Dynamic Sunlight Filter (DSF)

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ABSTRACT
Regulating optical power levels within various systems, such as cameras, requires today an electronic feedback control or offline data processing, which introduces complex and expensive systems. Sometimes the blooming is such that data is lost and cannot be recovered by any sophisticated software. We explore the unique capabilities and advantages of nanotechnology in developing next generation non-linear components and devices to control and regulate optical power in a passive way. We report on the Dynamic Sunlight Filter (DSF) enabling High Dynamic Range (HDR) for various types of camera. The DSF solution is completely passive and can be added to any camera as an external add-on.

Keywords: High Dynamic Range (HDR), Anti-blooming, Sunlight filter, Camera, Regulating light

1. INTRODUCTION

The need to regulate and control light power is relevant not only for sophisticated communication systems but also to everyday optical equipment such as consumer point-and-shoot cameras or even a common car rear-view mirror. Regulating optical power levels within various systems, such as cameras [1], requires today an electronic feedback control or offline data processing, which introduces complex and expensive systems. When regulation of light power fails, blooming effect is created. When light passes the lens of a digital camera and is captured by the CCD it is converted into an electrical charge. There is a limit to how much charge each pixel or photosite can store. Excessive charge in a photosite will overflow to its neighboring pixels causing an effect, which is called blooming. Manufacturers try to eliminate this effect by "anti-blooming gates" which can be compared to vertical drainage channels running beside each row of photosites [2]. These allow the overflowing charge to flow away without affecting surrounding pixels [3,4]. Though these anti-blooming gates are fairly successful at avoiding the problem, there are exposure situations where blooming can still occurs. Sometimes the blooming is such that data is lost and cannot be recovered by any sophisticated software.

The need for a better light control was the trigger for our effort in developing a family of products that are able to control and regulate light, in a passive way, all based on our already proven principles of Optical Power Control (OPC) [5,6] using nanotechnology and nanostructure optics. Most of our OPC past applications were controlling laser optical power for various optical systems and applications. We developed the Dynamic Attenuator for the Telecom [7] market, a device for limiting and regulating the optical power propagating in an optical telecom network. In this area we have also developed the Optical Fuse [8] that protects the optical network from over power and optical spikes. Based on similar nanotechnology we developed the Wideband Protection Filter (WPF) [9,10], which is designed to protect sensors as well as the human eye, from high power lasers impinging into optical systems, such as sights, binoculars, cameras etc.

In this paper we report on the Dynamic Sunlight Filter (DSF) [11], which is a passive solution dedicated to sunlight overpower, controlling and regulating applications. In the normal state, when incident light is below a predefined level the DSF is highly transparent, light just passes through it. As the light level is increased and gets more intense, such as in the case of morning sun, or the headlights of an approaching car facing the rear-view mirror, the DSF transmission decreases accordingly, eventually reaching a darkened state. The darkening effect is selective and is limited only to the intense light areas in the image. This process is reversible and the filter returns to its transparent state once the intensity of light decreases to its normal level.

2. DYNAMIC SUNLIGHT FILTER FOR ACHIVEING HIGH DYNAMIC RANGE IMAGE

The Dynamic Sunlight Filter (DSF), is a passive solution dedicated for sunlight controlling and regulating applications, and is based on the limiting mechanism [11]. The limiting functioning implies that in the normal state, when incident light is below a predefined level the DSF is highly transparent, light just passes through it. As the light level is increased and gets more intense, such as in the case of direct sun impingement or morning sun, the DSF transmission decreases accordingly, eventually reaching a darkened state. The darkening effect is selective and is limited only to the intense light areas in the image. This process is reversible and the filter returns to its transparent state once the intensity of light decreases to its normal level.

One of the DSF immediate applications, which is presented and discussed within this paper, is increasing the camera dynamic range. The major effect of the DSF, is reducing the saturation and blooming phenomena, and by that allowing the possibility of taking pictures at an intense high power environment, such as toward the sun.

