Technological Vision Systems Using Principle of Analysis of Changing Geometry and Spectrum of the Light

O I Deev, V V Debelov, D V Endachev, S M Zuev, Yu M Shmatkov, P S Shirokov
FSUE NAMI, Moscow Polytechnic University, Moscow, V.O. 10th Line, 33/35, Russia, 199178

E-mail: debelovvladimir@yahoo.com

Abstract. New road safety requirements, that recently accepted will lead to increasing quantity of ADAS - active driver assistant systems. These systems aimed to detect objects and traffic participants, adjust the vehicle's speed modes, inform the driver about emergencies, synchronize the braking and the steering systems to perform emergency maneuvers, hold car on the line and perform other functions.

1. Introduction

ADAS systems are widely using by the large automakers [1, 2], which annually represent new user’s functions of the car and expand the technical capabilities of the vehicle, facilitating the transition from manual control to semi-autonomous. Nowadays, Tesla, Audi, Porsche, BMW, Mercedes are leaders of the implementation ADAS systems. It should be noted that the driver and machine vision assistance systems are implemented as a form of research projects and as form of serial solutions by Google, RoboTaxi, Yandex that’s indicate priority of development the vector of “training” of autonomous vehicles for successfully analyzing environment without driver’s participation in this process.

At present, design of machine vision systems is highly topical task for the solution of ones, various technologies are used [3]. Often, such developments are based on the analysis of the ultrasonic waves speed in the air, reflected from the object, changing geometry of the projective image and its evaluation by various mathematical models, which contributes to formation of data array on objects located in the "field of vision" of the vehicle and the dynamics of changing their positions in coordinate system associated with roadway and car.

Despite the fact, that the machine vision systems have already reached a certain level of technological progress applicable to autonomous vehicles, there are a number of problems associated with the recognition of the external environment in downpour, snowfall, if the camera can’t capture the traffic passage (for example, in winter time) or distortion of ultrasonic waves from radars. According with the research, even the most modern scanning tools like Lidar can’t effectively assess the deviation of incoming parameters caused by factors, which leads to malfunction of control algorithms and, as result, increases probability of road traffic accident. Such incoming data can be considered as continuous random process \( \omega (t) \), "white noise" or "Gauss’s noise", in which the mathematical expectation \( E[4-7] \) and autocorrelation function satisfy the equation: \( E(\omega (t)) = 0 \). It is practically impossible to filter out information data corresponding to indicated type of form or designate correspondence of spectral density under stationary conditions to each value of spectral density range in conditions of poor quality incoming signal. Cloud synchronization will also not show
satisfactory results with processing big-data information. There are also the issues with blind spots of the radar, the problem of poor quality image from the camera at night.

To improve the accuracy of existing ADAS systems has been developed the machine vision system based on DLP technology. What do we know about DLP and its applicability in automobile industry?

DLP (Digital Light Processing) technology [8-11] uses the following principle: Light source illuminates the object in sequence of specialized vector images, which are projected by using three colors (RGB) LEDs optics and lens systems, as well as electronic digital mirrors, which splits the light beam into vector elements with exactly the given interval sequence of graphical elements which compose image. Due to the fact, the human eye cannot distinguish between the different colors of alternating projections and small intervals in between, and then this light is perceived as white light source. Camera in such systems is using for photography images in high resolution and with high-speed frequency (about 12 MP * 100 frames/s) [12]. The picture from the camera is converted into a digital format using a specific codec and sent to the DLP controller and control module which is a computer [13-15]. The resulting picture compares between the known data about geometry and the spectrum lines of the incident light on the plane, then we evaluate the distortion by the projection on surface of the analyzed object. After that, based on the mathematical mechanisms of digital processing DLP data build model’s surface geometry of object, located in front of source of projected light.
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Figure 3. Human’s eye and digital camera.

