Developing a New Type of Light System in an Automobile and Implementing Its Prototype

Spotlight on Hazards

An innovative new light function offers motorists more safety and comfort during night-time driving, using image sensors that detect potentially dangerous objects on the road and specially designed headlights that spotlight these objects. In field tests, this marking light presents a whole new picture of the roads at night.

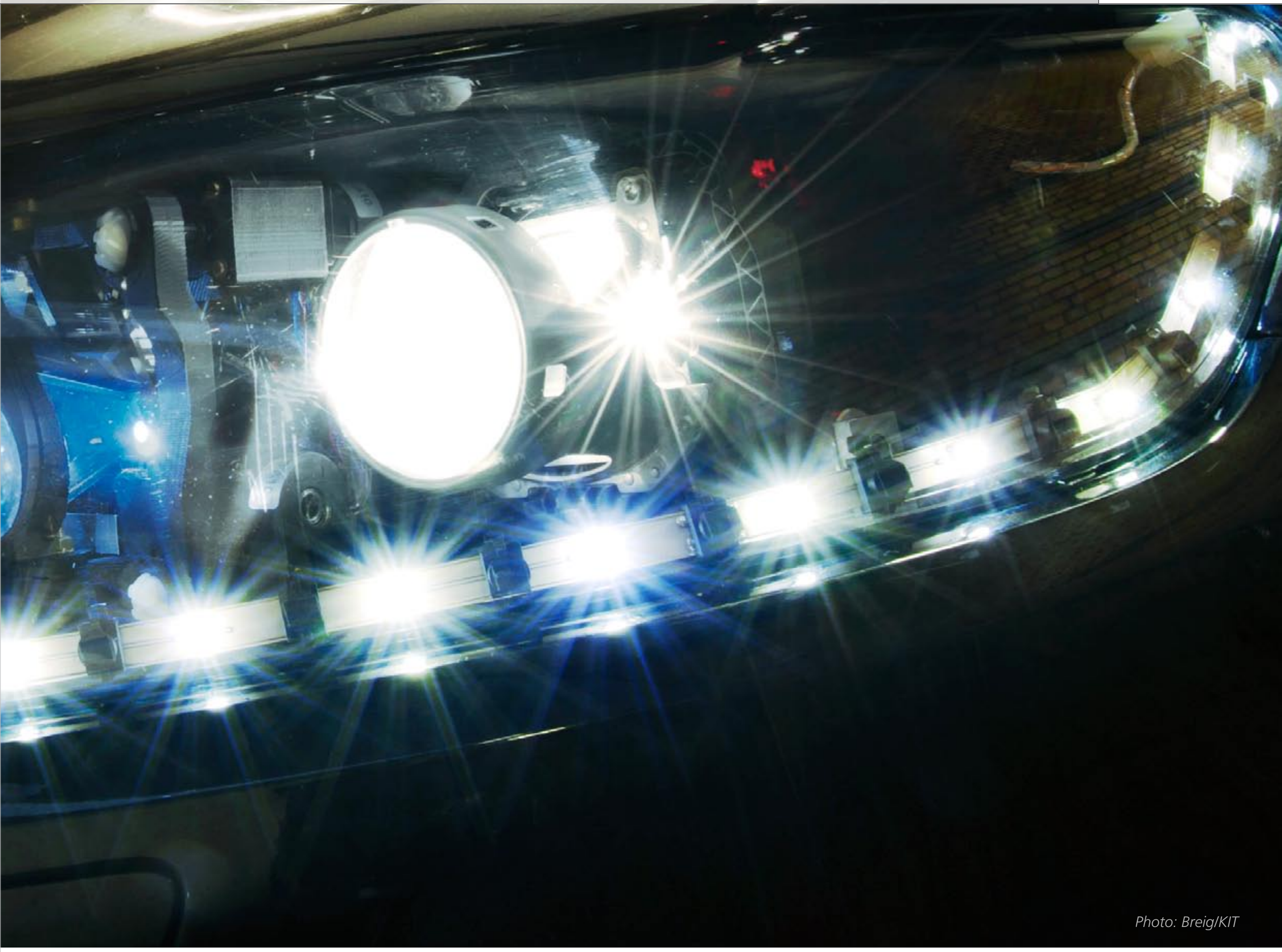


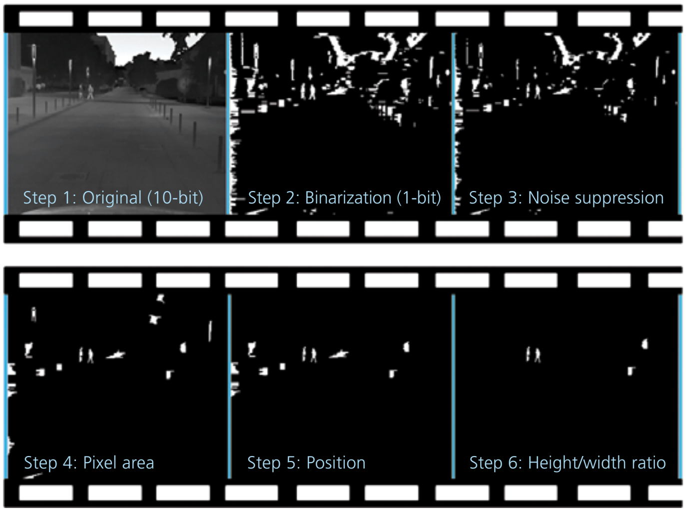
Photo: Breig/KIT

Motivation: High Accident Rate in Night-Time Traffic

The latest figures from the database of the German Federal Statistical Office speak for themselves. The year 2010 was the most accident-prone of the past eleven years. Around 2.4 million traffic accidents were reported in Germany, which is 4.2 % more than the year before. On the positive side, though, the number of traffic fatalities dropped to its lowest level of the past 60 years despite the increase in accidents. Although 3,648 people lost their lives on German roads last year, this is still 12 % less than in the year before. On closer inspection of the detailed records and reconstructions of how, when and where the accidents occurred, it is readily apparent

A potential collision object – a pedestrian – on the road is spotlighted (marked) by the intelligent light system.

Photo: Hörter/KIT



Candidates for spotlighting are detected in several image processing steps.

that the probability of being involved in a traffic accident is significantly higher at night. It is also clear that in contrast to the popular belief that highways are the most dangerous place for motorists, the country roads actually have the higher potential risk. Here, the speed traveled on roads outside of city limits combined with often inadequate road lighting and the high probability of hitting pedestrians, cyclists and wildlife can often lead to tragic accidents.

Live Objects on a Collision Course

