A Survey of Technical Trend of ADAS and Autonomous Driving

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ABSTRACT

For past 10 years Advanced Driving Assistance System (ADAS) has rapidly grown. Recently not only luxury cars but some entry level cars are equipped with ADAS applications, such as Automated Emergency Braking System (AEBS). The European New Car Assessment Programme (EuroNCAP) announced its introduction of AEBS test from 2014, which will accelerate the penetration of ADAS in Europe. Also DARPA challenge started from 2004 accelerated the research for autonomous driving. Several OEMs and universities have demonstrated autonomous driving cars. This paper gives a brief survey of technical trend of ADAS and autonomous driving focusing on algorithms actually used for autonomous driving prototype cars.

INTRODUCTION

At present, the topic of automated vehicles is still one of the most promising research areas as well as the hottest topic in the automotive industry. After the press release from Nissan at Aug. 2013, several major OEMs (car makers) and Tier1s (ECU providers) has expressed they will introduce autonomous driving products into the market by 2020.

Up to now many prototypes for autonomous or highly automated driving car have been developed and demonstrated. In the US, robot car contests called DARPA Ground Challenge (2004, 2005) and Urban Challenge (2007) were held. The team from Stanford University won the 2005 contest, and the team from CMU (Carnegie Mellon University) won the 2007 contest. Google car has been developed initially by members from Stanford and CMU. In 2010 Audi TTS prototype car developed by Audi and Stanford University demonstrated a driving of the Pikes Peak International Hill Climb without a driver. In EU a robot car contest called GCDC was held in 2011, the team from KIT (Karlsruhe Institute of Technology) won the contest. Also many research projects on automated driving such as HAVEit, SARTRE, interactIVe were held along with EU's FP7 framework. Some of these projects will continue from 2014 in the new research framework of HORIZON2020.

Autonomous or highly automated driving technology consists of sensing, perception, planning and operation. The technology is still in progress and many papers are published every year. However it is very difficult to understand the whole shape of the technology and its trend. It is because most of the papers define problems in narrow ranged ways with various boundary conditions. We can see each work produces a good result for its problem under its condition, however it is difficult to judge it works well in a whole autonomous driving system in combination with other portions. It would be useful for us to review technologies actually used in those prototype cars, however there are limited papers describing the technology in those prototype cars. Especially OEMs and Tier1s tend to dislike disclosing the technology.

In this paper we will give a brief survey of technical trend of autonomous driving algorithms. Those algorithms are picked up from the projects in which prototypes are developed. Those are three research projects as Daimler 6D-vision (www.6d-vision.com), KIT AnnieWAY (www.mrt.kit.edu/annieway) and CMU Tartan Racing (www.tartanracing.org).

LEGAL ISSUES

There are several issues other than technology towards the autonomous driving. Those issues are closely related to how much the driving functionality is automated. Several definitions for the extent of automation are given by iMobility [1], BASt [2] and NHTSA [3], but here a very simple definition from EU SMART64 report [4] is introduced as,

Automated driving: Driving enhanced by dedicated control, existing of autonomous (sub)systems that support the driver, while he/she is in control or able to timely get back in control and which is legally responsible throughout for carrying out the driving task.

Autonomous driving: The extreme end result of automated driving. In principle, no human driver needs to be active in operating the vehicle, although a driver can still be, but does not need to be in place.

Vienna Convention on Road Traffic

The Vienna Convention on Road Traffic is an international treaty designed to facilitate international road traffic, and requires

ARTICLE 8.1: “Every moving vehicle or combination of vehicles shall have a driver.”

ARTICLE 8.5: “Every driver shall at all times be able to control his vehicle or to guide his animals.”

The SMART64 report says that the Vienna Convention will have only a limited effect on automated driving systems, however it is quite unclear on autonomous driving. Vienna Convention is concluded by many EU countries. Japan and US conclude Geneva Convention on Road Traffic which is quite similar to Vienna Convention.

