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Control System Image Analysis of Unmanned Vehicles Based on Computer Vision Technology

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Abstract

The article shows the urgency of control system development by unmanned vehicles based on computer vision technologies. These technologies are used in such tasks as a car location determination, the detection of obstacles and a suitable parking place determination. These tasks are resource intensive and must be performed in real time. Therefore, it is important to develop effective models, methods and tools that ensure the achievement of the required time and the accuracy of use in unmanned vehicle control systems. At that, the choice of image representation model is important. In this paper, they considered the model of energy characteristics. On its basis, it is possible to develop the descriptions of images to highlight and analyze their characteristic features, also for the isolating of contours, regions, and special points. The effectiveness of the proposed approach to image analysis is conditioned by the fact that the objects (road signs, road marking or car numbers) under consideration that have to be revealed and identified are characterized by the relevant features. Besides, the use of wavelet transformations allows one to perform the same basic operations to solve a set of tasks in onboard unmanned vehicle systems, also for the tasks of image primary processing, segmentation, description, recognition and compression. The application of this approach will allow to reduce the time for all procedure performance and to reduce the requirements to compute the resources of the vehicle on-board system.

Keywords: Unmanned vehicle; Control system; Computer vision.

1. Introduction

In order to develop various sectors of the economy and to provide the defense capability, the solution of transport problems with the help of unmanned vehicles is of special importance, by which the vehicles equipped with automatic control systems and capable of moving without human participation are meant. At present, almost all foreign car makers work on the creation of unmanned vehicles, including General Motors, Ford, Mercedes Benz, Volkswagen, Audi, BMW, Volvo, Caddilac. A significant amount of work is carried out on a closed topic within the framework of the defense order, and for this reason the results of the research are almost not published in the open press. Complex high technology solutions, software, the sensors of control systems for unmanned vehicles are classified as dual-purpose products in many countries (Awad and Hassaballah, 2016). The main advantages of unmanned vehicles are the ability to ensure the transportation of goods in conditions dangerous for people, the reduction of transport operation costs, the ability of centralized traffic flow control, the reduction of human casualty number during road accidents. The effectiveness of unmanned vehicles depends on traffic control systems. The examples of practical results in this area are the following ones:

- Semi-automatic system Temporary Auto Pilot for an optimal degree of automation provision depending on the traffic situation and a driver's condition (Volkswagen);
- Traffic Jam Assistant system for traffic control in traffic jams (Audi);
- Connected Drive Connect system to drive along a motorway (BMW);
- Super Cruise automatic control system for maneuvering, braking and driving along the highway (Cadillac);
- Safe Road Trains for the Environment system to ensure traffic on the road in an organized line (Volvo).

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Thus, to overcome the gap from foreign manufacturers of unmanned vehicles, which began to perform active developments in the 1980-ies, one of the most high-priority scientific and technical domestic trends is the development of own unmanned vehicles. The creation of unmanned vehicles requires the use of a variety of technologies. In this case, the computer vision technologies, used, for example, to solve the problems of car location determination, to detect obstacles, to determine a suitable parking space, etc. are very important. These tasks are resource intensive and must be performed in real time. Therefore, it is important to develop effective models, methods and tools that ensure the achievement of the required time and accuracy to address these problems. The procedures, implemented by the means of computer vision, are based on the models and the methods of image processing and analysis. Images, as a rule, represent large volumes of data. Their processing requires the use of a large number of procedures, such as:

- Primary processing (noise reduction, brightness correction, geometric transformations);
- Segmentation (binarization, contour outlining, the highlighting of regions that are uniform in texture, brightness, or color);
- Description (formation of descriptors for points, borders and areas);
- Recognition (the detection and the identification of specified objects);
- Analysis (the determination of dimensions, speed and motion direction);
- Compression (redundancy reduction).

Therefore, it is important to create the algorithms for complex image processing based on the same mathematical models and procedures (Ismagilov, 2001).

