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Intelligent Headlights

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Abstract: The primary goal of an automotive headlight is to improve safety in low light and poor weather conditions. But, despite decades of innovation on light sources, more than half of accidents occur at night even with less traffic on the road. Recent developments in adaptive lighting have limited flexibility and are not designed for all driving environments. This paper is regarding an ultra-low latency reactive visual system that can sense, react, and adapt quickly to any environment while moving at highway speeds. A single hardware design can be programmed to perform a variety of tasks.

Keywords: LED, Halogen Lamps, Xenon Lamps, DMD source.

I. INTRODUCTION

Traditional headlights consist of a small number of lamps with simple optics to direct a light beam onto the road. The latest sources such as Halogen Lamps, Xenon Lamps and more recent LED sources provide bright and comfortable color temperatures improving driving experiences. However, even with these new light sources the only control offered to a majority of drivers is to switch between high and low beams.

Even after 130 years of headlight development, more than half of vehicle crashes and. fatalities occur at night despite significantly less traffic [1]. More than 300,000 crashes and thousands of fatalities are caused by rain and snow at night annually [1]. Approximately 30% of drivers are stressed by glare causing hundreds of fatalities every year [2]. Thus, a headlight that adapts to the environment can be critical to improving safety on the road during poor visibility conditions.

II. CONSTRUCTION

This paper presents a new computational illumination design for an automotive headlight that is flexible and can be programmed to perform multiple tasks at high speeds. The key idea is the introduction of a high-resolution spatial light modulator (SLM) such as the digital micro-mirror device (DMD) present in DLP projectors. A DMD divides a light beam into approximately one million beams that can be individually controlled to shape the collective beam for any situation. A sensor (camera) is co-located with the light source and a computer processes images to generate illumination patterns for the SLM. While the design may seem straightforward and follows many works on projector-camera systems in computer vision, there are many challenges in building such a system to serve as a headlight. The accuracy requirements can be high since small errors in beam positioning and flickering are easily perceived and can be more disturbing than standard headlights. High accuracy can be achieved by minimizing the time from when a camera senses the environment to when the headlight reacts (system latency). Low latency is also required to avoid the need for complex prediction algorithms to determine where an object will move next.

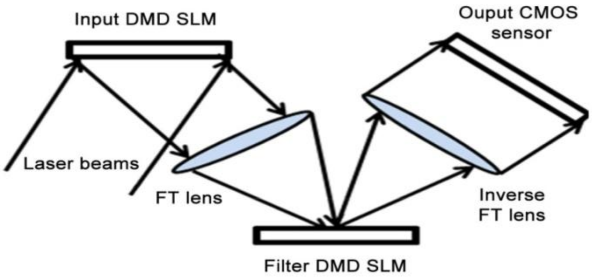

Fig 1: Ray diagram of DMD source

Intelligent headlight design consists of four main components: an image sensor, processing unit, spatial light modulator (SLM), and beam splitter. The imaging sensor observes the road environment in front of the vehicle. Additional sensors such as RADAR or LIDAR can be incorporated into the design to complement the camera. The processor analyzes image data from the sensor and controls the headlight beam via a spatial light modulator. The spatial light modulator (e.g., digital micro-mirror device, liquid crystal display, liquid crystal on silicon, etc.) modifies the beam from a light source by varying the intensity over space and time in two dimensions.

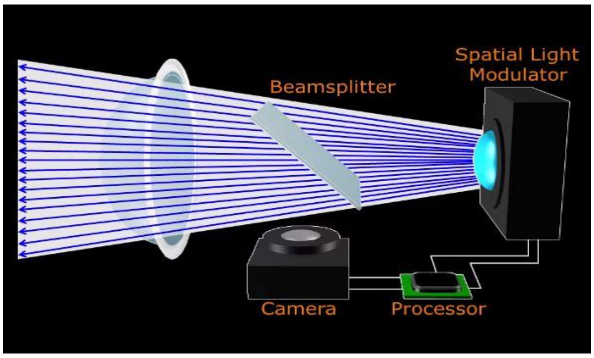

Fig 2: Construction of Headlights

The camera and SLM are co-located along the same optical line of sight via a beam splitter, which virtually places the image sensor and DMD at the same location.

III. MAPPING THE ROAD ENVIRONMENT

A camera with a CMOS sensor highly sensitive to light with correlated double sampling to significantly reduce noise was used to capture images. The camera is sensitive to visible and near infrared light since most objects of interest are detectable within this spectrum of light. Monochrome imagery is used to avoid the computational overhead associated with demosaicing the Bayer pattern. A global shutter with area scan is used to avoid distortion effects common with the rolling shutter. Latency is reduced via a pipelined pixel architecture that permits exposure during readout. A desktop computer provides an interface between the camera and SLM, performs image analysis, and controls the system. A PCI express 2.0 frame grabber (Bitflow Karbon SP) that transfers image data directly into computer memory without any buffering can be used.