Liability Issues

The "evaluation + legal aspect" sub-project of interactIVe project (www.interactive-ip.eu) gives an analysis for liability issues [5]. As for a product liability point of view the sub-project recommends to design the automated function allowing the driver to override any time he wishes to do so.

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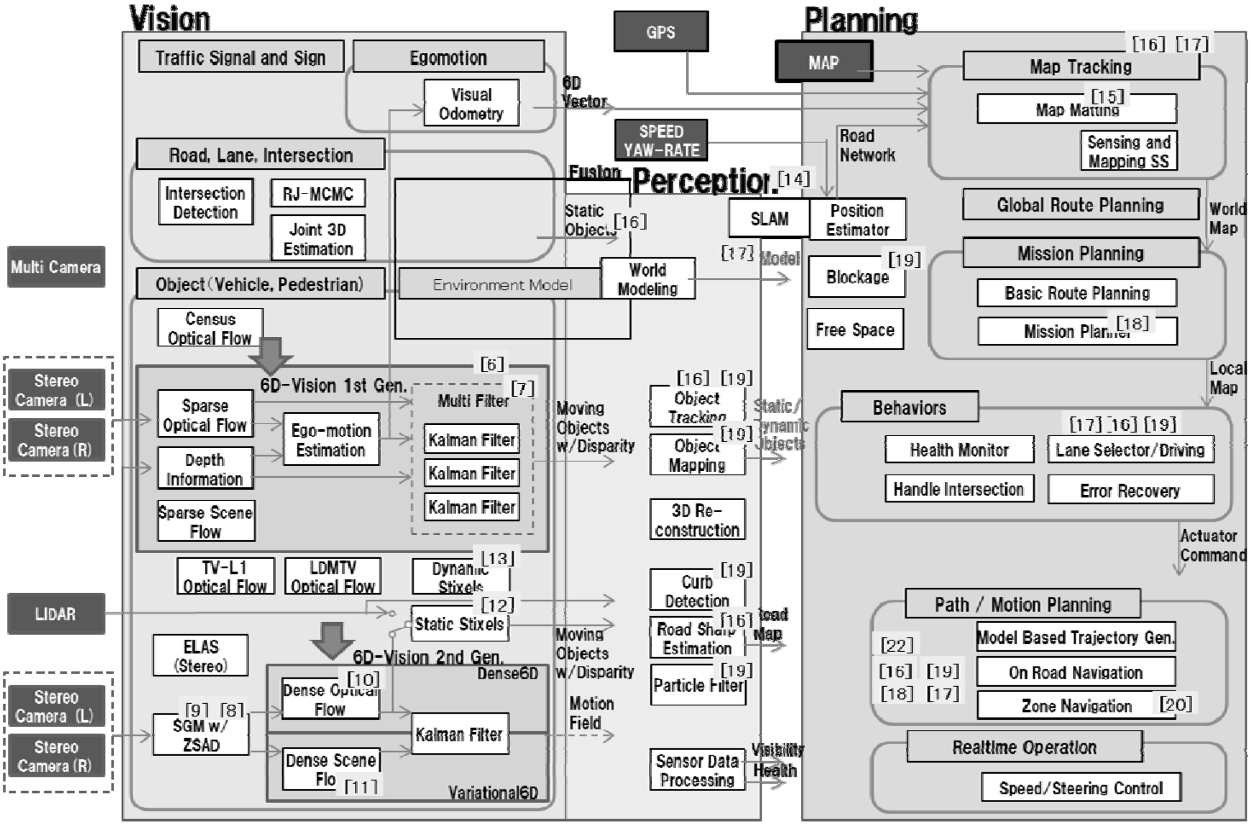

Figure 1: Assumed system block diagram for autonomous driving

ASSUMED SYSTEM BLOCK DIAGRAM

Figure1 gives a block diagram of autonomous driving system in concept level. This diagram is intended to give readers where the reviewed works in this paper are located in the entire system. The left hand side is the vision and perception, the right hand side is planning.