2. Methods

Over the past decades, many successful computer vision systems have been created, in which various approaches and paradigms have been implemented in various combinations. However, there is no single mathematical formalism and one generally accepted methodology to develop image analysis algorithms in these systems. When they design the systems for unmanned vehicles based on computer vision, a number of difficulties arise related to the limitations of software and hardware means and the conditions of their operation. Their overcoming is possible only in the process of new effective models and methods development for image processing and analysis to solve specific problems (Deng *et al.*, 2001; Stricker and Orengo, 1995). During the development of computer vision tools for their use in the control system of an unmanned vehicle, it is important to choose an image representation model. At that it is necessary to determine the signs of the images that will be used within the chosen model. Usually, they consider the signs of color, texture, shape and structure, which allow to describe the images in terms of their color content, spatial distribution of colors or brightness, the characteristics of regions, the presence of certain objects and their mutual arrangement. Among various models of image representation, they often use the models of their characteristic features, which include contours, regions and points of interest (Gonzalez, 2012; Sadikhov and Dudkin, 2006).

Contour models are based on the selection and analysis of boundaries between image areas. They use the methods based on morphological operators and the derivative operator by Roberts, Previtt, Sobel, Laplace, and others. Region models describe the color or the texture content of image areas. They are designed on the basis of color and texture features, the examples of which are a color histogram, a color connection vector, a correlogram of colors, color moments, a dominant color descriptor, statistical textural features, local binary patterns, spectral features, the signs of Tamura, etc. It should be noted that during the solution of filtering, contour isolation and image spectral feature problems in vision systems, fast algorithms of discrete transformations in various orthogonal bases are used effectively. The fastest algorithms are based on discrete orthogonal transformations by (Awad and Hassaballah, 2016; Villalobos-Antúnez, 2016). In addition, these algorithms are characterized by relative simplicity of the hardware implementation and can be implemented on parallel systolic-type computing structures, including programmable logic integrated circuits of FPGA class. Let's also note that during the solution of a number of problems of digital image processing, discrete transformations with respect to new orderings of Walsh function systems and their generalizations are of practical interest.

The models of points of interest are based on the detection and the description of so-called key points or special points. They use the appropriate detectors and descriptors for this. The first are designed to search for special points on images, and the second ones - to describe them. At present, there are many detectors and descriptors used in practice, for example, Moravez detector, Haris detector, susan, sift, surf, fast, brief, orb, gloh, freak, brisk. To solve various tasks of image processing and analysis in the on-board system of an unmanned vehicle, the best way is to use the methods that are based on the same transformations. This determines the effectiveness of approaches based on the wavelet transformation. The wavelet transform in general form is the following one (Tuceryan and Jain, 1998):

$$Wf(\mathbf{u},s)=\int_{-\infty}^{+\infty} f(\mathbf{x})\frac{1}{s^{D/2}}\psi^*\left(\frac{\mathbf{x}-\mathbf{u}}{s}\right)d\mathbf{x},$$

where Wf is the transformation result; f - initial function; ψ^* - the complex conjugation of the shifted and scaled function ψ, which has zero mean value, the center at the zero point, and the unit norm; D is the signal dimension; u is the D-dimensional vector of the shift parameters; s is the scale parameter. For digital images, discrete orthogonal multiple-scale wavelet transformations are used often, based on the representation of the discrete function f(x) describing the original signal as an expansion by orthogonal basic functions. These basic functions have the following form:

$$\varphi_{j,k}(x) = 2^{j/2}\varphi(2^j x - k),$$

$$\psi_{i,k}(x) = 2^{j/2}\psi(2^i x - k),$$

Where φ and ψ are the scaling function and the maternal wavelet function that determine the type of used wavelet transformation. After the wavelet transformation, the function is represented as the following sum:

$$f(x) = \sum_{k=0}^{2^{j_0}-1} a_{j_0,k}\varphi_{j_0,k}(x) + \sum_{i=j_0}^{J}\sum_{k=0}^{2^i-1} d_{i,k}\psi_{i,k}(x),$$

Where J is the number of decomposition levels; j_0 is the lowest level of decomposition; $a_{j_0,k}$ – approximation wavelet-coefficient; $d_{i,k}$ – detail wavelet-coefficient. Thus, the function is described by a set of wavelet coefficients of approximation and detailing.

