Image fusion for robust 3D reconstruction of traffic scenes

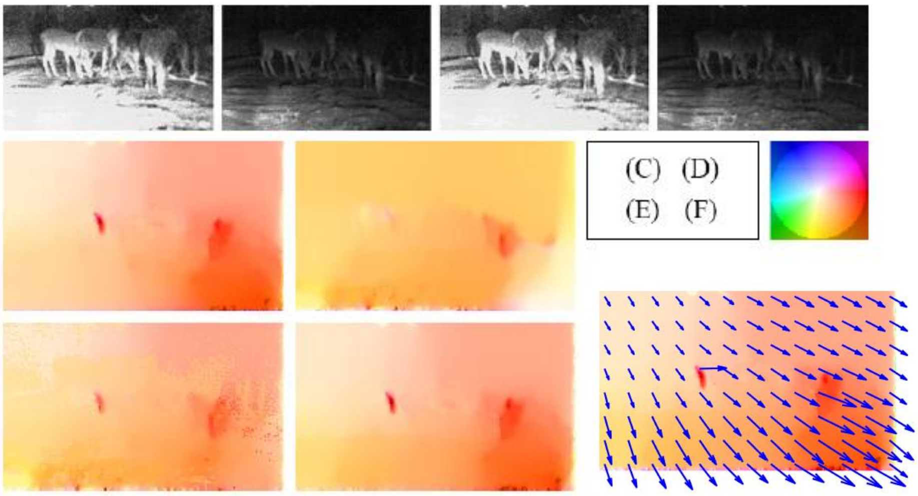

Figure 6: Image data sequence from our prototype camera system and the flow estimates for a set of data terms.

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1 Sammanfattning

This project is the natural continuation of a previous Vinnova project (VQM), where ideas for further research studies where identified.
The research subject concerns signal analysis from a video camera for image enhancement and reconstruction of 3D information of the environment.
Moving objects in the scene can be robustly identified even in the presence of severe limitations such as night time lighting conditions.
It is thus demonstrated that optical cameras are a good complement to radar and lidar systems, adding robustness to Active Safety systems.

The project concluded with the successful defence of a PhD thesis at Chalmers University of Technology in January 2016

2 Executive summary

Active Safety systems rely on sensors such as radar, lidar, and cameras to make critical decisions. The different sensors all have their own strengths and weaknesses, so a sensor fusion approach is needed for the active safety system to be robust. The sensors complement each others weaknesses.

In this project, the full potential of camera systems is explored through advanced image processing algorithms. It is shown that more detail information can be extracted from the camera by varying the exposure time, or by using small differences of consecutive images, or by utilizing the different sensitivities of the individual camera pixels. These methods are employed to make the camera robust to challenging situations where it would otherwise perform poorly such as fog, strong sun glare, or night time conditions.

This methodology is also applied to the problem of reconstructing 3D information of the environment from a series of 2D images, and to identify moving objects such as vehicles, pedestrians, animals etc. Cameras are thus a good complement to radar and lidar systems, adding robustness to Active Safety systems.

3 Bakgrund

Driven by the demand for automotive safety, research on advanced driver assistance systems (ADAS), such as the City Safety system at VCC, is pursued by the industry and academia. These systems, typically with a set of sensors based on radar, lidar and camera technology, may give warnings by sound or other alerts, or perform interventions such as autonomous braking and steering when a collision is at immediate risk or unavoidable.
Radar devices and laser-based devices, such as lidar, are both designed for range- measurements. They emit pulse signals and measure time-of-flight until the reflected pulses are received. Radar is well suited for range measurements of distinct objects, but its poor lateral resolution implies that it is not suitable to distinguish between different types of objects. Lidar is an increasingly relevant technology that has a high lateral resolution through mechanically scanning different viewing angles. It already exists in short-range

systems (City Safety is based on Lidar) but the practical implementation of the sensor for long-range sensing is expected to take several more years to reliably mature.

In line with previous research, leading manufacturers of sensor equipment for active safety features currently use a combination of radar and camera sensors. To classify objects at the side of the road that may or may not be entering the road in front of the host vehicle, cost effective camera technology which has a high lateral resolution and angle of view is suitable and assists with that task. The camera sensor output is used to detect objects of interest, such as pedestrians, and the radar helps by giving improved distance estimates of detected objects.

The high complexity of common traffic scenarios nevertheless makes the design of a reliable system challenging. As basis for the kind of critical decision-making that is involved in ADAS, highly reliable information is demanded for acceptable performance with regard to the rate of correct intervention and the avoidance of falsely triggered actions. The desire to reliably operate a system at increasingly high driving speeds adds to the challenge.