All the facts mentioned above are no reason to just accept these nighttime phenomena as a given. Instead, they motivate science and industry to strive towards finding innovative technical solutions that make driving on night roads safer bit by bit – until the ultimate goal of "accident-free driving" has become a reality. One piece in this puzzle could be "marking lights", also called "danger lights". This new light system explicitly shows its special strengths on the "hotspots", namely on country roads at dusk, night and dawn. Live objects that are calculated to be on a collision course with the vehicle are spotlighted or "marked" with a specially designed light source to help the driver recognize and react to the object earlier. The chosen marking strategy regularly alternates the marking phase with a phase of constant illumination of the object, guaranteeing a maximum recognition distance and the resulting collision avoidance.

Essential Technical Components

When it came to implementing this new idea, it soon became clear that the desire for creating a "hands-on" test vehicle would lead to a mechatronic project par excellence. The productive interaction between engineers from fields of mechanics, electronics and computer science and the technical equipment they selected ultimately lead to the complex mechatronic test setup that was integrated into the Audi Q7. dSPACE MicroAutoBox, the selected prototyping platform, with its diverse analog and digital inputs and outputs, CAN and FlexRay interfaces, and its excellent computing performance, formed an unbeatable team together with the specifically configured RapidPro unit, which was installed in the harsh environment of the engine compartment. This team made it possible to flash the different controller models onto the MicroAutoBox very quickly and intuitively. The RapidPro unit then converted the input signals (which were mostly on the TTL level) into output signals with more power, and passed them to the light actuators.

