High Dynamic Range Imaging for Stereo Vision in Automotive Applications

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***Abstract*—In this paper we analyze two high dynamic range (HDR) techniques, sequential multi-exposure and anti-blooming for their use in automotive stereo vision. Experimental results for scenarios at a tunnel entrance, tunnel exit and during driving within city speed limits are presented. We conclude that HDR imaging can be a vital tool for real world situations with difficult light conditions but may result in decreased quality in scenes with good illumination. The ghosting effect due to multi-exposure is present but not very significant for stereo vision.**

I. Introduction

Stereo vision, being a vital part in autonomous automotive applications and advanced driver assistance systems (ADAS), requires high quality image data to deliver acceptable results. Real world scenarios like tunnel entrances, tunnel exits, camera facing low sun or reflections of the sun can produce over- or underexposed regions in the image data if acquired without care. Figure 1 shows image frames from a video published by Hernandez-Juarez et al. [4] and demonstrates the problem statement. In the first frame, the scene is evenly illuminated by the sun and the disparity map thus does not show significant artefacts. In the second frame, the camera is blinded by the sun and its reflections on the road. The disparity map algorithm cannot deal with this situation, creating artefacts in the overexposed regions. The third frame depicts a tunnel exit. Since the scene outside the tunnel is vastly brighter than the interior, it is completely overexposed in the image data, which erases the majority of the information. A useful disparity map cannot be produced. The exterior of the tunnel could be exposed correctly by reducing the exposure time, however this in turn would underexpose the remaining parts of the image, e.g. the road directly in front of the vehicle.

These problems are due to a rather low dynamic range (LDR) of the image sensor in the camera. In image acquisition, dynamic range refers to the ratio between the brightest and the darkest light intensities of an image [8]. Modern commercially available camera sensors have a dynamic range of around 65db [10,11]. However, in the real world scenarios mentioned above, the dynamic range can exceed 80db, during night, with headlights and reflecting road signs this may even exceed 100db [3].

To deal with this, several techniques to increase the dynamic range can be applied. In this paper we first give an overview over current HDR techniques and then present our experimental data with two of those techniques for use in automotive stereo vision.

II. HDR-Imaging Techniques

A. *Sequential Multi-Exposure Imaging*

A well-known technique in the field of photography to produce HDR images, is to shoot multiple images with different exposure times one after another to cover the whole dynamic range of the scene and subsequently combine them to a single picture preserving the details [8]. The result is an image that can cover the dynamic ranges of the source images.

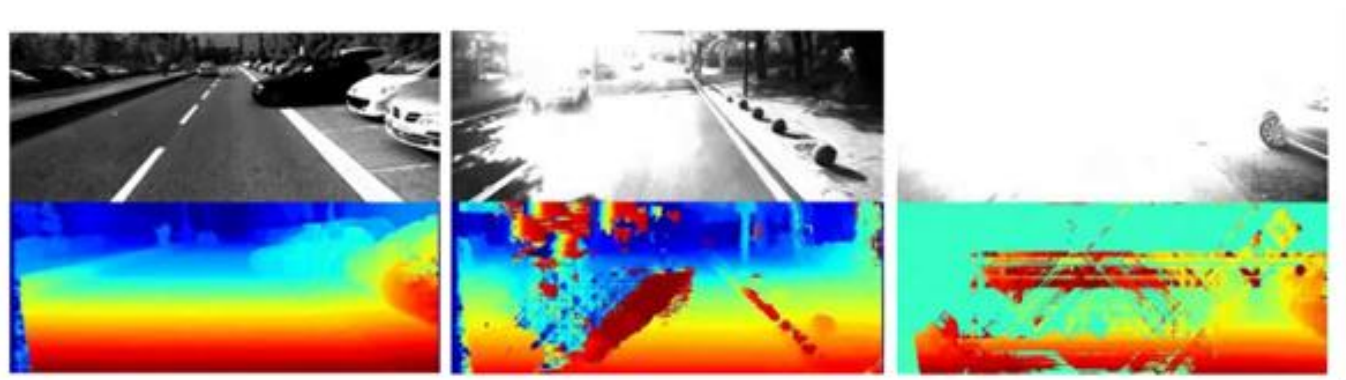

Figure 1: Three scenarios that are common in automotive vision applications and the corresponding disparity map below: evenly exposed scene (left), camera blinded by the sun and reflections (center) and a tunnel exit (right) Data published by [4].