The full potential of camera-based systems is not yet investigated to a satisfactory degree. The currently employed camera systems, due largely to insufficient sensor performance for the task at hand, leave much to be improved with respect to robustness to demanding external conditions such as poorly illuminated night situations or foggy rain. The failures of current detection methods often correspond to poorly contrasted images. Poor contrasts in the image data could arise from a set of scenarios. Either the scene content itself is poorly contrasted in a certain spectral band, such as the visual spectrum of ordinary cameras, or the dynamic range of the scene is high which causes some scene content to fall outside of the sensors operational range and thus become clipped in the image.

In the context of multisensory ADAS, camera technology serves as an integral part, at a low cost, for long-range systems for detection of objects that pose potential threats. The combination of radar and camera is beneficial, as they have different advantages that complement each other. Still, we believe that, in parallel to research on radar-camera fusion, it is beneficial to address the individual performances of the respective technologies.

4 Syfte, frågeställningar och metod

The aim of the project is to improve the robustness of the image analysis stage in a camera based ADAS system. The specific questions to be answered is how images sequences from sensors operated with spectral and exposure diversity should be analysed to provide an increased robustness in challenging situations. Specific focus is on HDR scenes and scenes with poor contrast. The research methodology is based on literature review, algorithm development based on statistical methods and tools from optimization theory. The derived algorithms are evaluated on both synthetic image date as well as image sequences collected from the real world.

5 Mål

The goals can be summarized as:

- An increased understanding how camera systems with an increased diversity can contribute to a more robust estimate of the surrounding traffic situation.
- An increased understanding how to specify the performance of camera systems that offers spectral and photometric diversity for use in active safety systems.
- The examination of a PhD.

6 Resultat och måluppfyllelse

Current automotive optical based active safety systems have severe performance limitations in certain scenarios. Examples of such scenarios are the case when the scene has a high dynamic illumination range or when the contrast is poor, e.g. foggy conditions.
The conducted research has demonstrated the benefit of using ordinary camera hardware in novel ways, extracting extra information from exposure control and spectral sensitivity of the image sensor in order to estimate the environment. Particular focus has been on developing methods for robust optical flow estimation based on image sequences with varying exposure settings and sensor methods providing diversity in the spectral domain. The developed methods have been described in publications [1,3-4] and are included in the PhD thesis [2].

The results of the project provide additional knowledge to the field of computer vision for automotive safety systems and autonomous drive systems and hence contribute to the overall goal of traffic safety. The close collaboration with VCC during the project has increased the knowledge level at VCC in the area of computer vision for automotive applications. Hence the project has contributed to strengthen the competitiveness of the company.

7 Spridning och publicering

7.1 Kunskaps- och resultatspridning

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	x	
Föras vidare till andra avancerade tekniska utvecklingsprojekt	x	
Föras vidare till produktutvecklingsprojekt	x	
Introduceras på marknaden		
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

7.2 Publikationer

[1] T. Bengtsson, T. McKelvey and K. Lindström, On Robust Optical Flow Estimation on Image Sequences with Differently Exposed Frames using Primal-Dual Optimization, under review for possible publication in *Image and Vision Computing (*2016)

[2] T. Bengtsson, Image Reconstruction and Optical Flow Estimation on Image Sequences with Differently Exposed Frames, PhD Thesis (Göteborg : Chalmers University of Technology, 2015), https://chalmersuniversity.box.com/s/5g7oc6tc4cbf33ds33ljccdcizhvlmtd

[3] T. Bengtsson, T. McKelvey and K. Lindström, "Optical flow estimation on image sequences with differently exposed frames", Optical Engineering: The Journal of SPIE 54 (9) (2015): Article Number: 093103. doi: 10.1117/1.OE.54.9.093103.

[4] T. Bengtsson, T. McKelvey and K. Lindström, "Variational Optical Flow Estimation for Images with Spectral and Photometric Sensor Diversity" (Sixth International Conference on Graphic and Image Processing (ICGIP 2014), Beijing, China, 24-26 October 2014), 2015. doi: 10.1117/12.2180109.

8 Slutsatser och fortsatt forskning

The results from the project show that motion estimation, through optical flow, of scenes with a high dynamic range of illumination can benefit from fusing information from sequences of images of a low dynamic range image sensor where the exposure time is altered between images. The next natural step is to evaluate the methodology on a larger set of data directly tied to to the active safety application.

9 Deltagande parter och kontaktpersoner

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