It was assumed that by configuring special patterns invisible for human eye, based on this, but visible for camera, could be fixed control points on the geometry of researching object.

2. **Principles of object visualization.**

It was found that using a set either of patterns or by creating a pattern by crossing the alternating bands, possible recognize the curvature of surface based on variable geometry within fixed area. The problem was solved within the basic postulates of Euclidean geometry, Riemann geometry, Lobachevsky geometry. With using a single pre-configurated pattern, only one light source is required, with the using of alternating stripes - two. Both options fit to technical capabilities of a modern automotive headlight.

![Figure 4. Change in curvature of the surface: R0, R-, R+.](image)

The configuration of imposed mesh allows the camera with a high definition detect frame the object’s geometry without capturing details from surrounding external space. In the subsequent passing image through the Kenny operator, curvature degree of surface is determined by inner area on which camera is focused.
The focus field is an area of space for creating control boundary points. The change in the patterns is described as intersection of K and J-emission sets from the left and right headlights, respectively, with the extreme values corresponding to 0 and 1.

The superposition of mesh allows us to describe the system in the form of a vector equation of the form:

\[
\begin{align*}
  x &= x(u, v) \\
  y &= y(u, v) \\
  z &= z(u, v)
\end{align*}
\]

DLP model could be described with elementary physics and geometry formulas. By these formulas, the projections of light objects are calculated, and on their basis 3D model of the object located in front of the DLP light source is built.

The light flow from light source is characterized by the distribution of the light energy in time and space:

\[
\phi_e = \frac{dQ_e}{dt}
\]

where \( Q_e \) - light energy

The light flow of source with line spectrum consists of monochromatic streams of individual lines that correspond to combination of different RGB colors:

\[
\phi_e = \phi_{\lambda_1} + \phi_{\lambda_2} + \cdots + \phi_{\lambda_n}
\]

where \( \lambda \) — monochromatic light flow of one color; \( \phi_e \) - the total light flow.
The spectral distribution of the radiation flux with continuous and striped spectra is characterized by the magnitude of the spectral density of light flow. 

\[ \phi_\lambda = \lim_{\Delta \lambda \to 0} \frac{\Delta \Phi_\lambda}{\Delta \lambda} = \frac{d \Phi_\lambda}{d \lambda} \]  

(4)

where \( \lambda \) — wavelength of the incident light.

The spectral density of the light flow is quantitative characteristic of distribution of light flow over the spectrum and it’s equal to ratio of elementary flow \( \Delta \Phi_\lambda \) corresponding to infinitesimal area to width of the illuminated section:

\[ \phi_\lambda = \frac{d \Phi_\lambda}{d \lambda} \]  

(5)

The spatial density of the light flow is called like intensity of light, and it is characterized by the ratio of light flow to angle with vertex at source location point, within which this flow is uniformly distributed:

\[ I = \frac{d \phi}{d \omega} \]  

(6)

where: \( \phi \) — light flow from the source; \( \omega \) — angle.

Illuminance at a certain point on surface perpendicular to direction of light propagation is defined as the ratio of light intensity to square of distance “d” from this point to light source:

\[ E_p = \frac{I}{d^2} \]  

(7)

Illumination at certain point on surface not perpendicular to the direction of light propagation. \( \gamma \) - angle formed by direction of incidence light and perpendicular to this plane:

\[ E_p = I \cdot \cos \gamma \]  

(8)

To calculate the horizontal illumination, it is advisable to change the last formula by replacing the distance “d” between light source and measurement point by height “h” from the light source to surface. On figure. 2:

\[ h = d \cdot \cos \gamma, E_p = I \cdot \cos \gamma \cdot \frac{h}{d^2} \]  

(9)

Horizontal illumination at the measuring point:

\[ E_p = I \cdot \cos^2 \gamma \cdot \frac{h}{h^2} \]  

(10)

Figure 7. Horizontal and vertical illumination.

