CONCEPT OF BUILDING AN ELECTRO-OPTICAL SYSTEM OF SEMI-AUTOMATIC CAR DRIVING ON HIGHWAYS

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ABSTRACT

Concepts of building intellectual car driving and collision warning systems (ICDCWSs) based on using new generation electro-optical systems were proposed. The proposed systems can perform automatic analysis of complex dynamic situations arising on highways, can work at any time of day and night, over a wide range of weather conditions, under any degree of smoke content on the route and with bright light sources in the field of view. The system includes two digital IR-cameras based on vidicons with a pyroelectric structured target, computer and TV-display. A distinguishing feature of such cameras is the absence of cryogenic equipment and optical-mechanical devices. IR-cameras can be installed in the headlight units. The field of view of each camera is 35°. Cameras are aligned so that the common field of view is 60° and the overlapping part of fields of view is 10°. Images generated by IR-cameras are input into the computer system. The current image is divided into three areas (stereo image area, lower and side parts of the image) each of which is processed with its own algorithms.

1. INTRODUCTION

Passive (TV cameras that may be combined into stereo pair) and active (mm and cm range radars) sensors (Graefe, V., 1989; . Ohzora, M., et al., 1990; Yakimovsky, Y., 1978; Aoki, K. et al., 1994) as well as sensors based on other physical principles (Yokoyama, T., et al., 1993) are traditionally proposed to use in the intelligent vehicle systems. However, not enough attention is paid to systems based on IR sensors working in far IR range. Perhaps, it is due to relative high cost of IR systems and optical elements. Nevertheless last achievements in IR technology give hope to great decreasing of such systems cost, that increases interest in using this sensors in intelligent vehicle systems.

In this paper we consider the intelligent vehicle system that can perform automatic analysis of complex dynamic situations arising on highways. This system is intended to make process of driving easier for driver, to warn him about dangerous situations arousing on the road and to perform some maneuvers automatically in some extreme situations. It is supposed here that in most cases driver makes decisions himself. It is enough for system to scan only some area ahead of it. The ahead section with zone of vision 60–90° is considered to be of great interest for these purposes.

ICDCWS tasks can be classified into three groups:

- road situation automatic analysis;
- indication and sound signaling;
- semiautomatic driving.

To the typical tasks of the first group the following ones can be referred:

- selection of moving and motionless objects in the field of view;
- determination of distance to the selected objects and their relative speed;
- moving objects dangerous maneuvers selection;
- detection of pavement edges and lane marking;
- calculation of maximum speed for the specified weather and visibility conditions and road characteristics.

Tasks of the second group include the following ones:

- display image of the observed scene on the TV screen in the TV standard;
- detecting road edges, fixed objects presenting a hazard to traffic and vehicles performing dangerous maneuvers on the current display;
- giving audible signals, including voice signals, warning of a possible collision;
- providing driver with recommendations on driving;
- change of the displayed field of view.

Tasks of the third group include the following ones:

- ensuring of automatic lane-keeping;
- save distance keeping;
- urgent braking to prevent collision with another vehicle or other obstacles;
- giving warning to another vehicles.

The list of the tasks performed can be expanded.

2. THE SYSTEM STRUCTURE AND SENSOR CHARACTERISTICS

The system includes two digital IR-cameras based on vidicons with a pyroelectric structured target. A

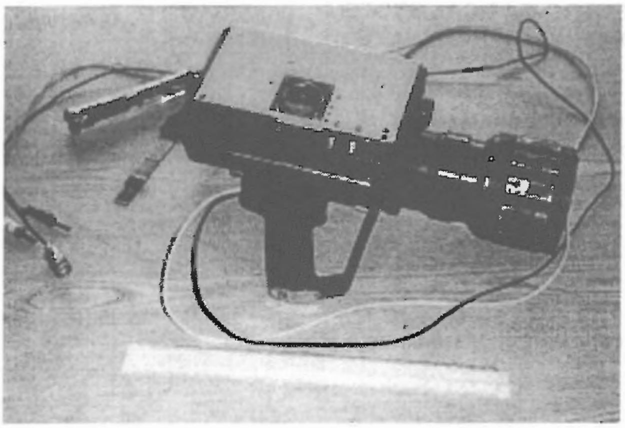

Figure 1.