Real-Time Database as the Central Synchronizer

First, it was necessary to master the flood of data that the integrated sensors provided (from an infrared camera, CMOS camera, inertial measurement platform, CAN connection, etc.). To handle this task, a real-time database was developed that not only synchronizes the varying arrival times of the sensor signals to a common time base, but also records the signals so that the test drives can be reconstructed in the laboratory whenever desired. For standardization reasons, this real-time database was implemented on an external, Linux-based high-performance computer that also communicates with the MicroAutoBox via a CAN network.

Image Processing Combined with Artificial Intelligence

In the causal chain of image preprocessing, detection, classification, object tracking and the subsequently derived warning strategy, image processing was a complex challenge because the input data (the appearance and pose of the objects to be marked) can come in very different shapes.

The goal of image preprocessing is to provide the most homogeneous base possible for the downstream

Photo: Breig/KIT

> "Right from the beginning, dSPACE stood by my side with help and advice, so I was promptly able to find the right combination of dSPACE products and have them available for us quickly."

Marko H. Hörter, KIT

processing steps. The existing gray-scale image (10-bit resolution) is converted into a binary image (1-bit resolution) by using a dual-adaptive threshold filter. This produces an image divided into two classes: foreground and background. At this stage, objects that are candidates for further consideration should be in the foreground.

The detector plays an important role: It discovers the image segments (blobs) in the preprocessed image scenery that have the same shape as one of the figures in the previously parameterized geometric shape pool. Simple, and thus real-time-capable, filter operations (such as length x width, number of pixels, position in the image, etc.) are used to minimize the number of potential image segments that are passed to the classifying mechanism.

However, before the classifier can decide whether a potential live object (such as a pedestrian, cyclist, deer, etc.) is present in the discovered image segment, this image segment needs a technical representation so that a numeric operation can compare the object with a previously trained data set. By converting the original image segment into a gradient image and dividing this into small square segments it is possible to depict the image information reliably enough for interpretation by a machine.

Performance Reserves for Separate Object Tracking

Thanks to the generous hardware resources of the MicroAutoBox, it was a natural decision to run the CPU-intensive operations, such as object tracking over time using Bayesian minimum-variance estimators, on the MicroAutoBox. By optimizing the process, it was even possible to execute several filter instances in parallel in order to estimate the initially unknown object size (such as the size of a human body) and thus more accurately infer the distance between the object and the vehicle. In addition, using the sheer unlimited modeling capabilities of MATLAB®/Simulink®, it was possible to easily and clearly implement the coordinate system transformations between the camera (2-D), the vehicle (3-D), and the light actuators (polar), and thus ultimately represent the entire function chain from the sensors to the final light-based object marking.

Interaction Thanks to a Common Language

To have not only the existing vehicle network but also all the decentralized components communicate with each other via CAN bus, all of the MicroAutoBox's available CAN channels were used. Whether from the light actuators (each with a dedicated microcontroller that also communicates via CAN), from the current speed, position or rotation rate of the inertial measuring platform, or even from the cyclically updated item list of the Linux-based high performance computer – all of the messages went to the MicroAutoBox communications node. Here they were reliably processed and, where appropriate, passed to a communi-

The technical components installed in the Audi Q7 test vehicle: 1) image processing, MicroAutoBox, inertial measurement platform, 2) signal conditioning (RapidPro), 3) light actuators, 4) FIR camera systems.

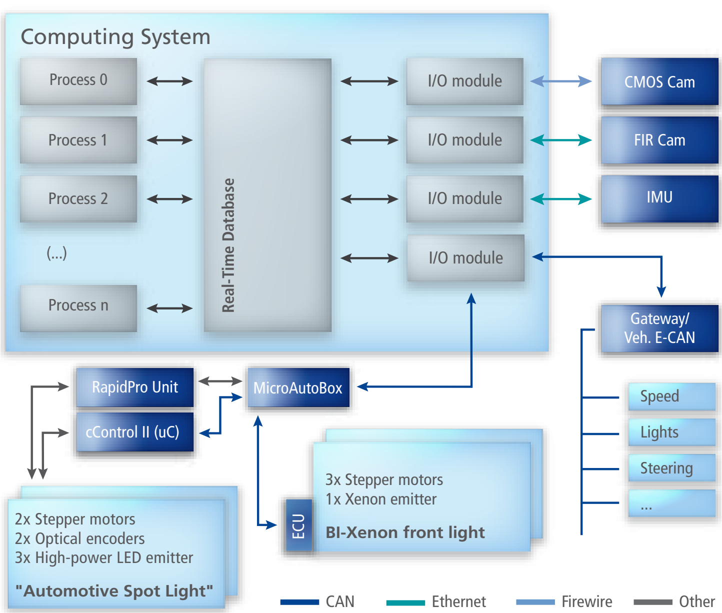
cation partner. This very valuable technical feature and the very intuitive modeling of the communication blocks in MATLAB/Simulink guaranteed a modular design and that the overall system could be adjusted flexibly to new technological conditions in the project.