The wavelet transformations of single-channel (for example, halftone) images are usually implemented in two stages: first the transformation for lines, then the transformation for columns is performed (or vice versa). The results of the transformation at the j-th level are grouped into the matrix of approximating coefficients $\left[LL_{j,m,n}\right]_{m,n=0}^{2^j-1}$ and the matrix of the detailed horizontal $\left[LH_{j,m,n}\right]_{m,n=0}^{2^j-1}$, vertical $\left[HL_{j,m,n}\right]_{m,n=0}^{2^j-1}$ and diagonal $\left[HH_{j,m,n}\right]_{m,n=0}^{2^j-1}$ coefficients. Each channel is individually converted for multi-channel (e.g., color) images.

For an orthonormal wavelet transform, we have the following:

$$\sum_{k=0}^{N-1}\sum_{l=0}^{N-1} f_{k,l}^2 = \sum_{m=0}^{2^{j0}-1}\sum_{n=0}^{2^{j0}-1} LL_{j_0,m,n}^2 + \sum_{j=j_0}^{J-1}\sum_{m=0}^{2^j-1}\sum_{n=0}^{2^j-1} LH_{j,m,n}^2 + \\ + \sum_{j=j_0}^{J-1}\sum_{m=0}^{2^j-1}\sum_{n=0}^{2^j-1} HL_{j,m,n}^2 + \sum_{j=j_0}^{J-1}\sum_{m=0}^{2^j-1}\sum_{n=0}^{2^j-1} HH_{j,m,n}^2, \quad (1)$$

Where $f_{k,l}$ is the brightness of the image point; $LL_{j,m,n}$, $LH_{j,m,n}$, $HL_{j,m,n}$, $HH_{j,m,n}$ – wavelet coefficients. The sums on the right-hand side of (1) show the contribution of the coefficients of different levels to the total energy of the image at different scales. This contribution makes it possible to obtain energy estimates for each point of the image. On the basis of the equality (1), the following procedure can be proposed to calculate the energy estimates of image points:

1) To perform the transformation to the level j_0;

2) To assume that $w_{j_0-1,m,n}^2 = K'_{j_0-1} LL_{j_0,m,n}^2$;

3) To calculate energy estimates sequentially for $j = j_0,\ldots, J-1$, where $J = \log_2 N$, $m = 0, 1, \ldots, 2^{j+1} - 1$, $n = 0, 1, \ldots, 2^{j+1} - 1$:

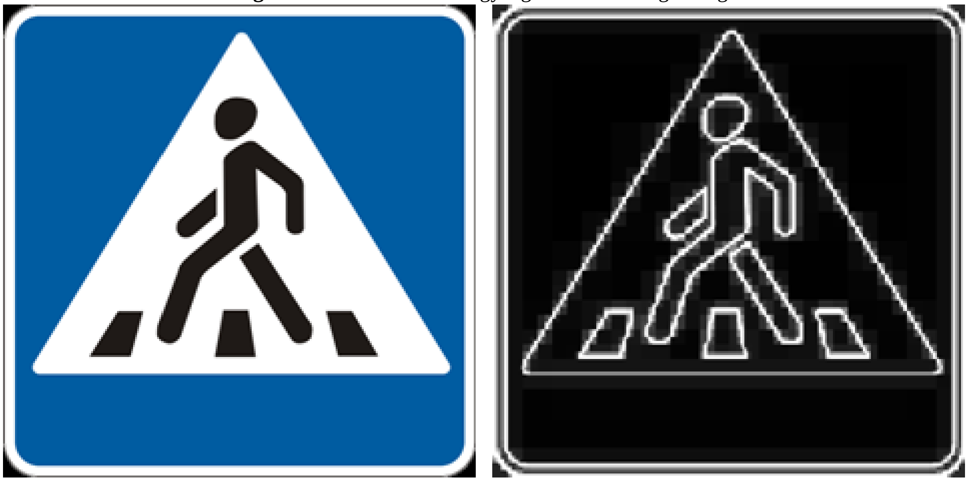
$$w_{j,m,n}^2 = K'_j w_{j-1,m,n}^2 + K''_j \times \left[LH_{j,m/2,n/2}^2 + HL_{j,m/2,n/2}^2 + HH_{j,m/2,n/2}^2\right].$$

The use of tuning coefficients K'_j and K''_j allows to provide an optimal calculation of the set of values $\left\{w_{k,l}\right\}_{k,l=0}^{N-1}$ in accordance with the problem being solved. In this case, these values can be considered as the weights of points. Thus, it is possible to develop a weight image in which each point will be associated with its weight - the energy estimate of a given point. The weight image itself is the model of energy characteristics (Huang *et al.*, 1999; Tamura *et al.*, 1978).