IV. ILLUMINATION OF ROADS AT HIGH SPEEDS

The DMD chip is 0.7” with XGA (1024×768) resolution, which, essentially means the headlight beam can be divided into 786,432 smaller beams each of which can be turned on or off. This type of modulation gives unprecedented control over the illumination in space and time. Illumination patterns are received from the host computer by USB 2.0. A fan can be used to improve Heat Dissipation. FPGA (Field-programmable gate array) can be programmed to display patterns faster than 1 kHz. The FPGA receives data streamed from the host PC and produces the commands for a DMD controller to display the appropriate patterns on the DMD.

V. ANTI-GLARE HIGH BEAMS

Glare from the headlights, especially high beams, of oncoming vehicles causes significant stress and distraction at best and temporary blindness at worst. Trucks and other vehicles with headlights at high positions are the worst offenders. Although, glare is not often reported as a cause of accidents, hundreds of fatal night crashes attribute glare as a contributing factor every year [4]. Glare is especially problematic for the elderly whom take eight times longer to recover from glare as compared to a 16-year old [3]. Although high beams are a nuisance to other drivers, they are beneficial on narrow, curvy, and poorly lit roads, especially in rural areas where wildlife routinely jumps onto the road. The anti-glare problem and our solution is illustrated in Figure 3. Headlights from oncoming vehicles are detected in the captured image. Headlights are detected using the assumption that they are the brightest objects in the system’s field of view. A very short exposure (100 µs) time is used and the image is thresholded. False detections can be reduced by excluding connected components that are too small to be headlights. Once the locations of the vehicles are known in the camera’s reference frame, it is transformed to the headlight reference frame and the spatial light modulator blocks light in that direction. Since the resolution offered by the SLM is very high, only a small region above the detected headlight overlapping the oncoming driver’s head is dis-illuminated. This type of beam blocking can be done for any number of oncoming drivers without significant loss of illumination. Tail lights are detected to avoid illuminating the rear-view mirror.

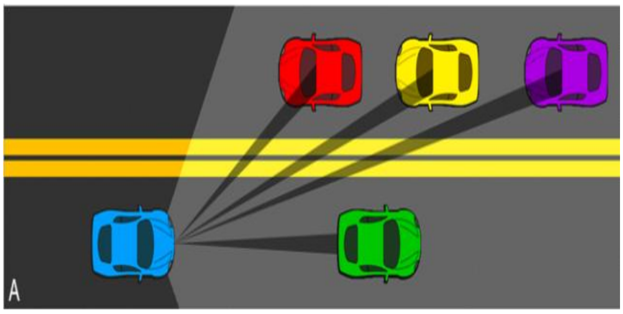

Fig 3: Illustration of high glare dis-illumination

VI. VERSATALITY OF THE SYSTEM

Intelligent headlight can also be programmed to perform other tasks, whereas, other advanced lighting systems may require additional light sources, sensors, mechanical parts, etc., or are insufficient due to low spatial resolution or high latency. The paper shows several tasks, such as visibility improvement in snowstorms, illuminating roads with better contrast and lane definition and detecting potholes and speed breakers.

A. Better Visibility in Snowstorms/ Rainfall

Driving in a snowstorm at night is incredibly difficult and stressful. Snowflakes are illuminated brightly and distract the driver from observing the entire road. Researchers in computer vision have proposed methods for removing snow from videos [5], [6], [7]. Processed videos can be displayed for the driver, but current implementations are not intuitive and, at times, distracting for the driver. This can be addressed with a solution similar to that for anti-glare, i.e., reacting to detected bright objects. The main difference, however, is that the density, size, and speed of snowflakes requires high-resolution, low-latency illumination to be effective. Therefore, we exploit the high-resolution and fast illumination beam control of the system to distribute light between falling snowflakes to reduce backscatter directly in the driver’s visual field. However, this application is significantly more challenging since (a) the size of snowflakes is very small compared to an easily detectable vehicle and (b) the quantity of snowflakes is several orders higher than the number of cars on the road. The goal is to send as much light as possible from the headlight to sufficiently illuminate the road for the driver while dis-illuminating snowflakes. Snowflakes were detected by performing background subtraction and binary thresholding.