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Drawbacks, especially for real-time and automotive applications, include increased computation time, which is required to merge the LDR images, a reduced frame rate, since several images are required to create the final image and artefacts from non-static scenes, often referred to as the ghosting effect. Ghosting occurs an object moves fast in-between the acquired frames, thus recorded by the camera as being in different positions. After combining the frames, this object appears twice in the HDR image, half-transparent resembling a ghost, hence the name.

Nevertheless, it is a viable option, since it is well researched and simple to implement. Therefore, we analyse it in this paper whether it is practical for automotive stereo vision.

B. *Simultaneous Multi-Exposure Imaging*

Aggarwal & Ahuja [1] have proposed a custom hardware setup to create HDR images. The light beam between the camera lens and the image sensor is split into multiple parts and redirected onto different image sensors using an assembly of mirrors. The sensors are then programmed to acquire data with different exposure times and the resulting LDR images are combined in the same manner as in the technique described above to create an image with higher dynamic range.

Alternatively, sensors which can acquire two different exposure times at the same time have been developed, e.g. by [9], however those cannot be easily purchased as off-the-shelf commercial products at the moment.

One obvious advantage of this method is that the images are acquired simultaneously, which reduces the undesired ghosting effect to a minimum and does not decrease the frame rate. On the other hand, it requires additional non-standard hardware components which are not readily available on the market and have to be custom made, thus increasing the cost, size and complexity of the system. Due to this, this approach was not considered in this paper.

C. *Non-linear Integration*

There are several variations of this method but in the end they all lead the same result, that the image sensor pixels have a response curve that resembles a logarithmic rather than a linear function. This means that, the more light a photodiode has already received, the more light is needed to increase its quantized pixel value. Many commercial image sensors (e.g. [11]) offer the feature of multi-slope or multi-reset integration, i.e. they allow to set one or more knee-points at which the photodiodes reduce their gain setting, yielding a piecewise linear response curve.

Although originally not designed to increase the dynamic range, similar results can be achieved with anti-blooming. In this case, special circuitry which allows a pixel to bleed off excess charge before it spills over to neighboring pixels and the image sensor response curve becomes logarithmic, similar to Figure 2 [12].

Contrary to the multi-exposure techniques only one image has to be acquired and no further post-processing is needed to yield a HDR image. On the other hand, in general the bright regions of an image suffer from reduced contrast.

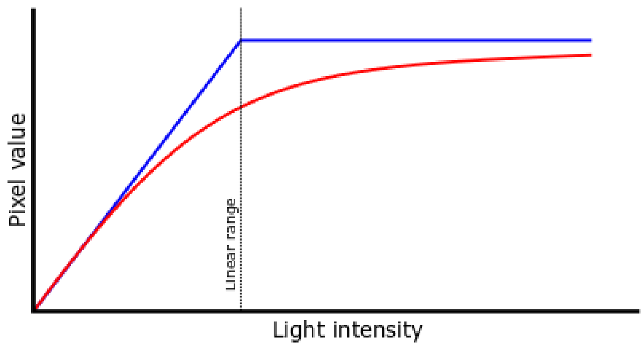

Figure 2: Schematic comparison of linear (blue) and logarithmic (red) image sensor response curves

III. Previous Work

Akhavan, Yoo & Gelautz [2] have explored possibilities for combining stereo matching algorithms with HDR image techniques so that the 3D-scene reconstruction benefits from the increased level of detail. Their work does not focus on a specific application area and only considers generated datasets, therefore does not deal with the challenges of real-world outdoor environments.

Görmer et al. [3] analyzed the problem of low dynamic range with automotive applications in mind, however focusing more on single camera tracking tasks, whereas our area of interest lies on dual camera stereo vision. Moreover, they used simultaneous multi-exposure image sensors, which are difficult to obtain.

They asserted that multi-exposure fusion with images taken one after another cannot be used for non-static scenes. In this paper we analyze whether this is really the case.

IV. Experimental Setup

The experiments were conducted with a stereo camera based on a custom PCB which employs the two commercially available E2V EV76C570 CMOS 2MP image sensors [10] 270mm apart. KOWA LM6HC lenses with 6mm focal length were used and their aperture set to the minimum of F2.8 to let in as much light as possible.