VISION AND PERCEPTION

Object Recognition

A motivation of Daimler 6D-vision comes from to reduce traffic accidents especially at urban intersections. In such situations, understanding of the scene is necessary, in particular a reliable detection of other moving traffic participants. The outcome of 6D-vision is composed of 1st and 2nd generations. The 1st generation [6, 7], at first, calculate movement and depth information from sequence of stereo images using stereo matching and optical flow technique. Using a Kalman filter attached to each tracked pixel, the algorithm propagates the current interpretation to the next image. The location and motion of pixels simultaneously which enables the detection of moving objects on a pixel level.

In the 2nd generation the main scope of the project moved to stereo vision and tracking algorithms. Figure 2 shows a trend of stereo vision algorithm.

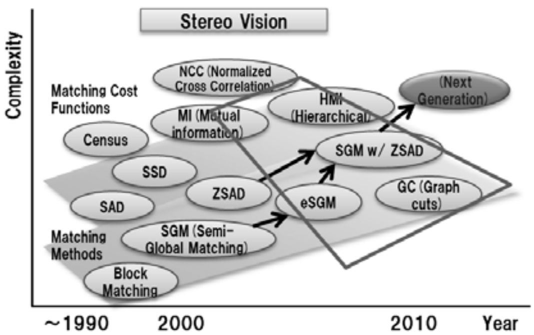

Figure 2: Trend of stereo vision

The stereo vision algorithms are combination of matching methods and cost functions. As matching methods, basic block matching method is not enough for autonomous driving due to poor robustness againt various object shapes. Although more detailed

SGM (Semi Global Matching) method [8] requires too much computation performance for embedded use.

Gehrig [9] introduced algorithmic extensions into SGM for automotive applications, and implemented on a FPGA platform. The input image is stereo 750x480 grayscale images with 12bit/px, but the computation is limited to 680x400 with disparity range of 0 through 127. Because of the computing power limitation, SGM is computed with small images by a factor of 2 in width and height at first, after that a second SGM runs on a smaller region of interest (ROI) with the original resolution. As for cost functions, a comparison among three major functions as ZSAD and Birchfield-Tomashi(BT) and Hierarchical Mutual Information(HMI) was made. The authors conclude ZSAD is suitable for automotive use, because HMI is sensitive to vignetting artifact of lenses and BT is sensitive to the brightness variation in image pair. Using Xilinx Virtex-4 FPGA, 25Hz processing under 3W power consumption was achieved.

The optical flow algorithm is another main scope of 6D-vision. Figure 3 shows a trend of the optical flow.

According to [10], the image based motion field estimation approaches are classified into the following three strategies:

- model based approaches,

- sparse feature tracking methods using multiple image frames,

- dense scene.

The model based approaches utilize physically constrained object or human models, but require models in a large variety of situations. The sparse feature tracking such as well-known LKT-tracker yields only sparse information for limited feature points, and not enough. The dense optical flow tracks for every single pixel of the input image. In addition scene flow tracks the pixels in 3D domain including distance. Dense 6D tracking algorithm was implemented on an NVIDIA graphics adapter with CUDA capability, and achieved 25Hz @ 640x480px input images. The scene flow algorithm is also described in [11].

Dense scene flow gives a flow information on each visible pixel, however a medium-level representation would be useful in order to capture the objects. A representation named "Stixel World" is introduced for such analysis, and dynamic stixel world is calculated from series of stereo images [12, 13].

SLAM

Simultaneous Localization and Mapping (SLAM) is important technique for robot navigation in an uncertain circumstance. For autonomous driving, in which a map is assumed to be provided, SLAM is important for localization and make a matching with the given map. Depending on the application, an emphasis is placed on either localization or making map. Figure 4 shows a trend of SLAM. There is a trend that grid based approach is for making map purpose, and landmark based approach is took for localization purpose. For autonomous drive the grid based approach is likely used [14,15].