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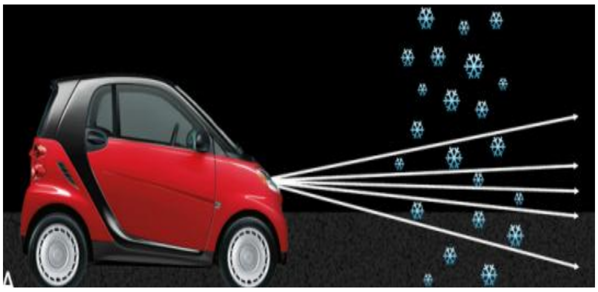

Fig. 4: Illustration of visibility in snow

B. Improved Lane Illumination

Sometimes the road is not clearly visible and no amount of illumination from a standard headlight can assist the driver. A few examples of such situations are snow covered roads, roads without lane markings or shoulders, and poorly lit roads. Our prototype can be used to brightly illuminate only the driver's lane to provide them with a visual guide. Opposing lanes, curbs, and sidewalks can be dimly illuminated to create a strong contrast with the driver's lane and also provide sufficient illumination to see obstacles (Figure 5A). For this application, images do not need to be captured or analyzed, and objects do not need to be tracked. After computing the homography with the road plane, the headlight acts only as an illumination device. For proof-of-concept, illumination patterns were pre-determined for the stretch of road. In practice, the position and speed of the vehicle will be used to dynamically determine the illumination patterns required for the road. Vehicles driving on the illuminated lane will experience disorienting illumination patterns because the system is calibrated to illuminate the road plane. Therefore, the beam can be adjusted where vehicles are detected in either lane as illustrated in Figure 5B.

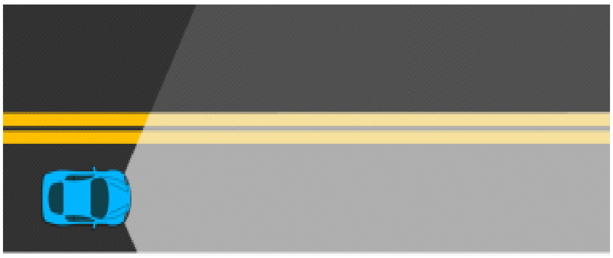

Fig 5A: Improved lane visibility

Fig 5B: Vehicle detection in either lane

C. Detection of Potholes and Speed Breakers

Major accidents in India are caused due to bad condition of roads especially during monsoons. Roads are laid with Potholes and Speed- Breakers which are a nuisance. Furthermore it affects the condition of the car and reduces the life of its suspension causing the car to break down in severe cases.

This problem can be addressed if the irregularities in the road are detected beforehand. Using image processing hardware integrated in the system, the image of the road environment is mapped. This image is then binary thresholded with the irregularities differently lit in contrast of the uniform surface of the road. The processor then receives a feedback of the existing irregularity in the road. It has to then signal the Intelligent Headlight to illuminate the irregularity differently so that the Driver can understand the vivid distinction between the irregularity and the drivable road.

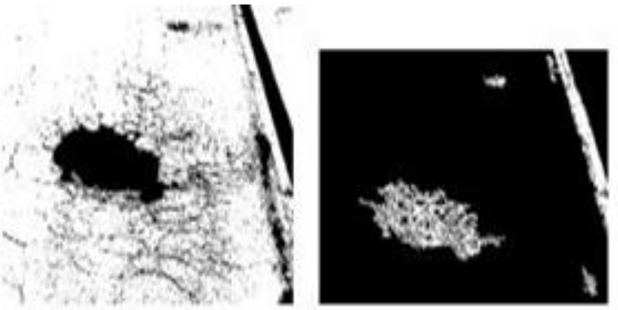

Fig 6: Binary thresholding of potholes

VII. OTHER APPLICATIONS

Generally speaking, programmable headlight is a low-latency reactive visual system with many uses outside of the automotive field. It has the flexibility of illuminating or dis-illuminating any fast moving object. An interesting application is studying the trajectory of fast moving objects or fast events. Typically, to capture these types of images, an expensive camera is needed and the room needs to be brightly lit causing a decrease in contrast. Instead, with our system, only the objects of interest need to be illuminated.

VIII. CONCLUSION AND FUTURE WORK

The intelligent headlight should not be a passive device that can only be completely switched on or off. It should be capable of adapting to the environment to improve safety in poor visibility conditions. Moreover, the design for adaptive headlights should not be limited to a single task. It should be capable of performing many different tasks to help the driver in multiple road environments. Intelligent headlight design provides unprecedented light beam control over space and time. It demonstrates the flexibility of the headlight for numerous tasks: allowing drivers to use high beams without glaring any other driver on the road, allowing drivers to see better in snow, and allowing better illumination of road lanes, sidewalks and dividers. This technology can quickly react to the road environment within 1 to 2.5 milliseconds, and, thus does not create any flicker to be seen by the human eye. Further research and development is needed to make this

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technology compact to fit within actual vehicle headlight compartments. Further engineering is required to make the system reliable in the presence of vehicular vibrations and heat. Lastly, more sophisticated algorithms and reliable software need to be developed before deploying this headlight design.

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