2.1 Saturation and Blooming in a CCD sensor

Saturation and blooming are related phenomena that occur in all charge-coupled device (CCD) image sensors under conditions in which either the finite charge capacity of individual photodiodes, or the maximum charge transfer capacity of the CCD, is reached. Once saturation occurs at a charge collection site, accumulation of additional photo-generated charge results in overflow, or blooming, of the excess electrons into adjacent device structures. A number of potentially undesirable effects of blooming may be reflected in the sensor output, ranging from white image streaks and erroneous pixel signal values to complete breakdown at the output amplification stage, producing a dark image [12].

Those effects prevent the camera user from being able to capture detailed and clear image, when the levels of very dark and very bright, are both at the same scene. There are several solutions developed in order to solve this problem and achieve the required High Dynamic Range (HDR) for the camera. Some of those solutions require additional software imaging processing [13] specialized in HDR photography. The idea is combining several photos of the same scene, taken at different exposure setting, into one photo. The details of dark areas (from a longer-duration exposure) are combined with the details of brightly lit areas (from a shorter-duration exposure). The result is a single photo that is correctly exposed in both the dark and light areas [14]. This technique requires several photos taken at several exposure settings, e.g. time consuming effort.

Other technique exist today in the market is the Digital Pixel System of Pixim [15]. The core invention in the Digital Pixel System technology is the inclusion of an analog-to-digital converter (ADC) within each pixel of the image sensor. The ADC translates the light signal into a digital value at the immediate point of capture, thus minimizing signal degradation and cross-talk in the array and allowing for greater noise reduction methods. Once the data is captured in a digital format, a variety of digital signal processing techniques are used for optimal image reproduction. Because each pixel has its own analog-to-digital converter and the information generated is captured and processed independently, each pixel in effect acts as its own camera. The exposure time for each pixel is adjusted to handle the unique lighting conditions at that pixel location in the image sensor array. This technique is already implemented in several CMOS sensors, but is still expansive and complicated.

Contrary to the above techniques, we propose a complete passive solution that can be added to any camera as an external add-on. This solution can be also implemented within the vicinity of the sensor itself, providing similar light power regulation to the add-on solution.

2.2 DSF: a passive solution for increasing dynamic range of a camera

In Figure 1, an illustration of the DSF function is presented. The idea is based on the limiting mechanism, as discussed in 5 and 11. The DSF is placed at a focal plane of the imaging system, either on the sensor itself, or at a focus of an external add-on module e.g. a 1 to 1 magnification telescope, having a cross over. The light reaching the DSF will be limited only if its intensity is above a predominated threshold, such as originated from the sun in Figure 1. The light below threshold will be passed the filter with no significant change. The overall result is that the blooming effect is prevented from occurring and we get a net image with better contrast, details observation and clarity.

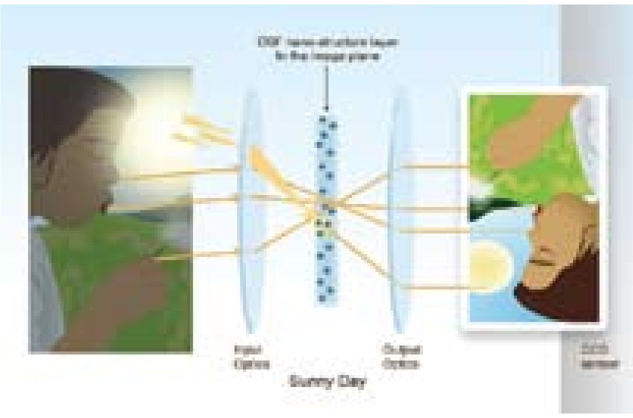

Figure 1:
Illustration of DSF effect when implemented into camera

3. DYNAMIC SUNLIGH FILTER (DSF) DEMONSTRATION

3.1 Experimental setup

The setup utilized for blooming preventing demonstration and attenuation measurements is presented in Figure 2

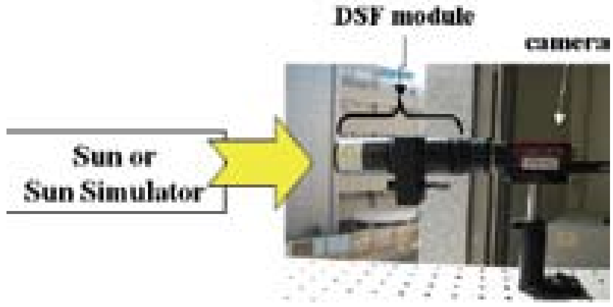

Figure 2: experimental setup scheme utilized for blooming preventing demonstration and attenuation measurements

