Video Based Curve Light System –

Sensor, System and Results

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Introduction

Following intensive research and development on part of the automotive industry and its suppliers our cars have been equipped with more and more intelligent systems for safety and comfort over the last decades. Systems like anti-lock braking systems (ABS), vehicle dynamic control (ESP) or the recent adaptive cruise control (ACC) require sensor technology of increasing complexity. While so-called inertial sensors were still sufficient for ABS and ESP, ACC and advanced safety or driver assistance functions rely on additional information about the environment. Thus, environment sensors are going to play an important role. Future cars will generate their own image of the environment.

As the driver gathers about 84% of all information relevant for driving visually [Sivak], vision based sensors have a great potential for environment sensing, e.g. the detection of the lane and objects in front of the car.

In the field of automotive lighting, high interest has been devoted on intelligent light control which takes advantage of the development of the sensors mentioned above. These systems are aimed to adapt the headlights to the vehicle environment and weather conditions. In the scope of an Eureka project [AFS], several lighting functions for an adaptive front light system have been defined. On winding country roads the light distribution is matched to the curvature of the road. To determine the curvature, sensors are necessary which measure either the current ego-state of the vehicle (e.g. acceleration, steering angle, ...) or the run of the lane in front of the vehicle. In this context, investigations have to be launched to identify the advantages for safety and comfort with curve light systems as compared to conventional low beam headlight. Besides, it is also of interest how non-predictive systems (e.g.

steering angle based system) differ form predictive (e.g. video based system) systems. First results on this topic can be found in [Hamm].

Safety advantages for the driver may not be based on safety disadvantages for the oncoming traffic so that glare aspects are be taken into account.

1 Sensors

A curve light system needs a sensor capable of providing information on the curvature of the road in front of the vehicle. Here, we have to distinguish between the run of the marked lane in front of the car and the future course of the vehicle. Assuming that the vehicle is been kept in the lane, both information is correlated but not identical. Differences can be identified on a straight road (pendulum movement) and in curves (cutting the corner).

The inertial sensors used in ESP systems (steering angle sensor, yaw rate sensor, acceleration sensor and wheel speed sensor) can only provide information on the current vehicle trajectory which can be predicted to a limited degree by qualified model based filters. The applied inertial sensors and their potential for course prediction are well known from the experience gained in the ACC development (e.g. [Uhler]).

In addition to vehicle position, environment sensors (video sensor, navigation system) are also capable of predicting the run of the road in front of the car. Investigations on navigation system based curve light control [Venhovens] show that the accuracy of the vehicle position from standard GPS and the accuracy of the digital map of a standard navigation system is not sufficient for all relevant situations. In contrast, the applicability of a video sensor for curve light control is rather unknown.

Hence, we use a video system as predictive system which is compared with a standard inertial sensor (steering angle sensor).

1.1 Video Sensor

The video sensor works on the principle of video based lane detection. There are numerous publications on this topic from various researchers, e.g.

[Diekmanns], [Franke]. The system used in our investigation is described in [Goldbeck]. As shown in Diagram 1, the video sensor consists of two monochrome CCD cameras (C1, C2) mounted behind the windscreen of the vehicle with a front view. The analogue stereo images are transmitted to a frame grabber for digitalisation. Similar to the human eye, 3D-data can be obtained from the stereo 2D image pair due to disparity.

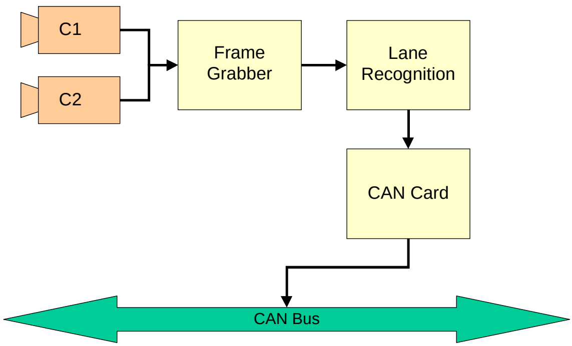

Diagram 1: Structure of vision system

For lane recognition, lane border points are searched in the grey value image. The search of the lane border points is based on the model of lane boundaries with a white or yellow lane maker on grey surface. In a grey value image these lane border points can be described by a characteristic dark-light-dark grey value transition. This transition consists of two (single) adjacent gradients of similar magnitude and antiparallel orientation, the so-called double gradients.

These points are used as input for a 3D-lane model (clothoid model) whose parameters (lane width, curvature, change of curvature, lateral vehicle offset, yaw angle) are estimated in a general extended Kalman filter [Bierman]. The estimated parameters can be transmitted via the built-in CAN card to the CAN bus and subsequent control units.

2 System

2.1 Headlight System

The test vehicle was equipped with a gas discharge lamp (GDL) projection module as low beam headlight. Rotation angles up to ± 20° in horizontal and ± 2° vertical direction could be realised by modifying a standard headlight. The control of the stepping motors for the rotation was accomplished by separate electronic control units with CAN bus interface.

Diagram 2: Headlight System

2.2 Control

Preliminary studies showed that the curve light control function and the swivel algorithm had to be matched to the different sensors. Hence, the comparison was carried out with one control algorithm for the predictive system and one for the non-predictive system. Both control algorithms run in parallel on the control unit to enable real-time comparison. Thus, control and sensor data of both systems can be recorded simultaneously while driving on the test track.