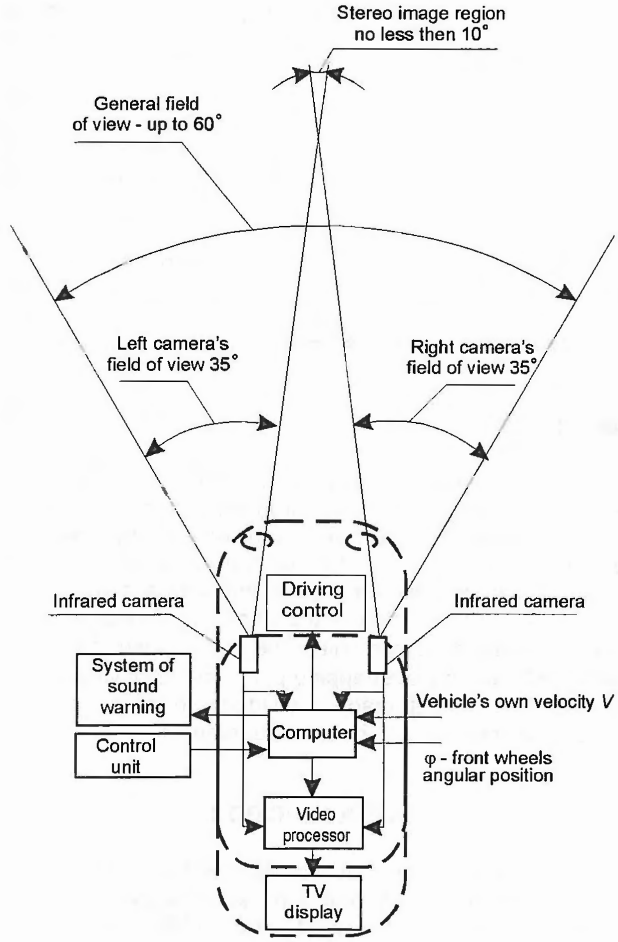

Figure 2.

distinguishing feature of such cameras is the absence of cryogenic equipment and optical-mechanical devices. The cameras proposed for using in the system can provide two modes of operation: with input radiation modulation and without modulation. The second mode permits to generate image with contrasting objects moving relative to the camera. The cameras are equipped with built-in digital systems of characteristics optimization and adaptation to the environment by controlling internal parameters:

- beam current;
- pedestal current;
- target polarization;
- shutter parameters.

Cameras provide two types of output signals:

- an analog signal, corresponding to the TV standard;
- a digital signal.

2.1 IR-Camera Main Characteristics

Wavelength band	8–14 μm and 3–5 μm
Temperature resolution	0.2 K
Photodetectors matrix size	400 × 400 pixels
Field of view of each camera	35 °
Angular resolution	5.25 ′
Inlet diameter	40 mm
Frame frequency	25–50 Hz

The external view of a pyrovidicon and a digital IR-camera with a built-in TV display is shown in Fig.1.

The system includes also a TV display and a computer. Displays are not considered in this paper and are defined by arrangement of the overall display system and dash-board. The computer system can be built on the basis of standard modules and is not considered here.

3. THE SYSTEM BLOCK DIAGRAM

The system block diagram is presented in Fig.2. IR-cameras are installed at the sides of the car. The best places for installation are front side parts of the roof or windshield top. If cameras installation is impossible in the specified places they can be installed in the headlight units. The field of view of each camera is 35°. Cameras are aligned so that the common field of view is 60° and the overlapping part of fields of view is 10°. Current images, vehicles' own speed value, front wheels angular position and pavement state are input into the computer system.
Current images are also input into the videoprocessor which generates the image in the TV display. Audible signals, including voice signals, are given through the audio system controlled by a computer system.