The illumination of the same point P in vertical plane oriented to light source can be represented as a function of height (h) of the light source and the angle of incidence (\( \gamma \)) light intensity (I) (picture 7):

\[ E_{vert} = \sin \gamma \cdot \frac{I}{d^2}, d = \frac{h}{\cos \gamma} \]  

Follow: \( E_{vert} = \sin \gamma \cdot \frac{I}{h^2} \cdot \cos^2 \gamma \).

For the characterization of surfaces luminous due to light flow passing through or reflected from them, is the ratio of light flow emitted by the element to area of this element:

\[ M = \frac{d \phi}{d s} \]  

(11)

The luminosity can be expressed in terms of the spectral density of energy luminosity of radiating body: \( M_{e\lambda}(\lambda) \):
M = 683\int_0^{2\pi} M_{\phi \lambda}(\lambda)V(\lambda)d\lambda \quad (12)

In this way, the image is corrected for capture by the camcorder.

3. Experimental setting and confirmation of the theory

The system of technical vision consists of a set of different elements for which an evaluation of technical characteristics is presented in order to calculate measurement error and response time. The system includes following elements: light source, electrically controlled mirror system, DLP Controller, high-resolution camera, embedded image processing system, computer. Appearance of the light source DLP4500 Light Crafter and receiver of video image FireWire Cam is shown in figure.

Let us consider in the most detail technology of projecting light onto an object under study. In order to illuminate object with light beam of given configuration, light source is used that includes the following elements:

- DLD4500FQE DMD (Digital mirror device)
- Heatsink DMD
- LEDs of red, green and blue colors
- Beam Focus Control System
- Projection system of lenses.

To evaluate proposed concept, experiment was performed with installation containing DLP system, controller, digital projection engine debugger, object on which geometric shapes are projected, a software kit for modulating a set of patterns, and an industrial FW camera.

Using the presented laboratory setup, model of cube surface was detect, which is located in front of a light source realizing sequence of graphic patterns. The accuracy of geometry of the model obtained about 200 microns for a distance of 1 m. As the distance increases, the accuracy decreases, which subsequently requires an error estimate of the DLP method in the headlamp headlight.

Figure 8. Research object. 4 patterns with different light wave length.
Comparing different patterns via C++ programm 3D projection the object has been created.
Future of this technology - integration model to headlamp including a powerful light source - RGB LED, DLP control module with a DMD module, lens system with adjustable focal length. The proposed concept solves the problem of lighting individual zones, adjusting brightness of light, facilitates implementation of DLP mechanisms and expands functions of headlights used.

Considering the given system, it is worth noting that it allows not only implement object identification mechanism, but also become a new element of ADAS system that provides tips to driver and other road users through graphical projections of various images onto roadway, which will make them less distracted on other elements of car identification and concentrate their attention solely on the traffic situation.

4. Conclusion
Contemporarily systems of machine vision have disadvantages, and the development of new principles for analyzing the environment is an important task for scientific and technical community. Using of systems based on analysis of object geometry like DLP-technology allow to increase accuracy of surface recognition, reduce dependence of final result on external interference, for example, changing weather conditions.
The conducted researches showed that Lidar's inefficiency can be compensated by using DLP technology, for which signals from radar and ultrasonic sensors can be reference signal source. The accuracy of DLP technology for laboratory layout is not inferior to use Lidar and ranges from 200 to 500 microns at distance up to 5 meters. The frequency of the frame change, up to 200 Hz, allows creating an even light beam and at the same time ensuring the operation of DLP system.

In view of the fact that contemporarily car headlights are equipped with powerful LED or laser light sources, the use of DLP technology will require integration of DMD component in the car headlight. Integration of DMD component will also enable the digital projection of graphic hints on roadway and information messages.

The presence of system of digital mirrors will adapt functions of Cornering light, Adaptive light without using specialized actuators, as well as make changes to the geometry of the light spot projected onto the road surface.

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