3 Performance Tests

The objective of our study is to evaluate curve light systems as seen by both the driver and the oncoming traffic. For this purpose, we used an approach as shown in Diagram 3. A subjective rating of comfort and safety as well as a measurable objective gain in safety are of interest from the driver's point of view. For the oncoming traffic, glare properties of curve light are compared with conventional low beam system.

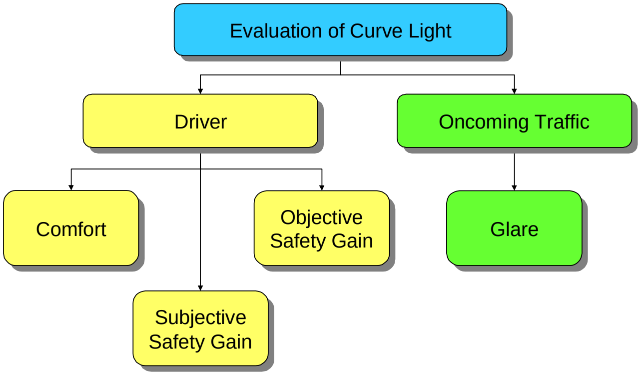

Diagram 3 : Evaluation scheme

The dynamic tests of the curve light systems were carried out on a public road with 12 curves on a distance of 2.8 km. This test track includes radii between 25 m and 450 m. All measurements were performed without disturbance of oncoming traffic.

3.1 Detection Distance

Detection distances of objects in curves were measured to investigate the objective safety gain. The test was carried out as shown in Diagram 4. Test objects were placed as targets on the right side of the test track in curves with different radii. The objects measured 0.4 m x 0.4 m in size with a reflection factor of 5%. The test persons were familiar with the shape and size of the objects and with the approximate position on the track. In a well defined distance to the target (offset) a retro-reflecting stop tag was fixed in a way that no additional point of visual orientation was given to the observer. Each of the test persons had to fulfil two tasks: firstly, to drive the test vehicle on the test track and, secondly, to press a button immediately after detection of the target. A distance measurement started when the button was pressed. A vehicle-mounted light barrier stopped the measurement when passing the retro-reflecting tag.

Three different systems were investigated: a conventional system, a steering angle based system and a video based system.

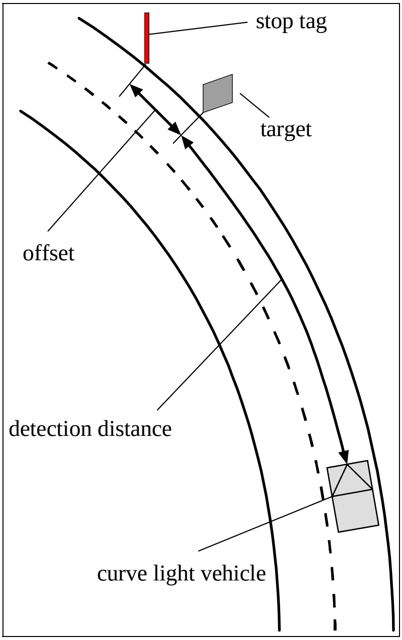

Diagram 4: Test setup

The detection distances determined for the three systems in left-hand curves of different radii are depicted in Diagram 5. Additionally, a typical breaking distance (at speeds of 50 km/h, 60 km/h and 70 km/h) is displayed for each curve radius.

As expected, the detection distance increases with increasing radii. Curve light systems, particularly the video based system, are capable of enhancing the detection distance compared with the conventional system. The advantage of the curve light systems increases with the radius. Of course, this only applies for the curve light relevant scope of curvature. Curve light systems will not be applied to very large radii.

Regarding the displayed breaking distance in Diagram 5 it becomes obvious that the detection distance of the conventional system is in any case nearby or even lower than the breaking distance. Therefore, any enhancement of the driver’s view yields a relevant gain in safety.

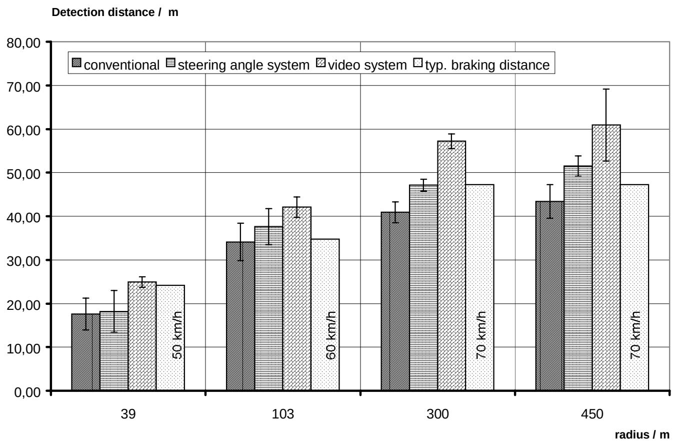

Diagram 5: Detection distance for left-hand bend (dynamic test)

The gain in response time can be derived from the differences of the detection distance (assuming vehicle speeds as mentioned above). Compared to the conventional system, the gain in response time is remarkable as shown in Diagram 6. With a curve light system based on steering angle information the driver is able to detect an obstacle in a left–hand bend up to 0.4s earlier and with a video based system even up to 0.9s earlier.

The detection distances are larger in right-hand curves (Diagram 7) than in left-hand curves due to the asymmetric light distribution of the headlights. In consequence, all detection distances even those of the conventional system are larger than the typical breaking distance mentioned above. The differences between the tested systems are quite small. Nevertheless, a slight increase in the detection distance can be found for curve light systems with small and medium radii.