4. DATA PROCESSING ALGORITHMS CONSTRUCTION PRINCIPLES

Using the above-considered IR-cameras alignment permits to have high resolution while maintaining a sufficiently large common field of view of the system (60°). In the area where IR-cameras fields of view intersect we have stereo image. The field of view of each camera is 35°. Thus the stereo vision area makes 10°. With road turning radius equal to 1200 m such field of stereo vision permits to observe vehicles' own lane at the distance no less than 200 m. Angular resolution of the system is 5′.

Images generated by IR-cameras are input into the computer system. The current image is divided into three

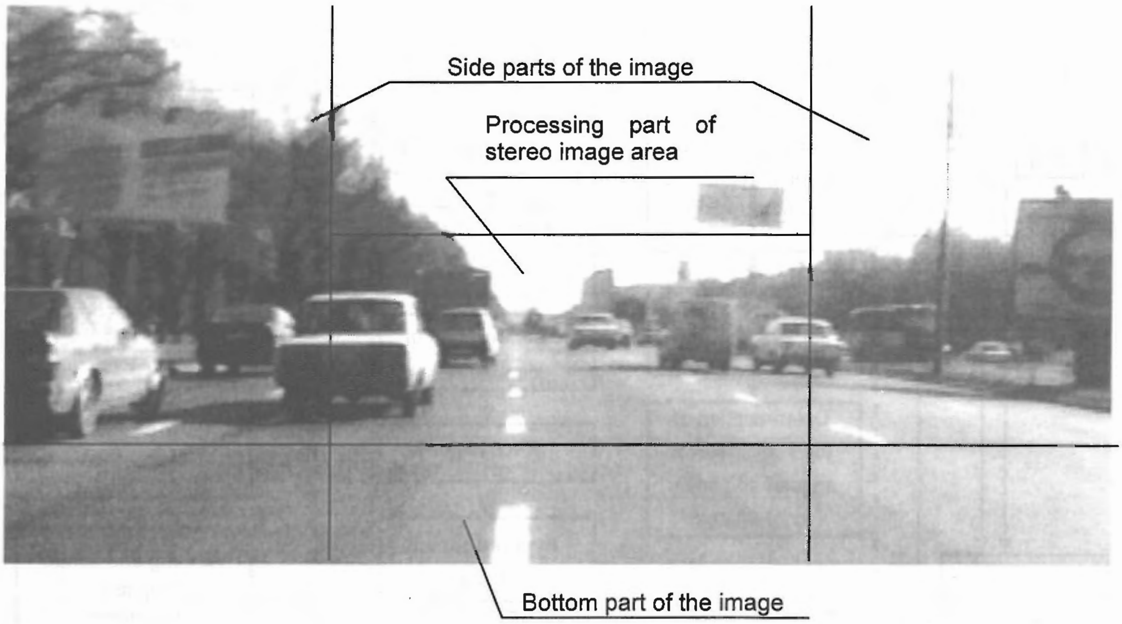

Figure 3.

areas (Fig. 3), each of which is processed with its own algorithms:

- stereo image area;
- lower part of the image;
- side parts of the image.

Processing of the stereo part of the image permits:

- to carry out image segmentation by stereo fragments correlational match including the isolation of objects images shading each other;
- to perform vehicle recognition up to the type of a vehicle (cars, trucks, buses, motorcycles, etc.)
- to calculate distance to the selected objects by the table method;
- to calculate relative speed of objects;
- to pass objects leaving the central part of the image to programm tracking.

Image processing of the side parts of the image permits:

- to track objects selected in the area of stereo vision;
- to select newly appeared objects and to determine distance to them;
- to select dangerous maneuvers of moving objects.

Processing of the lower part of the image permits:

- to detect pavement edges and lane marking;
- to provide automatic controlled motion on the lane using the lane marking.

Functional block-diagram of image processing is shown on the fig.4.

Let's consider the concepts of forming primary algorithms of data processing. We note that definition and connection of coordinate systems are general problems and are not considered in this paper.

