High-resolution laser headlamp - Generating adaptive light distributions with acousto-optic deflectors

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For generating light distributions in automotive headlamps, acousto-optic deflectors can be introduced in a new application. Their ability of high dynamic deflection makes them particularly interesting for scanning headlamp systems. For this application a suitable optical design and control electronics are required.

1 Introduction

Innovative automotive lighting technology has the goal to make driving by night more comfortable and safe. To achieve this, lighting evolves towards higher resolution systems that offer full adaptability in forming light distributions. This includes projections of informative symbols in the vicinity of the vehicle and goes hand in hand with increasing automation. Various technological approaches are in the race to become the future automotive lighting technology for high-resolution systems. They offer different characteristics in terms of resolution, efficiency and complexity [1].

One of these technological approaches are laser scanning headlamps. Scanning in this context means illumination by fast dynamic deflection of light, so that an observer perceives a stable illumination in the desired area. Scanning systems work on the additive principle. This means they generate light only where desired and do not rely on shutters or absorbers, so they are particularly efficient from an energetic point of view.

2 New approaches for laser scanners

Since scanning systems significantly rely on the performance of their deflection devices, this component is of high importance for the overall functionality. One type are mechanical deflection units that contain rotating or swivelling mirrors. Some of their disadvantages are: sensitivity to vibrations and shock, unfavourable deflection patterns and lack of dynamic adaptability due to their inert components. Scanners with mirror deflectors can only change the intensity distribution by timed modulation of the light source [2, 3].

2.1 Acousto-optic deflectors

In the presence of a longitudinal wave the refractive index of the material through which the wave travels changes periodically. This phenomenon is described by the elasto-optic effect and can be used to form a reflective diffraction grating. An acousto-optic deflector (AOD) takes advantage of this effect by applying acoustic waves to a crystal. An incident laser beam is deflected by Bragg diffraction, while the deflection angle can by controlled by the applied frequency or the spacing of the diffractive grating respectively. Due to their inertia-free operating principle, acousto-optic devices have a very high dynamic bandwidth and high angular accuracy. But they reach very small deflection angles compared to mirror systems [4, 5].

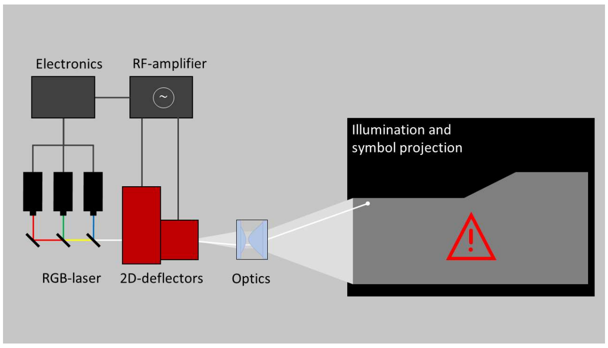

Fig. 1 *Schematic sketch of the laboratory setup. Combined with an RGB laser system and suitable optics, the AODs can be used for illumination with white light and the projection of coloured symbols.*

2.2 Lighting applications

For headlamp applications the ability to form various adaptive light distributions is most important. This can be achieved by using two AODs aligned perpendicular to each other to get a two-dimensional deflection. The high dynamic bandwidth of AODs opens up the possibility of forming the light only by adapting the scanning pattern. This is carried out by control electronics which determines the deflection angles at any time. One possible setup is illustrated in Fig. 1. It contains an RGB laser, two deflectors, optics and the corresponding electronics. White light can be generated by additive colour mixing of the three laser wavelengths, while the two-dimensional deflection carried out by the AODs gives full freedom of adjusting the deflection pattern.

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3 Optical characteristics

Since acousto-optic devices work by diffracting incoming light, their performance is wavelength-dependent. When deflecting three wavelengths simultaneously a result as shown in Fig. 2 can be observed. For lighting applications only white light is usable, therefore it is the regime where the wavelengths can be brought to an overlap which is interesting for the purposed setup. An electronic control reduces the deflection regime to the white light area by deflecting the wavelength after each other. This synchronised serial deflection eliminates the colour effects in the deflection pattern, but does not lead to a larger scan range.