The experimental setup is composed of a digital camera, e.g AVT Stingray F125C or F504C or Canon A75. In front of the camera we introduce an add-on module, which is composed of a 1x1 optics with ±11° field of view. We then introduce the DSF, in the focus of the module, with the possibility of removing it for reference experiments. During the experiments, the camera together with the add-on module were directed toward the sun, or the sun simulator. In order not to be dependent only the sun, we used a sun simulator system, which simulate the solar spectrum and power density. The intensity of the sun or the sun simulator was roughly 1kW/m^2. The following camera images are presented without any software modification.

We tested the DSF integration close to the sensor using the AVT Stingray F504C, and in this case without any add-on required (Figure 3)

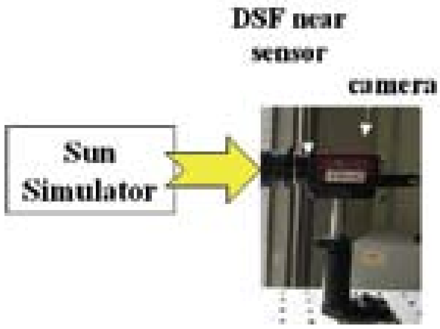

Figure 3: experimental setup scheme utilized for blooming preventing demonstration, where DSF is integrated in sensor approximation

3.2 Blooming preventing demonstration

The experiment was performed using the Canon A75 in Automatic mode, aligned together with the add-on module toward a building at a distance of few tens of meters. Both images that appear in Figure 4, left and right, were taken during the morning hours, looking into sunrise from behind the building. The first image, left, was taken without the DSF in the add-on module. Here the

only control was the Automatic Gain Control (AGC) and other software options implemented in the Canon A75 itself. Although the camera was on automatic mode, enabling it to choose its own gain and other parameters, the picture shows a very large blooming effect and hardly no details of the building can be seen due to the saturation of the sensor. This saturation is the result of the sun over-power, which creates the blooming phenomena as we discussed in section 2.1.
Next we introduced the DSF into the add-on module focus and kept all other camera parameters unchanged. By doing that, we managed to lower the blooming effect to the level where the building itself can be seen (see Figure 4, right). The improvement of the image clarity when using the DSF is demonstrated by comparing the two images (Figure 4). The image in Figure 4, left is completely saturated and therefore the building is completely hidden by the blooming effect. However, the image in Figure 4, right, has much better contrast levels with no significant blooming effect. As so, the building appears in the image with all details that could not been seen when blooming effect hidden everything.

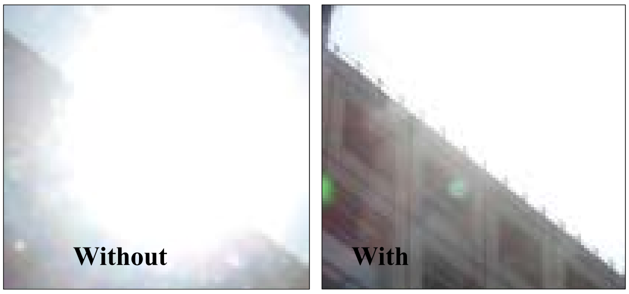

Figure 4: Image of a building with morning sun shining behind it, taken through the add-on module, **without** (left) and **with** (right) the use of the DSF

For "cleaning" the solar effect from the image, one should attenuate only the high power rays and keep the rest of the light rays at their initial power levels. This is exactly the DSF functions: above a certain threshold it limits the power passing through it to a constant level. In order to decrease only the blooming due to the sun, the DSF provides a local attenuation measured to be around 20dB. Within the rest of the field of view, the attenuation is kept low in the order of less than 1dB.
The experimental results show a significant improvement in the image dynamic range when using the DSF. It shows that the DSF provides a passive High Dynamic Range solution for cameras that do not possess this ability, and increases even more the dynamic range for those having this function already.

Similar results are presented when using the AVT Stingray F504C instead of the Canon A75 (refer to Figure 5). The blooming effect, which is the white line alone the building image (left image), is reduced dramatically when using the DSF (right image). The blooming effect decreases visibility of the whole image, and not only near the saturated pixels. The effect of adding a DSF enables the user the possibility of taking pictures in front of the sun and still be able to have a reasonable clear image.