The processed part of the stereo image presents two images with the size 128×128 pixels. To segment and detect moving and motionless objects the following criteria and algorithms are used:

- presence of vehicles' infrared contrast against the background of the pavement;
- a known value of vehicles' own speed is used for motionless objects selection;
- correlational match of the selected contrast fragments on the corresponding parts of the stereo image permits to segment volume objects and to detect surfaces of the vehicles' body observable parts;
- using images sequence interframe processing methods permits to select moving and motionless objects, to determine parameters of their relative movement and to track the objects.

To determine distance to the objects results of segmentation procedure are used. For each detected object on both parts of the stereo image corresponding identical parts of the object's patterns are found, for example, the image of the car's body rear part. Correlational match of patterns is performed. In this process elementary algorithms of line-by-line match can be used as patterns are matched in the vertical direction owing to cameras alignment. As a result image shift estimation is carried out at the subpixel level.

A distance expectation value is calculated in advance for each combination of a selected pattern center column number and a shift value. From the specified values a table is formed. Thus from the combination of a column number and a shift value a distance value is determined by the table method. Precision of correlation match depends on the pattern size. Based on the possibility of

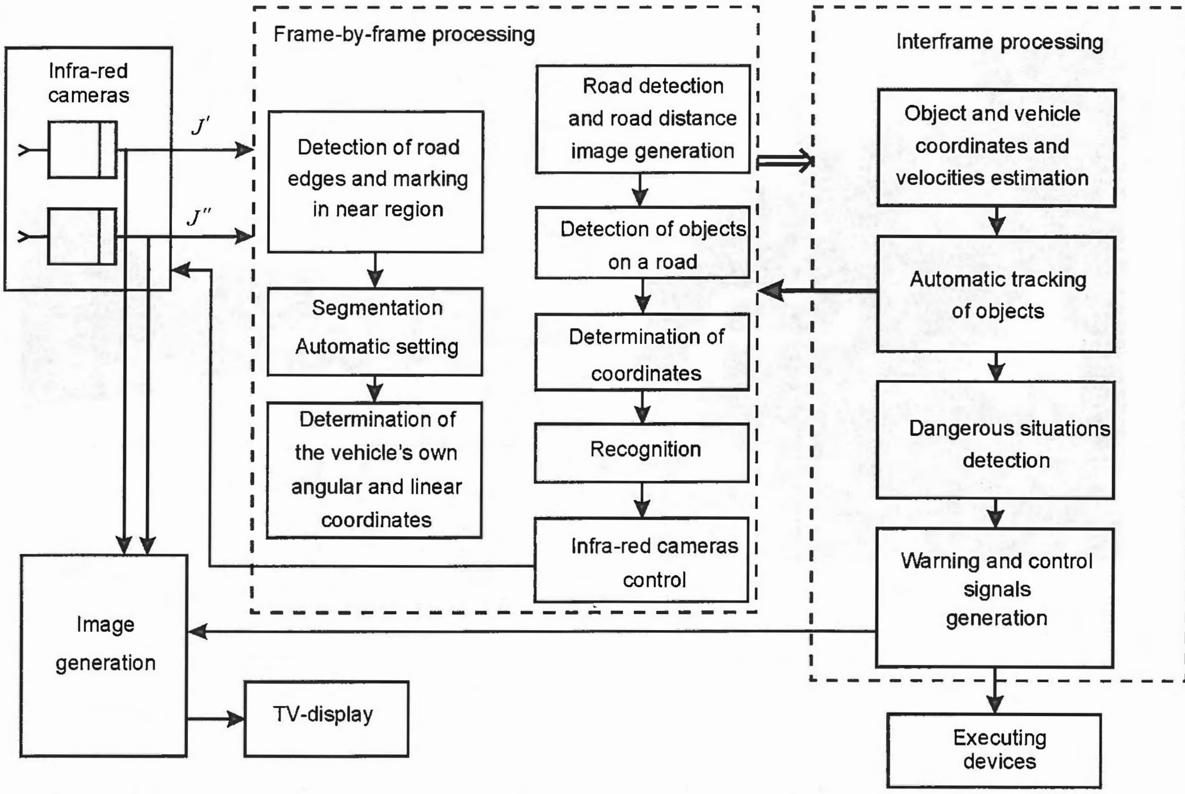

Figure 4.