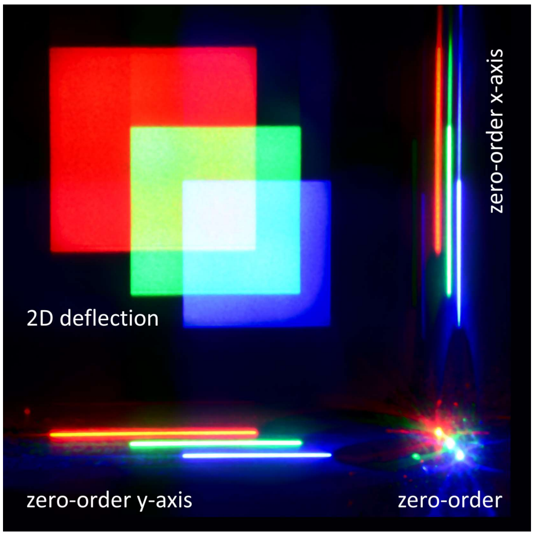

Fig. 2 *The wavelengths 450 nm, 320 nm and 638 nm are deflected onto a screen by two AODs in their full deflection range. As a result a 2D deflection regime can be observed with a wavelength-dependent angle separation. There are zero-order beams that pass the AODs without deflection.*

To cover most automotive lighting functions the scan angle has to be at least 40° in the horizontal direction, while it might be lower in the vertical axis. The angular range in which the colours overlap depends on the design of the AODs. In the laboratory setup they are optimised for the RGB wavelengths and reach an overlap angle of 19 mrad or approximately 1°. Obviously this scanning range is not sufficient for the envisioned application. For this reason an optical system was designed to enlarge the scan angle. This has to be achieved while preserving the beam characteristic of the outgoing light. The divergence angle of a laser beam determines the area it illuminates on the target plane. Therefore the divergence of the light beams exiting the scanner limits the optical resolution of the system.

Telescopes are optical systems that can fulfil the given requirements. They work with parallel input and output beams, while amplifying an angle deviation by their magnification factor [6]. Of course, the output beam's divergence is also enlarged by this factor. Fig. 3 shows an example of a telescope which was evaluated by simulation as well as experimentally. It proved suitable for the desired application in the laboratory setup.

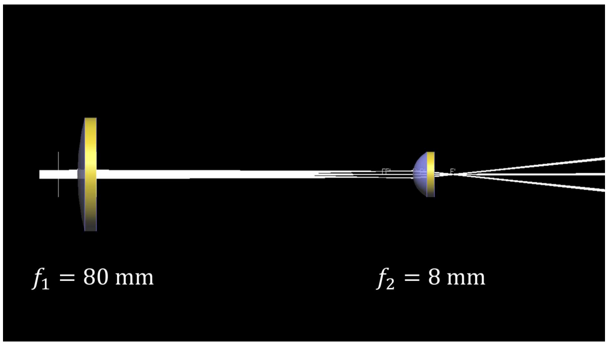

Fig. 3 *Simulation of a keplerian telescope to enlarge the scan angle of the AODs by the magnification factor of 10.*

4 Conclusion

Acousto-optic deflectors offer new possibilities to form light distributions for the application in automotive lighting. Their deflection works without any moving parts, which allows a high dynamic bandwidth. This means the scanning pattern can be adjusted according to the desired intensity distribution on the target area. But acousto-optic devices have a very small deflection angle that induces a need for an optical system that enlarges the field of view. For this application telescopic systems have been identified as a suitable solution by optical simulations and experimental evaluation. In the future we will develop more effective optics for the described application that are less complex, need less assembly space and have a performance that is highly adapted to the automotive application.

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