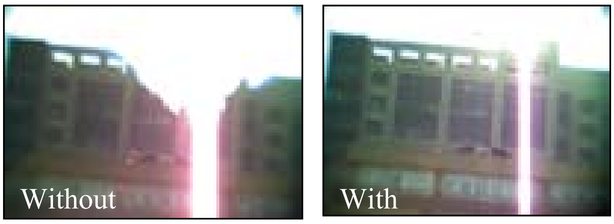

Figure 5: Image of building without (left) and with (right) DSF within an external module.

3.3 DSF integrated in sensor's proximity

We repeated the experiment with AVT Stingray F504C with DSF integrated near the camera sensor itself as described in section 3.1. Results of anti-blooming effect of the DSF when the light source is a sun simulator are presented in Figure 6. The image present KiloLambda's logo as viewed through the camera without (left) and with (right) DSF integrated near the camera sensor.

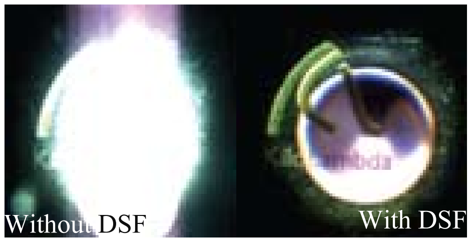

Figure 6: Image of KiloLambda's logo without (left) and with (right) DSF integrated near the sensor

4. DSF APPLICATIONS

DSF technology enables users to benefit from passive light control in a number of ways. The DSF element is designed to automatically vary its transparency in accordance to the amount of incident light without the need for active participation of the user or an electronic circuitry.
For instance, in photography, shooting toward the sun creates a tremendous challenge for the camera and the photographer. A DSF, when installed in a camera, will greatly ease this problem and even allow shooting directly toward the sun. Taking a photo toward the sun will no longer result in large areas of the image that is completely "burned" (or overexposed). The DSF has the unique property that it automatically reduces its transparency in the regions of intense light to a lower level that is acceptable by the camera, permitting correct exposure of the image. As a result, the unwanted glare associated with shooting against the sun and the reduction in dynamic range of the shaded regions will be eliminated. Thus images taken with a DSF will be greatly improved and reveal details that were otherwise obscured by the harsh sunlight
Digital photography is a wonderful technique, but it is not so great at handling scenes that are comprised of both very dark and very bright-lit areas. The human eye is great at it, but the sensors in digital cameras are not. We demonstrated in this paper a passive solution to overcome this problem, and show a way to transform any camera into a High Dynamic Range imaging tool. The DSF can be incorporated in the camera, either at the level of the sensor itself, or as an add-on module. The DSF will provide the ability to control the image contrast in a passive way, no need for a user interface. One of the early adaptors will be the use of the DSF as

an add-on for a security camera placed outdoors. In certain times of the day, for example, when the morning sun shines through the buildings, the camera will be completely saturated, and as so, the security system will be blind and useless. When adding the DSF solution events of zero data for periods of time are eliminated, thus increasing the reliability of the security system.
Todays battlefield has imaging systems everywhere, from simple observation and up to very sophisticate warning and offensive systems. Each imaging system has at least one camera. Since the direction of viewing is not always known and can be in certain cases in toward the sun, such events of camera blinding are very likely to occur. Adding the DSF as an add-on to the cameras, will increase their dynamic range and provide the user with the ability of continue operation even when looking towards the sun.

Figure 7: DSF applications range from camera protection, through sunglasses and finally windows covering

Other application of the DSF will include passive regulation of sunlight in several surfaces configurations, such as: car rear-mirror, sunglasses and windows. When DSF will be installed in a car rear-mirror, the blinding glare of approaching headlights will automatically activate the DSF to darken selectively the glared area and reduce the amount of reflected light to the appropriate low level. The same effect of automatic darkening of intensely illuminated regions should apply to windows and sunglasses. This exciting, cutting-edge technology will allow people to enjoy a cooler room in a sunny summer day by automatically darkening the window to a predefined level, thus passing less heat and resulting in energy saving.

KiloLambda's OPC technology is KiloLambda patent pending

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