Table 1.

Distance to the object	50 m	100 m	150 m	200 m	250 m	300 m
Maximum error while evaluating by one pixel	2.39 m	9.6 m	21.95 m	39.6 m	63.2 m	93.6 m
Maximum error while evaluating with the use of sub-pixel matching	0.5 m	2.7 m	7.4 m	15.4 m	27.6 m	45.4 m
Error as a percentage of distance	1.0%	2.7%	4.9%	7.7%	11.0%	15.1%

image matching with an accuracy of 0.2 pixels and taking into consideration the task symmetry the table size will be 64 Kbytes.

Fig. 5 shows an uncertainty zone of pattern element position for the given stereo pair. It is the mentioned uncertainty that limits distance determination accuracy with a single observation and distance evaluation by one pixel. It is necessary to note that the smaller is the distance to the object the higher is the accuracy. Table 1 presents distance determination error values for various distances with evaluation by one pixel and with evaluation with the use of image matching sub-pixel procedure.

To determine relative speed of objects we use distance value and the largest characteristic dimension of the object (height or width of the vehicles' body rear part selected in the image). We determine the time interval during which the pattern characteristic dimension changes in the image by one pixel. By the known distance and relative change of pattern dimensions the object relative speed is calculated as

$$V = \pm \frac{D}{(n \pm 1)\Delta t}$$

Here V is the object relative speed; D – distance to the object; n – the object pattern characteristic dimension in pixels; t – time interval during which the pattern dimension has changed by one pixel; "+" corresponds to approach; "–" – to moving away of the object. For car characteristic dimension 1.7 m relative speed determination error will be no more than 1% for distance 100 m and 3% for distance 200 m.

In the process of object observation distance and speed are refined using the Kalman filtration. In case if the object approaches and leaves the stereo vision area, going into the side part of the image, its current distance, speed and attitude are transmitted to programs tracking objects in the image side part. If the object continues to move uniformly and along a straight line, its movement in the display coincides with programm tracking which means that the

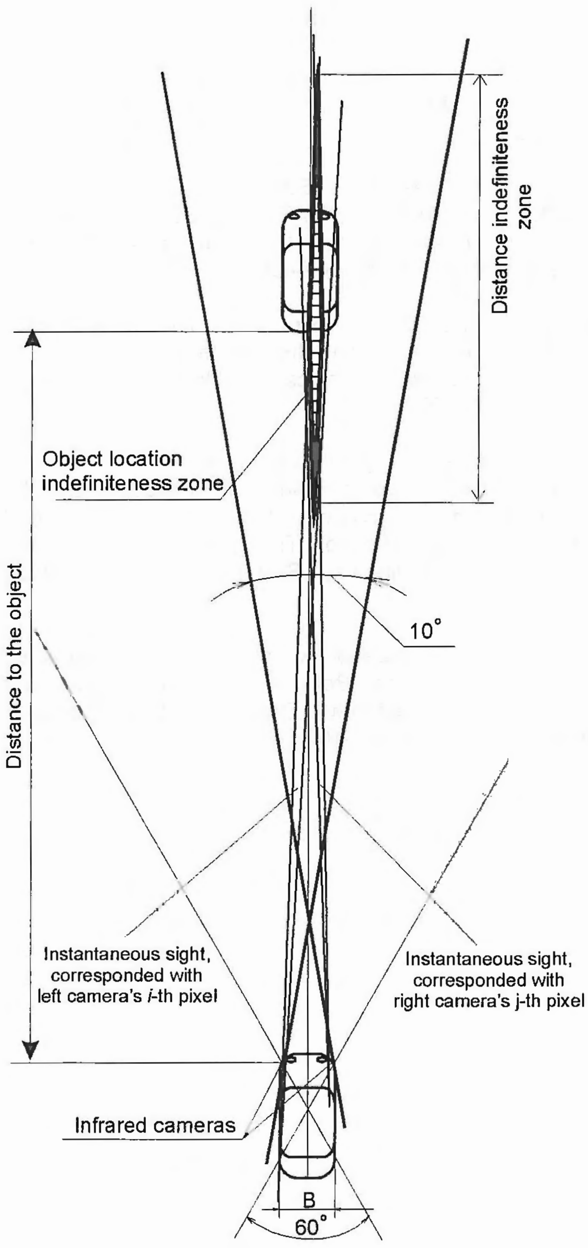

Figure 5.