The image sensors were programmed to have multiple region of interests (ROI) to be taken automatically one after another, each with a different exposure time. This guarantees

Figure 3: The camera used in the experiments, assembled and as a PCB

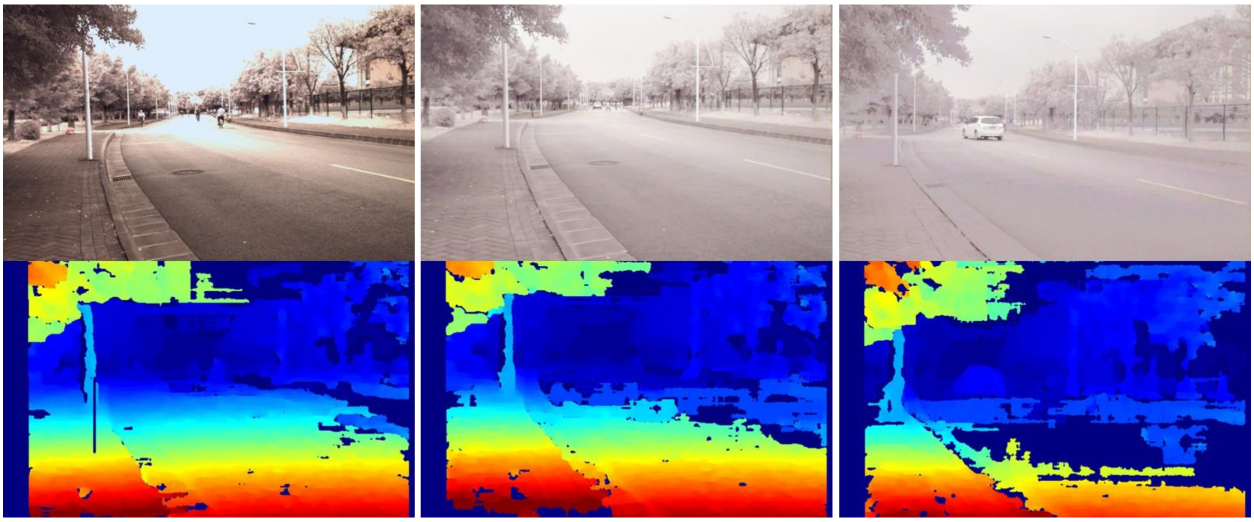

Figure 4: LDR image (left) compared to multi-exposure HDR images with exposure time difference factors of 4 (center) and 8 (right) and the corresponding disparity maps in good light conditions

minimum delay between the acquired images, which is required to reduce the ghosting effect for sequential multi-exposure HDR imaging. To further keep the ghosting at a minimum, only two different exposure times were taken to be merged into one. An additional measure is to ensure that the image with the shorter exposure time is taken first.

EV76C570 also supports control of the photodiode anti-blooming. For the anti-blooming experiments, the corresponding parameter was set to the highest possible value in the image sensor and turned off in the other cases.

The experiments were conducted during sunny weather with measured light differences of almost 80db. For the LDR and anti-blooming images, the exposure time was set to 42ms to inside the tunnel and 1ms outside. In the multi-exposed case the exposure time of short exposed (darker) image was fixed to 5ms inside the tunnel and to 0.3ms outside. If not otherwise mentioned (as in figure 4), the exposure time of the long exposed (brighter) image was set to a factor of 16 times higher than the short exposed one. The two unequally exposed images were merged with the technique described by Debevec and Malik [7] and afterwards tone mapping was applied with the operator described by Reinhard et al. [6].

For all three approaches pre-processing by histogram equalization and bilinear filtering was applied, before computing the disparity maps. The disparity maps were created with the semiglobal matching algorithm by Hirschmüller [5]. The parameters were kept the same across the three different approaches to be comparable.