3. Results and Discussion

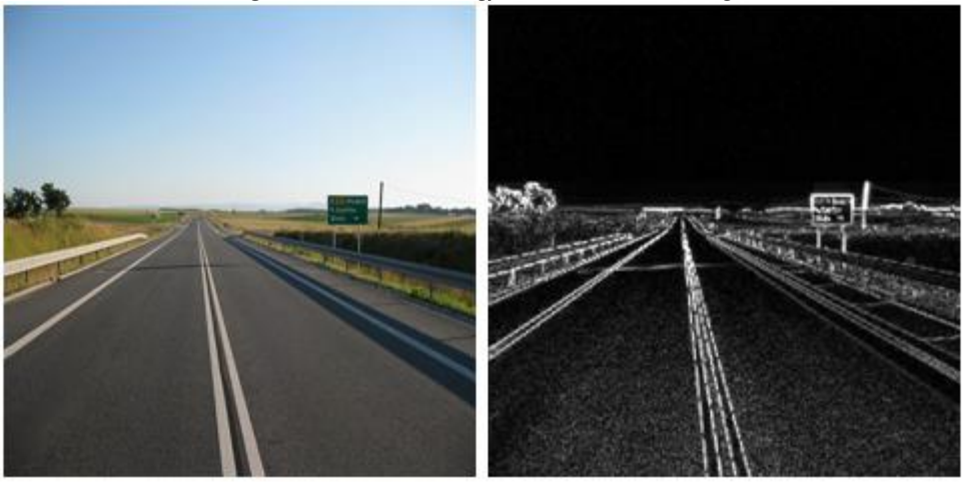
On the basis of the energy characteristic model, it is possible to develop effective descriptions of images for the isolation and the analysis of their characteristic features. For example, you can choose the adjustment factors that will provide large values of the weights at the boundary points in comparison with the values of the weights of the region interior points, which, in its turn, will allow us to delineate the boundaries on the images. If we consider the distribution of image point weights, we can obtain the description of a texture that characterizes its different regions (Pietikinen *et al.*, 2011). You can also select and describe the special points, by which the points of set sizes with the largest weights in the vicinity are meant. The effectiveness of the proposed approach application to image analysis in onboard unmanned vehicle systems is conditioned by the fact that the objects (for example, road signs, road markings or car numbers) that need to be identified are characterized by contours. Figures 1 and 2 show the results of energy feature model development in the form of weighted images based on Haar wavelets (Fig. 1a and 2a) for the images of a road sign (Fig. 1b) and road markings (Fig. 2b) (Ismagilov, 2006).

Figure-1. The model of energy signs for a road sign image



a) b)

Figure-2. The model of energy attributes for road marking



a) b)

As can be seen from the presented figures, the model of image energy characteristics allows us to isolate their contour accurately (Klyoster *et al.*, 2018).

4. Summary

Thus, the use of the presented energy characteristics model allows to provide an efficient description of images for their subsequent processing and analysis. The use of wavelet transformation makes it possible to use the same basic operations to solve a set of tasks in onboard unmanned vehicle systems, including image primary processing, segmentation, description, recognition and compression. The application of such a unified approach will allow to reduce the time for the implementation of all procedures and requirements for computing resources of the on-board system of an unmanned vehicle (Ismagilov, 1996; Pass and Zabih, 1996).

5. Conclusions

Research works in this trend correspond to the roadmap of the National Technological Initiative Autonet within the framework of the elements of the computer vision system of an unmanned vehicle. It allows to contribute to the overcoming of the following main technological barriers for Russian and foreign producers (Long *et al.*, 2003)

- The need to ensure safety (including quality control) when they use cars with the intelligent systems on public roads;
- The need to increase the autonomy of cars with intelligent systems (common technologies of robotics);
- The requirements for a long duration of autonomous movement provision and operating cost reduction.

Besides, it should be noted that the proposed approach is more general and can be applied for the detection and the recognition of objects in various systems based on computer vision methods and means.

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