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A STRUCTURED LED LINEAR LIGHT AS AN ECONOMICALLY PRICED AND TECHNICAL ALTERNATIVE TO A LASER LINE GENERATOR

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Abstract **–** An interesting option for 3D object recognition is the triangulation principle. For this purpose a laser line generator is often used. But other structured linear light sources are also possible. For this the linear light has to have a defined width, brightness and sharpness. The linear light on the object, e. g. a groove, is changed by the object's surface and is detected by digital image processing.
Until now such linear light has been created with the help of a complex visual system using laser diodes. Because of some optical disadvantages of laser light, like speckles, in optical measurement applications, this paper examines the effect of using a structured LED light source instead of the laser generator. Consequently, the focus of this research lies on the necessary width, brightness, sharpness, length and depth of focus of the linear light generated by a LED light source for high-precision measuring. This research has been carried out by extensive computer-aided simulations. Several solutions are given and assessed in this paper.

Keywords – linear light, structured LED light source, triangulation, detection of 3D surfaces.

I. INTRODUCTION

A frequently used method for measuring distances and surfaces is triangulation, typically using a laser as the light source [1].
If the beam sent out is a point, only the distance can be measured. But if the beam is structured into a more complex geometric shape, e. g. a line, surfaces can also be measured.

In order to use the principle of triangulation, the laser source, the detector and the object are arranged in a triangle.
A directed laser beam spot will be reflected at the object onto the detector, e. g. a CCD camera. The position of the object point can be calculated from the known geometry of the optical setup [2].

The widespread use of laser beams is limited by the occurrence of speckles which limit the line width [3].

II. ADVANTAGE OF STRUCTURED LED LIGHT SOURCES COMPARED TO LASER LINE GENERATORS

The use of laser is negatively influenced by the occurrence of speckle patterns due to the coherence of laser light interference patterns on the surface of the test object. Speckles have a strong influence on the linear line with regard to focus, shape and homogeneity. The speckle pattern depends on the surface and the material and may lead to the fact that precise measurements are not possible, such as for example in the case of highly reflective metal and polished surfaces.

Furthermore, hand laser diodes have got the disadvantage that additional protective measures are necessary because of the extreme heat and the dissipation of power. Therefore, measurements are made with LEDs as light sources.

By using LED the disadvantages of laser diodes can be avoided. LEDs do not cause speckles, but the light of LEDs is partially coherent. The main argument for the replacement of laser diodes with LEDs in optical measuring devices is their ability to generate the necessary intensity.

If required, different switchable line colors are available by using RGB-LEDs.

For this reason a laser-based 3D object recognition system is inappropriate for certain measuring tasks.

There is an enormous supply of different LEDs on the market. The diversity of power, spectral color and structural shape allows solutions to nearly all measuring tasks.

III. GENERATION OF A STRUCTURED LED LINEAR LIGHT

The illumination of LED is distributed in all directions (Fig. 1 – left side). A solution for creating a powerful point light source, which is needed for almost all classical optical setups, is using an aperture for creating a point light source. The big disadvantage of this optical system is the loss of nearly 90% of the illumination.

Another solution can be achieved by attaching an optical device on the LED (Fig. 1 – right hand side).

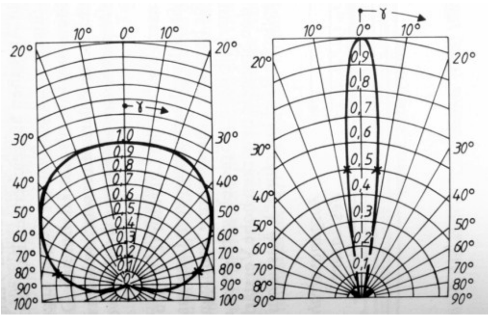

Fig. 1: DIRECTIONAL CHARACTERISTIC OF DIFFERENT LEDS [5]

One prerequisite, a point light source has already been mentioned. Another condition is that beams have to be parallel and bundled before modeling by optical systems with apertures, splits and lenses. Secondary radiation has to be reduced by apertures. The elementary way to bundle LED light is using a biconvex lens as collimator. Therefore the LED has to be placed in the focal point of the biconvex lens [4].

