AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

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PROBABILISTIC APPROACH TO OBJECT DETECTION AND RECOGNITION FOR VIDEOSTREAM PROCESSING

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Abstract

Purpose: *The represented research results are aimed to improve theoretical basics of computer vision and artificial intelligence of dynamical system. Proposed approach of object detection and recognition is based on probabilistic fundamentals to ensure the required level of correct object recognition.* ***Methods:*** *Presented approach is grounded at probabilistic methods, statistical methods of probability density estimation and computer-based simulation at verification stage of development.* ***Results:*** *Proposed approach for object detection and recognition for video stream data processing has shown several advantages in comparison with existing methods due to its simple realization and small time of data processing. Presented results of experimental verification look plausible for object detection and recognition in video stream.* ***Discussion:*** *The approach can be implemented in dynamical system within changeable environment such as remotely piloted aircraft systems and can be a part of artificial intelligence in navigation and control systems.*

Keywords: Bayesian approach; BLOB; probability density function; object detection; recognition; video stream.

1. Introduction

Object recognition is one of the main categories of tasks studied in computer vision. Computer vision has many applications such as industrial inspection, robotic manipulation, automatic vehicle navigation, document processing, image compression and enhancement, medical applications such as microscopy and radiology, remote sensing, and visual inspection of industrial products.

The automatic recognition of objects is difficult problem for many reasons. The details of the human visual and perceptual processes are incompletely understood. Because of this, it is difficult to provide a sufficient mathematical description for these processes, and they are often treated partially in the development of algorithms [1, 2]. Extensive research in physiology has been performed to understand how the brain functions, but it has proved not to be an easy task for reasons of the complexity of brain and ethical considerations that forbid experimentation on humans. Expecting vision systems try to infer 3-D information about the world or scene, mostly from 2-D images, to achieve results similar to those of a human being. On the other hand, humans are equipped with two eyes, and this makes the Human Visual System inherently equipped for stereo vision and the consequent estimation of depth [3]. Human Visual System which is invariant to rotation, size, and position of the object under consideration is another problem that recognition systems attempt to model.

2. Analysis of the research and publications

Various authors give a different classification of methods for object recognition. Some authors single out parametric, nonparametric, and heuristic methods. E.g., in [4], the following classification of pattern recognition methods is used:

– Methods based on the principle of separation,
– Statistical methods,
– Methods based on "potential functions",
– Methods of estimation (voting),
– Methods based on the calculation of propositions, in particular on the tools of logic algebra.

D.A. Pospelov [5] identifies two main ways of knowledge representation such as intentional and extensional groups.

3. Aim of the paper

The goal of the article is to analyze existing object recognition methods, to highlight peculiarities of their application, and to propose and verify Bayesian approach for object detection and recognition in case of video stream data processing.

4. Classification of object recognition methods

In the common approach object recognition methods can be divided into intentional and extensional groups. Intentional methods represent knowledge in the form of a scheme of relationships between attributes. Extensional – by means of definite facts (i.e., objects, examples).

The group of intentional methods includes methods based on the estimates of the distribution densities of attributes values, methods based on the assumptions about the class of decision functions, logical methods, and linguistic (structural) methods.

The group of extensional methods includes method of comparison with the prototype; the *k*-nearest neighbors method; method of estimation (voting) and collectives of decisive rules.

Methods based on the estimates of the distribution densities of attributes values are used for problems with a known distribution, normal one as a rule. They require a big data set and a search through the entire learning sample in recognition. Methods have high sensitivity to the unrepresentative learning sample.

Methods based on the assumptions about the class of decision functions assume that classes must be well separated and the system of attributes should be orthogonal. A form of the decision function must be known in advance. The impossibility of taking into account new knowledge about the correlations between the attributes is a disadvantage of the methods.

Logical methods are used for problems of small dimension of attributes. During the selection of logical decision rules, a complete search is necessary. High computational complexity is a disadvantage of the methods.