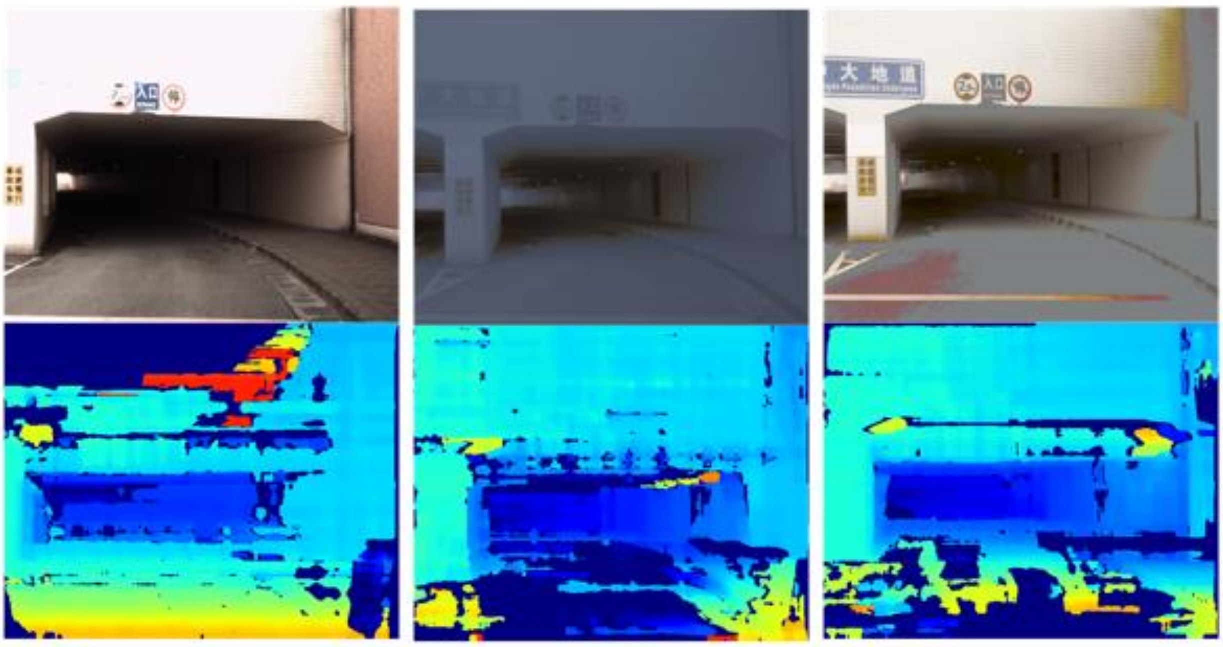

Figure 5: Comparison of LDR (left) and HDR with anti-blooming (center) or multi-exposure (right) and the corresponding disparity maps when facing a tunnel entrance