When optical systems are designed an optical system consisting of light source, aperture and lens, it is customary to use simulation programs, e. g. ZEMAX. This allows the simulation of dimensions and the theoretical testing of the developed system.

There are different basic setups to generate a line light:

- projection of a split
- beam molding with a cylindrical lens
- beam molding with a parabolic reflector
- a combination of them

First of all several principles have to be found how to generate a linear light in an economically priced way.

As there is a wide variety of combinations regarding the assembly of the setup, the measuring tasks must be defined and restricted by the specifications shown in Table 1.

Table 1: CRITERIA FOR GROOVE MEASURING AND REALISED CRITERIA

Criterion	Specification	realised criteria
light source	LED white colored	LED Vishay (TLCR5100-white)
width	≤ 500 µm	336 µm
length	10 mm	9,4 mm
depth of focus	≥ 5 mm	6 mm
illuminance	0,1 lm/mm²	0,03 lm/mm²
low cost	< 350 €	145 €
working distance	< 50 mm	40 mm

Cylindrical optics widen a beam anisotropically, because of the property that light rays will be focused in a particular direction (line width) and will be diverged in the other direction (line length), see also Fig. 2.

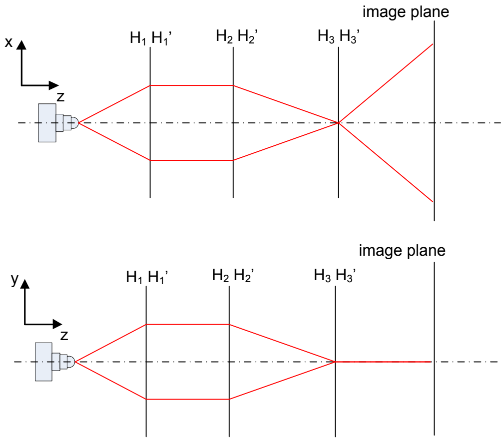

Fig. 2: RAY PATHS AT CYLINDRICAL LENSES (TOP: LINE LENGH, BELOW: LINE WIDTH) [5]

Different solutions were simulated with the optical program ZEMAX. The best results under consideration of the criteria of Table 1 for a measuring task were reached for an optical system consisting of a split and a cylindrical lens for the generation of a linear light (see Fig. 3).

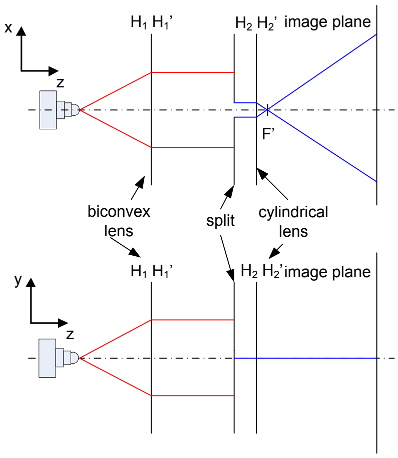

Fig. 3: BEAM PATH WITH SPLIT AND CYLINDRICAL LENS

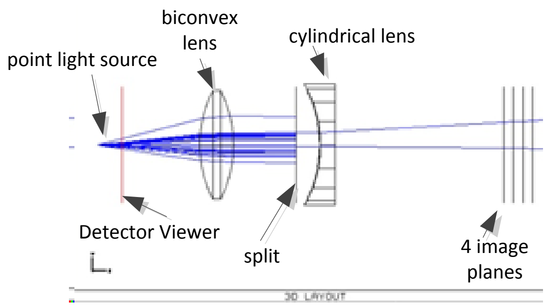

Fig. 4: ZEMAX 3D LAYOUT

ZEMAX allows applying special parameters of the optic elements used, e. g. the lens diameter, the radius of the lens and so on. These data are stored in catalogs that are available in ZEMAX. The results of the data can be seen in the 3D-Layout (see Fig. 4).