Linguistic (structural) methods are used for problems with small dimension of attributes. The task of defining a grammar by some set of objects descriptions is difficult for formalization.

Comparison with the prototype method is used for problems with small dimension of attributes.

There is high dependence of classification results on the measure of distance (metrics). Uncertainty of the optimal metric is a disadvantage of the method.

The *k*-nearest neighbors method is used for problems with small dimension of attributes and classes[6]. The method has high dependence of classification results on the measure of distance (metrics). It is a necessary to search through the training sample at recognition. The method involves complicated computations.

Method of estimation (voting) is used for problems with small dimension of attributes and classes.

There is a dependence of classification results on the measure of distance (metrics), and it is necessary to search through the learning sample at recognition. The method has high technical complexity.

Collectives of decisive rules are used for problems with small dimension of attributes and classes. The method has very high technical complexity and a lot of unsolved theoretical problems.

5. Bayesian approach for object detection and recognition

A popular method based on estimates of the distribution densities of attributes values is probabilistic Bayesian approach [7, 8]. The key point of the approach is that probability of correct object recognition is guaranteed at the highest level that can be set up by a user.

Suppose that N classes of objects are given. They correspond to prior probabilities $p_1, \ldots, p_N$, where

$$p_i > 0,\ i = 1, \ldots, N,\ \sum_1^N p_i = 1.$$

If there is a vector signal $\xi \in \Re^q$ from the object of kth class, it has a probability density function $\rho_k(x;\theta)$, $x \in \Re^q$, $\theta \in \Theta \subset \Re^d$.

Here θ is a parameter that sets the observation conditions, such as certain angles associated with object; Θ is parameter set for θ, i.e., a set, where θ can vary. We suppose that the parameter θ is known exactly.

If none of the classes is observed, than the signal ξ has a probability density function $\rho_0(x;\theta)$. It corresponds to the probability distribution of noise which does not contain a useful signal from neither object of neither class [7].

We will consider the procedure of object detection and its recognition if it had been detected.

6. Object detection procedure

Describe a likelihood ratio criterion. It is a generalization of Wald test in case of densities dependent on the parameter θ.

Denote by $x_1,..,x_n$ the varying in time independent observed signal values ξ; $\theta_1,..,\theta_n$ are the corresponding θ values.

Let $\bar{\rho}(x;\theta) := \sum_1^N p_i \rho_i(x;\theta)$ be an average prior density of a signal ξ, in case a signal from each of the object is available.

Using subsequent observations we want to check a hypothesis H_0 about an absence of a signal from the object vs. the alternative $\overline{H_0}$ about a presence of a signal from the object. We treat it as follows: it is necessary to make a choice between the two densities $\rho_0(x;\theta)$ and $\bar{\rho}(x;\theta)$.

Introduce a test statistic

$$T_n = \prod_{k=1}^{n} \frac{\bar{\rho}(x_k;\theta_k)}{\rho_0(x_k;\theta_k)}.$$

Suppose that α and β are given levels of probabilities of a type I error (when $\overline{H_0}$ is accepted under true H_0) and type II error (when H_0 is accepted under true $\overline{H_0}$), $\alpha+\beta<1$, $\alpha>0$, $\beta>0$. We choose threshold values as

$$0<B<1<A<\infty,\ A=(1-\beta)/\alpha,\ B=\beta/(1-\alpha).$$

We continue observations until one of the inequalities is fulfilled:

$$T_n \geq A \text{ or } T_n \leq B.$$

In the first case, $\overline{H_0}$ is accepted (an object is detected), and in the second case, H_0 is accepted (an object is not detected).

Under mild conditions it holds:

$$P_{\overline{H_0}}(T_n > C) \to 1, \text{ as } n \to \infty, \text{ for all } C>0;$$

$$P_{H_0}(T_n < \varepsilon) \to 1, \text{ as } n \to \infty, \text{ for all } \varepsilon > 0.$$

Hereafter $P_{H_0}(A)$ is probability of the event A in case H_0 is true; $P_{\overline{H_0}}(A)$ is the corresponding probability in case the alternative hypothesis $\overline{H_0}$ is true.