System Tests in the Lab

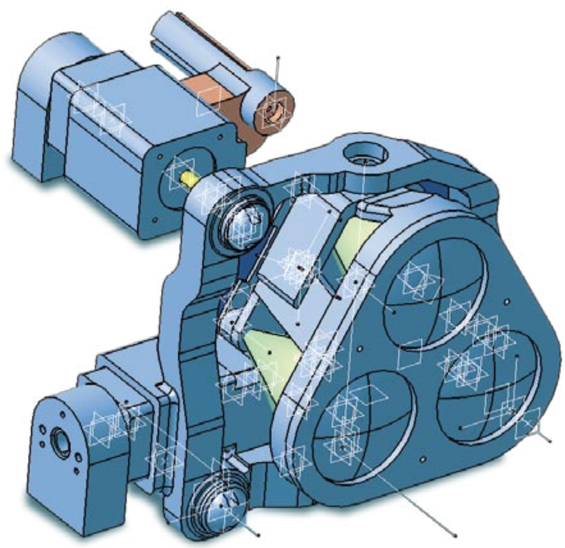
To use valuable work hours efficiently during the development of the overall system, the system tests in the laboratory played a very important role. These tests included identifying which light actuator parts needed to be controlled, then finding and parameterizing a suitable controller for them offline. In addition, thanks to the recording capabilities of the real-time database, complete test drives with all of the relevant accompanying information were reproduced in the lab, which greatly simplified the coordination of component interfaces.

System Tests with Real Test Persons

As is common in research on lighting technology, only the final field study can determine the usefulness and benefits of a new light application. Such studies rely on the most critical and most sensitive of all measurement instruments: people themselves. For this project, 35 volunteers enjoyed the opportunity to drive the test vehicle, filled to the roof with the new technology, on a closed-to-the-public highway through the Palatinate Forest. Measurement technology was used to determine the recog-



Prototype setup of the systems for object recognition, analysis and actuators.



Mechanical setup of the actuator integrated in the front light for the marking light.

Conclusion

- Technical realization of an experienceable entire system
- Easy system integration thanks to compatible interfaces
- Real-time requirements met by means of decentralization

nition distance as well as the optimal marking strategy. The first variable, recognition distance, describes the distance between the detection point at which the test person notices the test object and the position of the test object in the traffic area. The second variable, related to the marking strategy, reflects the ratio between the periodic marking phases and the static phases where the objects in front of the vehicle are spotlighted.

Empirical Findings

A statical analysis of all the data that was input in the system when the test drivers activated the steering wheel levers indicated an increase in the mid-range recognition distance of up to 35 meters for all test objects. At a cruising speed of 70 km/h, this meant an average of a nearly 2-second gain in driver reaction time for all test objects.

Marking Lights

The field study was completed without any significant technical complications, and all the subcomponents performed their services stably. Most of the voluntary test drivers were enthusiastic and look forward to this new lighting system someday going into production. Thus, the testbed implemented by the Karlsruhe Institute of Technology (KIT) is one of the first of its kind on an academic level that can clearly performs sensor activity and light-based object marking in traffic scenes. The original idea has finally become experienceable reality. ■

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> "dSPACE MicroAutoBox offers an enormous flexibility and computing performance to process the many different signals reliably."
>
> *Marko H. Hörter, KIT*

MBE Marko H. Hörter
As a research assistant, Marko H. Hoerter (MBE) developed an experienceable overall system in the field of light-based driver assistance systems at the Karlsruhe Institute of Technology (KIT), Institute of Measurement and Control Technology (MRT, Prof. C. Stiller) in Karlsruhe, Germany.