The peak illuminance is shown in the False Color Detector Viewer in Fig. 5. With it the homogeneity of the linear line is represented. The Cross Section Row Detector

Viewer in Fig. 6 represents a cross section through the linear line and the Cross Section Column Detector Viewer in Fig. 7 shows a longitudinal section through the line. With this information it is possible to get the geometrical dimensions of the width and the length of the linear line. The significant criterion of the line data has been the 50% value of the maximum peak illuminance.

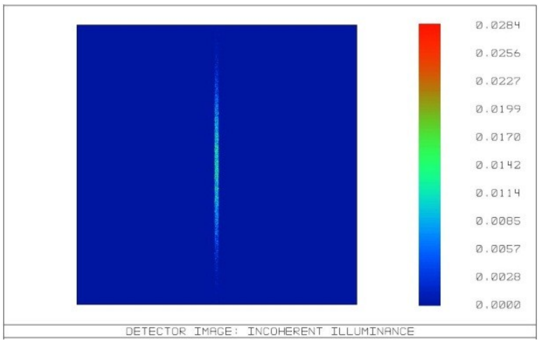

Fig. 5: FALSE COLOR DV

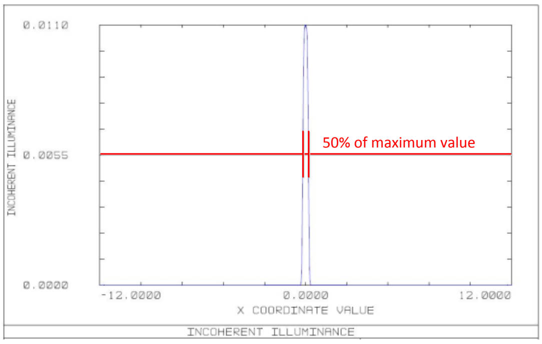

Fig. 6: CROSS SECTION ROW DV – LINE WIDTH

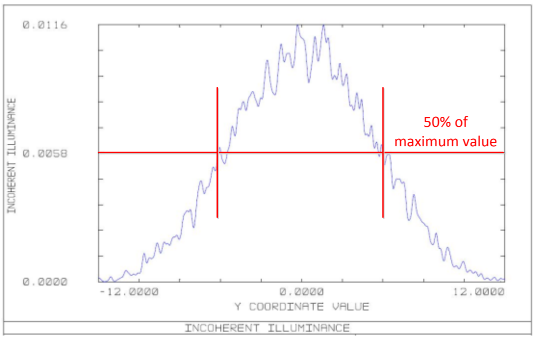

Fig. 7: CROSS SECTION COLUMN DV – LINE LENGTH

In the simulation the split had a width of 300 µm and a length of 12 mm and projected the linear light on the image plane. The cylindrical lens was used to expand the beam and due to this the illuminance was reduced with increasing working distance.

After that all principles were simulated and evaluated especially in view of the depth of focus, the length and the width of the linear line.

It can be noted that the line width was constant with a width of 336 µm over the entire working distance (Fig. 8) and the line length increased due to the expanding effect of the cylindrical lens (Fig. 9) in the simulation. The intensity of light was reduced with increasing working distance, as expected (Fig. 10).