The sequential algorithm will be terminated with probability one. Herewith, for probabilities of type I error α' and type II error β' the following relations are fulfilled:

$$\alpha' \leq \alpha/(1-\beta),\ \beta' \leq \beta/(1-\alpha),\ \alpha'+\beta' = \alpha+\beta.$$

Thus, the sum of error probabilities is controlled by the sum $\alpha+\beta$.

7. Object recognition procedure

Suppose that an object was detected. We continue the observations and receive new data $x_n,..,x_m$, $\theta_n,..,\theta_m$, $m \geq n$.

We will use the observation x_n which was received at the moment of recognition algorithm termination, and new observations as well.

We describe a sequential decision rule. Denote by H_k a hypothesis that detected object belongs to the kth class, $1 \leq k \leq N$.

Posterior probabilities can be evaluated as follows:

$$q_k^{(m)} = \frac{p_k \rho_k(x_n;\theta_n)\rho_k(x_{n+1};\theta_{n+1})\ldots\rho_k(x_m;\theta_m)}{\sum_1^N p_i \rho_i(x_n;\theta_n)\rho_i(x_{n+1};\theta_{n+1})\ldots\rho_i(x_m;\theta_m)},$$

with $k = 1,\ldots,N$.

Suppose that it is defined a value P_C for an average probability of correct recognition, $0.5<P_C<1$. This value can be equal, e.g., $P_C=0.9$ or $P_C=0.95$.

The observations can be terminated if the following condition holds true:

$$\max_{1 \leq k \leq N} q_k^{(m)} \geq P_C.$$

If in this relation we have “strictly less”, then we continue observations until the termination condition is fulfilled. After the termination, the hypothesis H_j is accepted if

$$q_j^{(m)} = \max_{1 \leq k \leq N} q_k^{(m)}.$$

Since $P_C>0.5$, the accepted hypothesis is uniquely defined.

8. Simulation results

One of the applications of object detection and recognition is video stream data processing.

Consider a problem of object detection and recognition by patterns in video stream. In typical situations the objects may be described by a set of parameters such as length and width. During measurement process some parameters may be lost. In this case lost data can be recovered [9]. For verification of proposed probabilistic approach, a small experiment with video registration was done. Within an experiment, a video stream with rotated object images was fixed by a camera and saved at the laptop for further analysis. The scheme of experimental equipment is presented in Fig.1. A video stream from fixed camera was divided into the sequence of images within MATLab environment.

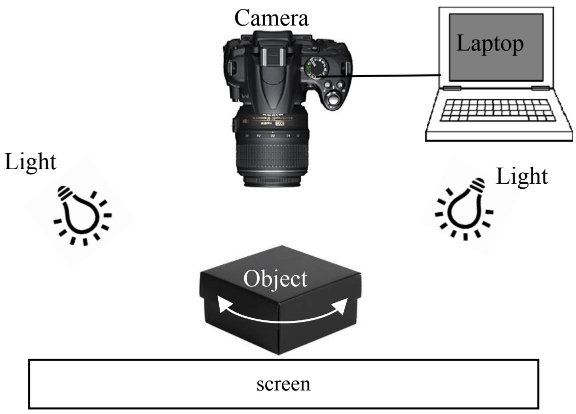

Fig. 1. Scheme of experimental equipment for video stream registration and processing

Further, color images were transformed to images represented as intensities of black color with selection of Binary Large Objects (BLOBs). Built-in algorithms give the possibility to get in pixels two parameters of each BLOB such as its width and length. The usage of calibration factor gives the possibility to convert pixel data to the metric size. The obtained data (width, length, etc.) can be used as input data for the object detection and recognition procedure.

Within an experiment, three objects with different shapes and sizes were used. The sequence of observations by video stream was utilized to obtain statistical characteristics of objects. Mean values and standard deviations were used for probabilities densities estimation. Probability density functions of the length and width parameters for three classes of objects are presented in Fig. 2 and 3, respectively. Posterior probabilities were evaluated by Bayes' formula based on prior information and the estimated probability density functions (see Fig. 4–5).