PLANNING

There are limited papers describing planning algorithm of autonomous driving. According to the papers describing the general architecture of robot cars [16,17,18], the planning portion consists of roughly three layers as,

- Mission Planning,

- Behaviors (Maneuver Planning), and

- Path/Motion Planning.

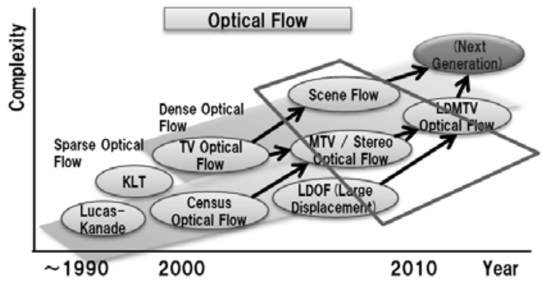

Figure 3: Trend of optical flow

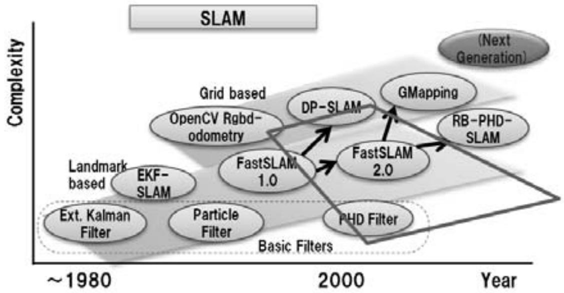

Figure 4: Trend of SLAM

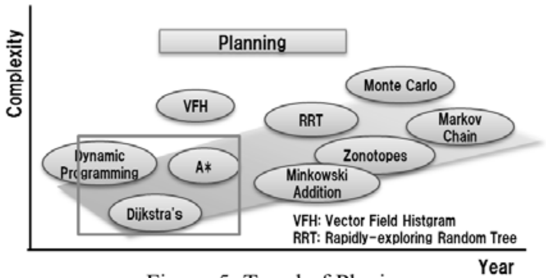

Figure 5: Trend of Planing

Mission Planning

The mission planning is most abstract and at the highest layer of the hierarchy. From a given road network information, it creates a directed graph which represents the way the vehicle should follow. In AnnieWAY [17] it finds the optimal route from checkpoint (start) to another (goal) using A* graph search algorithm operating on the internal representation of the road network.

Behaviors

The behaviors or maneuver planning is located at the middle layer of the hierarchy and computes actual driving maneuvers to achieve the waypoints specified along the path determined by the mission planner. It is based on the concept of identifying driving contexts such as, making lane-change, precedence, and safety decisions respectively on roads, at intersections, and at yields [19]. The behavior subsystem of the robot car Boss [19] is provided a cost graph containing the cost-to-goal associated with available path from the mission planner as an input. The cost graph is the baseline for current road and lane decisions by behavior subsystem.

Path/Motion Planning

The path/motion planning computes an actual moving path avoiding obstacle or collision. It is divided into two parts depending on the environment of the vehicle as planning in lane/road and planning in zone/parking.

Lane/Road Planning: The lane planner in Boss [20] computes a plan to follow the current lane and to avoid static and dynamic obstacles. In order to achieve this, a trajectory generation algorithm [21] is used to compute dynamically feasible trajectories. AnnieWAY [22] uses a Spatiotemporal stat lattices [23] for searching the path.

Zone/Parking Planning: The zone planner in Boss[20] uses a lattice planner that searches over vehicle position and orientation using a search algorithm described in [24]. The zone planner in AnnieWAY is described in [17].

CONCLUSION

In this paper a brief survey of technical trend of autonomous driving algorithms is shown. The research for autonomous driving are still going on, there should be more advanced algorithms until actual autonomous driving car is introduced into the market.

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