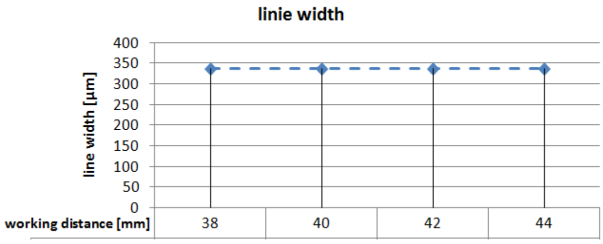

Fig. 8: SIMULATED RESULTS OF THE LINE WIDTH [2]

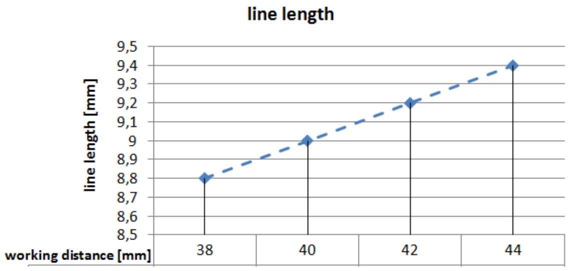

Fig. 9: SIMULATED RESULTS OF THE LINE LENGTH [2]

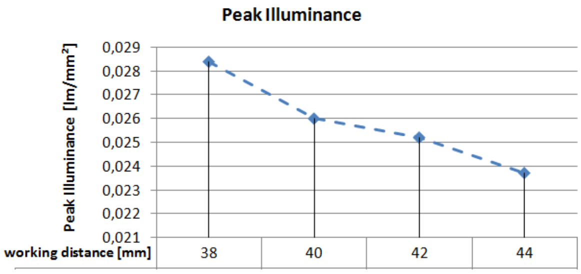

Fig. 10: SIMULATED RESULTS OF THE PEAK ILLUMINANCE [2]

Examples of the simulation are given in Fig. 5, Fig. 6 and Fig. 7, e. g. the False Detector Viewer, the Cross Section Row Detector Viewer and the Cross Section Column Detector Viewer.

IV. REALISATION OF A STRUCTURED LED LINEAR LIGHT

After simulation the assembly was realized in practice. As detector a monochromatic CCD-camera with 1360x1024 pixels was used. The analysis of the results in terms of the images was carried out by grey value analysis in Matlab.

For that the adequate LED had to be found. To provide for optimum sharpness of the line and a maximum line length, the viewing angle of the LED must be as small as possible. The light intensity is the most important aspect for the selection of the LED next to the viewing angle.

The LED Vishay TLCR5100-white was used. This LED has a size of 5 mm, a viewing angle of 4° and an intensity of 2.5 cd. E. g.

Fig. 11 and Fig. 12 show the evaluation of the lines generated.

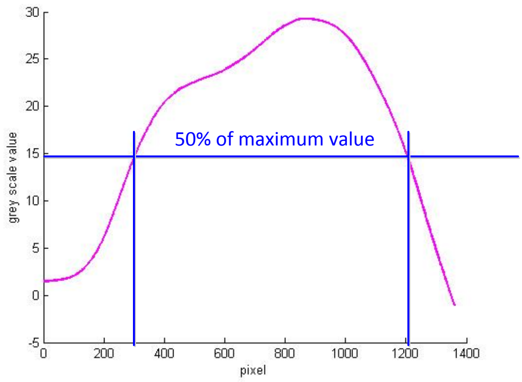

Fig. 11: REALIZED LONGITUDINAL SECTION THROUGH THE LINE

For this purpose the conversion of the pixel values is necessary. In the case of the longitudinal section through the line 1360 pixels were used to create the image. One pixel equals 0.025 mm in length. For the determination of the line width 1024 pixels were used. Here one pixel equals 0.024 mm. E. g. the line width was determined with 14 pixels which corresponds to 336 µm [5].

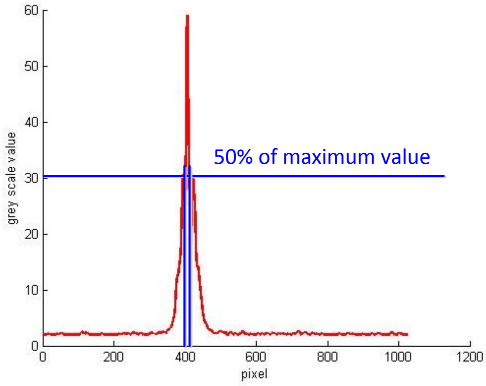

Fig. 12: REALIZED CROSS SECTION THROUGH THE LINE

At the point of the pixel with the highest grey scale value a longitudinal section and a cross section were made through the line. These measurements were repeated reproducibly. In addition to the simulations the sharpness of the line was determined by an extraordinary algorithm. Therefore the maximum increase in the edge angle was identified (see Fig. 13 and Fig. 14). It may be noted that the lines produced an outstanding sharpness and were thus well suited for measuring systems.