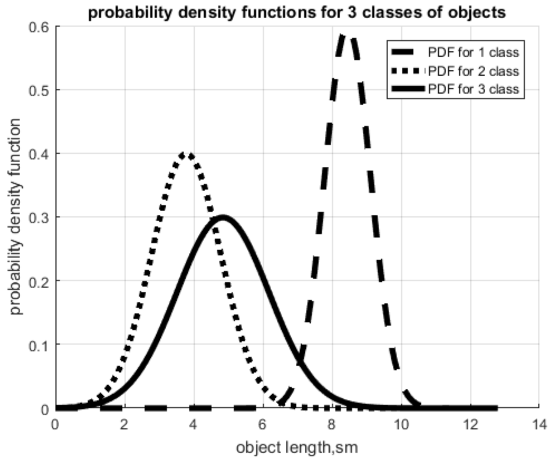

Fig. 2. Probability density functions of the length parameter for 3 classes of objects

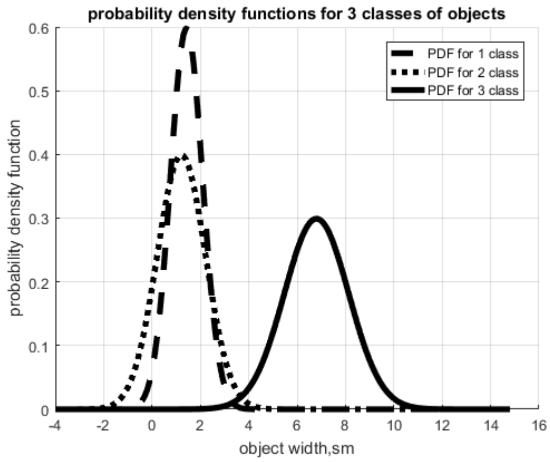

Fig. 3. Probability density functions of the width parameter for 3 classes of objects

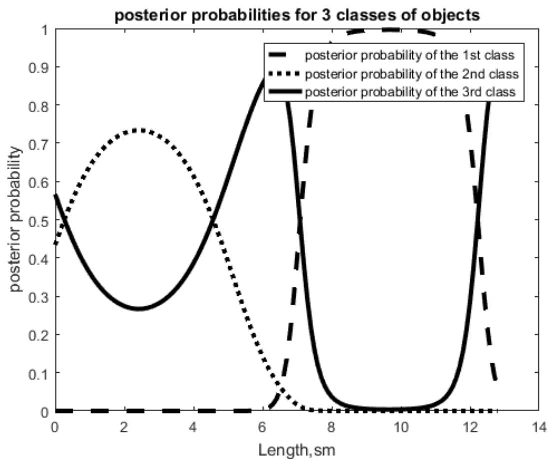

Fig. 4. Posterior probabilities of the length parameter for 3 classes of objects

In case of several parameters of detected objects, a multivariate normal probability density function can be used (see Fig. 6).

