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Application of HDR algorithms to solve direct sunlight problems when autonomous vehicles using machine vision systems are driving into sun

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ABSTRACT

Just after sunrise and before sunset the sun can shine directly into driver's eyes making it more difficult to see the road ahead. The direct sunlight problem creates a serious risk for human drivers as well as machine vision systems for autonomous vehicles. In 2016, the on-board cameras of a Tesla level 2 autonomy vehicle were unable to detect the side of a white truck due to bright sunlight. In order to solve the direct sunlight problem, we apply high dynamic range (HDR) imaging algorithms to the machine vision system of Lawrence Technological University's autonomous electric research vehicle and measure how well the system performs in direct sunlight. A Raspberry Pi is used to capture several manual exposure frames and compose HDR frames using three HDR algorithms provided by OpenCV 3. The resulting frames are supplied as input to the autonomous vehicle. Standard dynamic range (SDR) images captured using auto exposure are compared to equivalent HDR frames using various quality metrics. Objective assessment metrics are also performed to compare the color and contrast of HDR and SDR frames. Results show the system performs best when using HDR frames generated by the Mertens algorithm.

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1. Introduction

1.1. Driving in direct sunlight

Driving into direct sunlight during sunrise and sunset is considerably difficult for human drivers. Local and international news outlets have reported thousands of accidents [6] and several deaths [12] that have occurred due to the difficulty of driving into direct sunlight.

An analysis of a large car crash database by Sudeshna Mitra at the Indian Institute of Technology Kharagpur found “evidence that sun glare affects intersection crash occurrence” and concluded that “periods of extreme sun glare reduce the ability to safely operate a motor vehicle.” [8] Gray et al. conducted a study on the safety margin drivers use when making turns and found that “the presence of glare resulted in a significant reduction in the safety margin used by drivers” and that the “the mean number of collisions was significantly higher in the glare conditions than in the non-glare conditions.” [3].

Intelligent computer vision systems such as autonomous vehicles are also susceptible to glare caused by direct sunlight (See Fig. 1). In 2016, the first death in an autonomous car occurred when a Tesla Model S collided with a white tractor trailer. Tesla stated the incident occurred because “neither Autopilot nor the driver noticed the white side of the tractor trailer against a brightly lit sky.” [13].

The presented research aims to reduce susceptibility to glare caused by the sun using high dynamic range (HDR) imaging algorithms. An analysis is provided by comparing HDR and standard dynamic range (SDR) frames. Performance is measured using Lawrence Technological University's Autonomous Campus Transport Vehicle (ACTor) [14] and by analyzing image metrics.

1.2. Machine vision

Digital cameras are only able to capture a very small range of brightness values [10] because they must capture an entire frame at a given global exposure. Since the luminance space is limited, the auto exposure algorithms must make trade-offs in an attempt to display the relationship between light and dark areas. Cameras capturing images of direct sunlight with standard dynamic range must correct for the bright sun and the resulting image typically

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Fig. 1. Image of direct sunlight using automatic exposure correction. Road lines are difficult to see in direct sunlight and the image is slightly discolored.

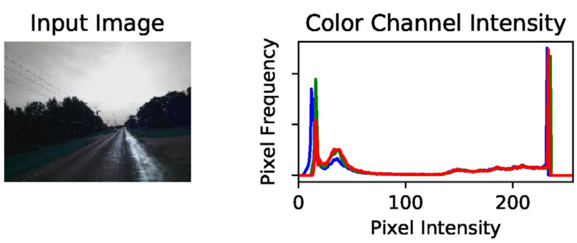

Fig. 2. Image of road taken in direct sunlight has a large amount of low and high intensity pixels. Very few pixels are of optimal intensity.

has an over-exposed background and an under-exposed foreground. Fig. 2 shows how a single global exposure creates too many very bright or very dark pixels.

In order to reduce this effect, images must optimize local exposure. This means the exposure of a given pixel is only effected by the brightness of nearby pixels.

1.3. Previous work

Nayar et al. proposes a method for local exposure correction on a per-pixel basis [9] called High Dynamic Range (HDR). Several images are taken at various exposures ranging from over exposed to under exposed. An HDR exposure fusion algorithm then blends the images so the image is properly exposed in all regions.

Three HDR algorithms are implemented in OpenCV: *Debevec*[2], *Robertson*[11], and *Mertens*[7].

Robertson [11] and Debevec [2] generate HDR images by using recorded exposure times for each frame to recover radiance values for each pixel of the image. The radiance values are converted to weights which are applied to each frame. The resulting pixel is the weighted average of the frames. The primary difference between these algorithms is the objective functions used to recover radiance values and the method for computing weights.

Mertens is an exposure fusion algorithm which composes an image by applying weights to each pixel using saturation, contrast, and exposure measures recovered from the frames themselves. Unlike Robertson and Debevec, the physical exposure times for each frame are not needed. Finally, Laplacian pyramids are used to blend the final image by applying the computed weighted averages to each frame [7].

HDR requires several images to be taken at various exposures very quickly and has therefore traditionally been used exclusively for photography. Recent works have proven that HDR can also be used for real-time video which is required for most computer vision applications. Hu et al. discussed how to reduce the ghosting

Fig. 3. Lawrence Technological University's Autonomous Campus Transport (ACTor) vehicle driving autonomously on parking lot roadways.

caused by the blending of several video frames of varying exposure [4]. Zimmer et al. apply HDR algorithms to freehand video and fast moving scenes [16]. Krawczyk et al. have developed methods for enhancing HDR in real time [5].

Though there has been much research regarding using exposure fusion algorithms to combat over or under exposed images of bright scenes, very little work has been done to analyze computer vision performance of HDR when used for autonomous vehicles driving in direct sunlight.

2. Methods

2.1. Data

For the presented research, a Raspberry Pi and Raspberry Pi camera module[1] is used as a low cost solution to measure the performance of HDR in computer vision. The Python camera module API is used to control the exposure of the camera and capture frames. Due to hardware limitations of the camera module, images are captured at a low frame rate in order to improve image quality for analysis. The Raspberry Pi is an excellent low cost solution for capturing low frame rate HDR video but specialized hardware is required for higher frame rates.

The OpenCV implementation of all three HDR algorithms discussed in the previous section is used to blend several frames into a single HDR frame. A frame is also captured using single auto exposure for comparison. The database used for this analysis contains over 150 images of roadways taken in direct sunlight using various exposures and exposure techniques.[2]

2.2. Performance evaluation

The primary method for evaluating the performance of HDR in direct sunlight is to use frames as input for Lawrence Technological University's Autonomous Campus Transport (ACTor) vehicle (Fig. 3).

ACTor is an autonomous electric vehicle who's software is currently being developed by LTU students. The vehicle is capable of safely navigating various roadways by recognizing lane markings, making intelligent decisions regarding physical surroundings (such as humans or other road obstacles), and autonomously following basic roadway actions such as making

[1] The Pi model 3B is used with the 2016 (v2) edition of the Raspberry Pi camera module.

[2] The complete dataset is available at https://robofest.net/datasets/direct_sunlight.zip.

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