It is the aim that both edge increases of the linear line possess an identical rise and steep edges. For the application as a measurement system it is necessary that the linear line has a high degree of sharpness. This is indicated by a steep edge increase.

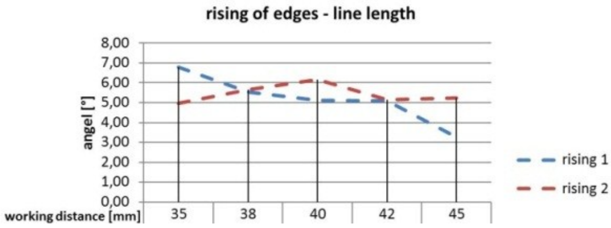

Fig. 13: RISING OF EDGES – LINE LENGTH

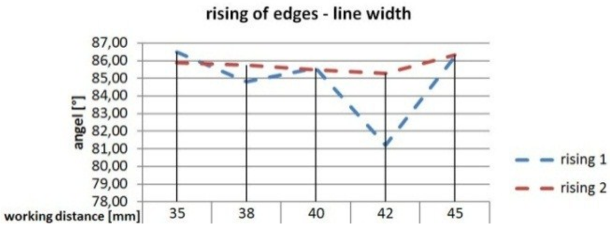

Fig. 14: RISING OF EDGES – LINE WIDTH

The deviations of the results of the simulation are partly due to the image plane, which could not be precisely aligned orthogonally to the beam path. The noise of the camera image causes deviations of the measurements. The fluctuations of the measurement results in comparison to the simulation show that the adjustment of the alignment of the elements for the test with a LED line generator must be very precise [5].

The simulation results in ZEMAX were generated under ideal circumstances which could not be realized in practice as well as in the simulation. Nevertheless the simulation is a very good tool for creating optical systems in practice. As an example for a very good result the line width can be mentioned, which reached the same value of 336 µm in simulation and in practice.

V. CONCLUSIONS

Finally it can be established in what cases it is appropriate to use an LED light instead of a laser source for generating a linear light.

In general, both laser and LED line generators can be used in measurement systems. If economic efficiency is to be the main aspect, it is also recommended to use LED line generators. On the other hand, whenever a huge depth of focus is required, the use of laser line generators can be recommended.

The development of the LED line generators is not completed yet. Thus in the development of novel high-power LEDs there is much potential for such measurement tasks. Moreover, particular attention is focused on special optics which can be placed on LEDs (see Fig. 15) [6]. These optics can realize a better shaping of the beam to reduce the stray radiation of the emitted light.

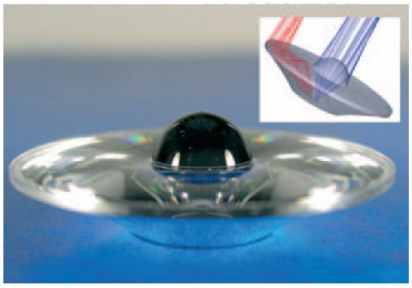

Fig. 15: DIAMOND TURNED PROTOTYPE OF A REFRACTIVE/REFLECTIVE CONCENTRATOR [6]

All in all, the high demands for generating a structured LED linear line, such as depth of field, line width and line length are reasonably easy to realize by using optical devices like LEDs, cylindrical lenses and apertures but they have to be designed for a special measuring task.

VI. ACKNOWLEDGEMENTS

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