object presents no hazard to vehicles' own motion. If the object deviates from programm tracking, its trajectory is analyzed, and it is found out whether its trajectory intersects with vehicles' own trajectory and if it does where it takes place. If the intersection takes place at a sufficient distance, the object gets into the stereo vision area again. If the trajectories intersection point is in the immediate vicinity of the vehicles' own position, a warning signal is given, the object image is singled out in the current image and maybe forced braking is carried out.

In case when objects in side parts of the images appear as a result of overtaking, their patterns are selected using the interframe processing procedure. In doing so presence of movement in reference to the surrounding background is used. Distance to these objects is determined using the table by the image line number to which the nearest lower edge of the objects' body corresponds. The direction of their motion is defined by the marking lines correspondence.

Detecting pavement edges and lanes marking is carried out by adaptive threshold processing of the current image lower part. In doing so we use the fact that lane marking under any weather conditions, both by day and at night, has infrared contrast with reference to pavement owing to a great difference of radiation coefficient. Interframe processing of an images sequence permits to determine a marking pattern shift in the current image. Determination of real vehicles' shift with reference to lane marking can be used for generating control signal and providing automatic controlled motion within the lane borders.
To simplificate current images processing front wheels attitude current value is used to determine starting and finishing moments of vehicles' own maneuver.

The required frequency of repetition of the mentioned above algorithms should be determined on the base of experiment results.

To determine the maximum permissible speed the range of visibility is determined. To do this both moving objects and motionless objects situated on the road shoulder (poles, signs, transparencies etc.) can be used. The pavement state (dry, wet, with icing areas) is either input manually or defined by specialized sensors. Maximum allowed speed is calculated taking into consideration that bracing distance should not exceed range of visibility having regards to decision making time.

In this paper indicators are not considered. Thus in the second group of tasks we shall point out only the following features. The total image from two cameras has the size about 700×400 pixels, which is inconsistent with the TV standard. Therefore two display modes could be provided:

- displaying the whole field of view in width. In this case the image in height is smaller than the screen dimensions;
- displaying the central part of the image on the whole screen on an enlarged scale.

To provide the possibility of image scaling as well as to single out vehicles and objects presenting a hazard, road edges, etc. on the image, it is necessary to use a video processor. Singling out could be performed by using color marks, whereas infrared image is black & white.

5. THE ELECTRO-OPTICAL SYSTEM EXPECTED CHARACTERISTICS

Wavelength band	8–14μm
Total field of view of two IR-cameras	60°
Stereo vision area	10°
Field of view in angle of elevation	35°
Angular resolution of each camera	5′15″
Temperature resolution	0.2 K

Distance to the object determination error in the stereo image area:

with distance 100 m	±2.7 m
with distance 200 m	±15.4 m

Objects relative speed determination mean error in the stereo image area:

with distance 100 m	1%
with distance 200 m	3%

Car detection range by day and at night:

under good weather conditions	no less than 1000 m
under bad weather conditions (attenuation 3 dB/km)	no less than 500 m

Visibility range in the vehicles' own lane stereo image area with road turning radius 1200 m:

6. CONCLUSION

Using IR sensors with pirovidicons in intellectual car driving and collision warning systems make it possible to use these systems at any time of day and night, over a wide range of weather conditions, under any degree of smoke content on the route and with bright light sources in the field of view. Last achievements in the area of technology and using mirror lenses instead of germanium ones causes us to anticipate that the proposed system (with not more then 2 IR sensors) cost in full-scale production will not be exceed the cost of similar systems developed with the use of remote sensing active means. However, to use IR sensors it is necessary to develop new image processing algorithms that use features specific for IR images. Concept of system and principles of image processing proposed in this paper gives opportunity to analyze road situation using two IR cameras.

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