach is described in detail in [11]. The main idea is to use the Unscented transformation [12] in order to accurately approximate the probability density function of a situation parameter by a Gaussian density. For instance, if the task is to calculate a Time to Collision \( t_c \) between the ego vehicle and the closest object, the Unscented transformation can be applied in order to estimate the expectation \( E[t_c] \) and the variance \( \sigma^2_t \) of this quantity. The key idea is to make the conditional probability table of the likelihood node in the Bayesian network dependent on \( \sigma^2_t \). By doing so, the uncertainty of the perception is directly reflected inside the Bayesian network.

An alternative approach is presented in [13], where the discrete probability distribution of a node inside the Bayesian network (so-called soft evidence) is calculated manually from the perception results based on the Unscented Transformation and combinatorial calculations. In [13], this is illustrated on the example of a risk assessment of tracked vehicles, which includes assessing their association to the current lane of the ego vehicle and their threat level.

In order to exploit uncertain knowledge about the current situation for tracking algorithms, the Meta Model Filter (MMF) has been proposed in [14]. This method models the transitional probability matrix of the Interacting Multiple Model filter as a part of a Bayesian network. By doing so, the transition probabilities can by adapted to the current situation. For instance, if an object is located in the left neighbor lane at a very close distance, it is unlikely that the ego vehicle will perform a lane change maneuver. By applying the MMF, this (uncertain) information can be used to decrease the transition probability from the state \( \text{KeepLane} \) to the state \( \text{LaneChange} \).

III. METHODOLOGY & APPLICATION

In order to demonstrate the benefit of the proposed algorithms, an application has been set-up which perceives and evaluates the vehicle’s surrounding on highways in order to derive lateral maneuver recommendations. For instance, the system may advise the driver to stay on its lane or to perform a lane change maneuver. Details about this system can be found in [11]. This application has been implemented on a research vehicle. Furthermore, this vehicle has been used for recording large amounts of data from numerous test drives in order to evaluate the proposed approaches in real-world environments.

In addition, proprietary simulations have been used in order to evaluate particular parts of the presented algorithms. For instance, it has been analyzed how the decision confidence of the lane change maneuver recommendation is changing if the uncertainty of the tracked vehicles is increasing (see [13] for some examples of the simulation results).

REFERENCES