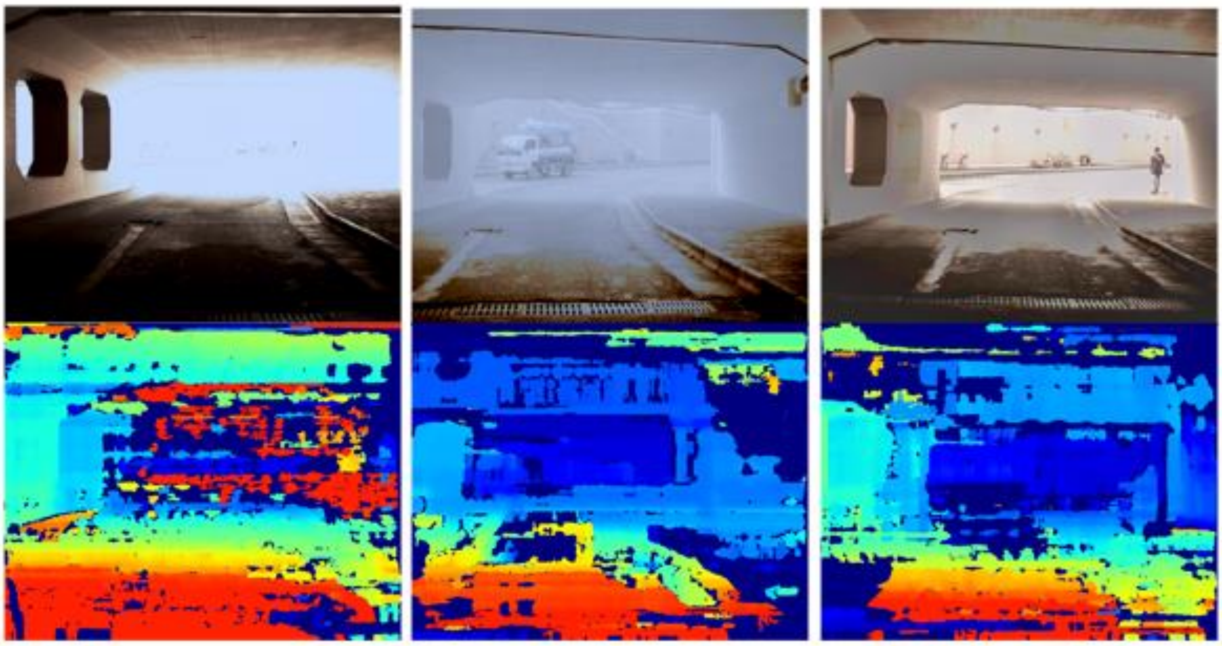

Figure 6: Comparison of LDR (left) and HDR with anti-blooming (center) or multi-exposure (right) and the corresponding disparity maps when facing a tunnel exit

V. RESULTS

A. Normal light conditions

A first test is performed to compare the disparity maps from HDR- and conventional images in a situation with good light. In Figure 4, a single-exposed image next to HDR footage with a difference factor of four and eight are shown. The result from the conventional method performs best as its disparity map gives the smoothest transitions of depth changes. The disparity maps from HDR images show increasingly noise and areas on the street without depth information. Hence, due to better quality of disparity information and less necessity for computations, conventional imaging is preferred in good light situations.

B. Facing tunnel entrance

Figure 5 a scenario when approaching a tunnel entrance. In the LDR image, only the exit is visible. Note that the tunnel is in fact illuminated, yet this is still not enough to recognize details, e.g. people or obstacles on the road, in the LDR image, because the sun outside is vastly brighter. For the LDR image, the disparity map for the scene outside of the tunnel can be computed quite well (except for the top left corner which is overexposed), the inside of the tunnel however lacks detail, e.g. the curvature of the wall. These details can be resolved with both of the tested HDR approaches, however, similar to the normal light situation from figure 4, the computed disparity of the road suffers from lack of contrast compared to the LDR image.

C. Facing tunnel exit

The situation when exiting a tunnel is more challenging, since the incoming light overexposes an even larger area in the image, than the underexposed parts in the tunnel entrance scene and erases the information almost completely as seen in the top left image in figure 6. The corresponding disparity map can hardly be used to infer information about the situation outside of the tunnel. The anti-blooming HDR image shows much more information but clearly lacks contrast in the bright regions. In its corresponding disparity map the distance to the wall and the vehicle can be estimated, albeit rather inaccurate. Similar results can be seen in the disparity map of the multi-exposed image. Here, the person on the right side of the image can still be recognized.

D. During driving

To examine the influence of the ghosting effect on the disparity map algorithm, scenes from a car, driving at a speed of 50km/h on a street were analyzed. As figure 7 shows, very little ghosting is present for cars moving in the same direction, since the speed difference relative to the viewer is comparatively small. The largest effect is visible on the road sign in the top left of the image: after merging it is displayed twice, slightly displaced. This might be a problem for sign detection and tracking algorithms, for disparity map computation however, this does not matter significantly. The result is simply, that the object on the disparity map becomes slightly wider than in reality, in the case of the road sign by 10 pixels or approximately 19%. Driving with speeds much larger than the examined 50km/h will certainly increase this effect.

VI. CONCLUSION

Experimental results for using high dynamic range imaging with stereo vision in difficult light situations were presented. The largest benefit is present in scenarios when entering and exiting a tunnel, to be able to recognize the details on the

Figure 72: Top: a multi-exposed HDR image taken at a speed of 50 km/h. Center: the top left corner of the above image showing details of the ghosting effect. Bottom: Detail of the disparity map computed from the top image

inside or the outside, respectively. Overall, HDR through multi-exposure fusion performs slightly better than non-linear response curve HDR.

Although the ghosting effect is obviously present in multi-exposure fusion, for the disparity map computation it is not very significant when driving within city speed limits. Moreover, it could be reduced by increasing the frame rate. Both HDR techniques suffer from a lack of contrast in the image, which increases the noise and holes in the final disparity map. This is especially evident in the almost textureless parts of the scene, most importantly the road. Preprocessing, e.g. through histogram equalization can reduce but not completely eliminate this problem because this procedure also contributes to the noise in the image. Therefore, we recommend to keep HDR off in normal light conditions and only activate it when needed.

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