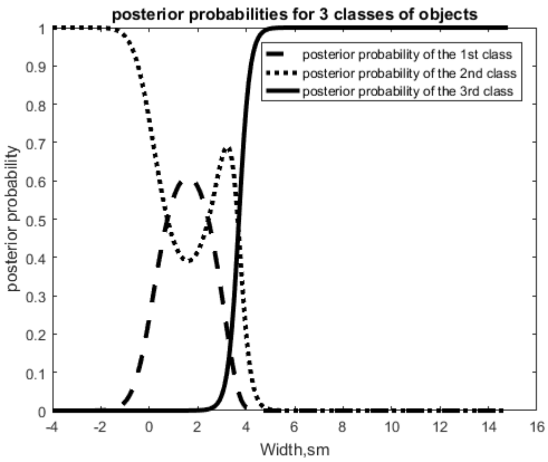

Fig. 5. Posterior probabilities of the width parameter for 3 classes of objects

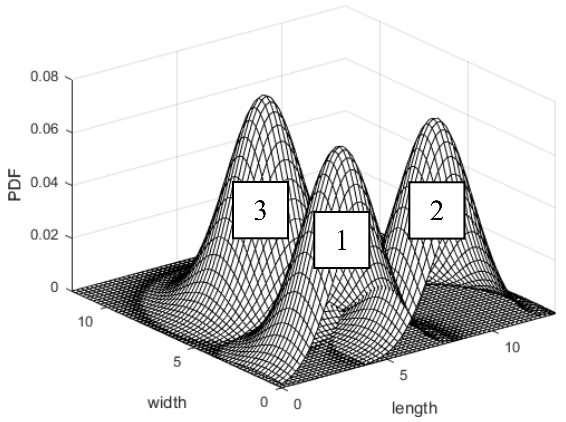

Fig. 6. Bivariate normal probability density functions for 3 classes of objects

In the proposed object recognition procedure, a threshold value for the probability of correct recognition was set to 0.95. In the reported experiment, the observation of a detected object was continued until the posterior probability of the object classification exceeds the set value.

8. Conclusions

The proposed Bayesian approach to object detection and recognition for video stream data processing has several advantages in comparison with existing methods due to its simple realization, short time of data processing and guaranteed level of object recognition, and the latter level can be set by user. The possibility to consider the object under different angles of observation is one of key points of the proposed approach that increases the probability of correct recognition. Presented results of experimental verification show the possibility of its implementation for object detection and recognition in video stream.

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Виявлення та розпізнавання об'єктів за допомогою ймовірнісного підходу при обробці відеоданих

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Мета: Представлені результати спрямовані на розвиток теоретичних засад комп'ютерного зору та штучного інтелекту динамічних систем. Запропонований підхід до виявлення та розпізнавання об'єктів базується на ймовірнісних методах забезпечення необхідного рівня правильного розпізнавання об'єктів. **Методи дослідження:** Представлений підхід базується на методах теорії ймовірності, статистичних методах оцінки щільності ймовірності та комп'ютерному моделюванні. **Результати**: Запропонований підхід для виявлення та розпізнавання об'єктів при обробці відеоданих продемонстрував ряд переваг у порівнянні з існуючими методами завдяки простоті реалізації та швидкій обробці даних. Представлені результати експериментальної перевірки виглядають перспективно для виявлення та розпізнавання об'єктів у відеопотоці. **Обговорення:** Підхід може бути реалізований у динамічній системі в умовах мінливого середовища, наприклад, у дистанційно пілотованих авіаційних системах, та може бути складовою штучного інтелекту в системах навігації та управління.

Ключові слова: Байєсівський підхід; виявлення об'єкту; відеопотік; розпізнавання; щільність імовірності.

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Обнаружение и распознавание объектов с помощью вероятностного подхода при обработке видеоданных

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Цель: Представленные результаты исследования направлены на развитие теоретических основ компьютерного зрения и искусственного интеллекта в динамической системе. Предложенный подход к обнаружению и распознаванию объектов основан на вероятностных предположениях и служит для обеспечения необходимого уровня правильного распознавания объектов. **Методы исследования:** Представленный подход основывается на методах теории вероятности, методах статистического оценивания плотности вероятности и компьютерного моделирования для верификации. **Результаты:** Предложенный подход к обнаружению и распознаванию объектов при обработке видеоданных продемонстрировал ряд преимуществ по сравнению с существующими методами ввиду простоты реализации и быстрой обработки данных. Представленные результаты моделирования выглядят многообещающе для применения в задачах обнаружения и распознавания объектов в видеопотоке. **Обсуждение:** Описанный подход может быть реализован в динамической системе в условиях меняющейся среды, например, в дистанционно пилотируемых авиационных системах, и может быть частью искусственного интеллекта в системах навигации и управления.

Ключевые слова: Байесовский подход; видеопоток; обнаружение объекта; плотность вероятности; распознавание.

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