UDC 629.735.051-52: 629.735.051 (045)

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ALGORITHM OF MORPHOLOGICAL CORRELATION-EXTREME NAVIGATION SYSTEM

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Abstract—*The paper deals with correlation-extreme navigation to define coordinates of unmanned aerial vehicles more precisely. Normalized morphologic correlation coefficient was chosen as criterion function. Images were processed with the help of intensity based and auto tracking methods. The comparison of these methods by their robustness and normalized morphological correlation coefficient assessment was done on the series of test images with different informative levels.*

Index Terms—Correlation-extreme navigation system; morphological analysis; normalized cross-correlation; feature extraction.

I. INTRODUCTION

Global Positioning System (GPS) and Inertial Measurement Unit (IMU) are integrated aboard Unmanned Aerial Vehicle (UAV). It usually has ability to perform automatic navigation along planned waypoints. But if the GPS signal becomes unavailable, the state estimation solution provided by data from IMU alone drifts in time and will be unusable. Correlation-extreme navigation is one of alternative solution in such case and may be additional source of data fusion in the integrated navigation complex.

The principle of correlation-extreme navigation system (CENS) operation is based on a comparison of image of the Earth's surface or current image and reference one received in advance. But the core problem of modern image analysis is the need to consider the probabilistic nature of the real image, to account a prior information, to ensure the stability (robustness) of image analysis procedures with respect to various kinds of noise.

The purpose of the work is to develop method of morphology as a unified approach to the description, development and use of image analysis algorithms, based on the brightness and geometric characteristics of the image. It leads to the distinguishing basic distinction between simple correlation coefficient assessment and morphological one. The first compares images as brightness functions, but morphological correlation coefficient characterizes correlation between brightness of the first image and geometrical form of second image [1].

So, the proposed method of morphological analysis is developed and is used to describe the probability of the structural aspects of image analysis procedures based on brightness and geometric characteristics.

II. PROBLEM STATEMENT

Knowledge of image brightness at each point of the visual field is redundant to solve many problems of the scene analysis. Much more important is the “structure” (called in the morphological analysis as the image form), which is not changed by variations of the conditions of its formation.

In the morphology, images are treated as piecewise constant functions of the form

$$g(x,y)=\sum\nolimits_{i=1}^{n} g_i \chi_{Gi}(x,y),$$
$$\chi_{G_i}(x,y)=\begin{cases}1, & \text{if } (x,y)\in G_i;\\ 0, & \text{otherwise,}\end{cases} \qquad (1)$$

where n is the number of regions of segmentation G of image Ω on the connected non-crossing regions of constant brightness, $\mathbf{G}=\{G_1,\ldots,G_n\}$, $\mathbf{g}=(g_1,\ldots, g_n)$ is vector of the actual brightness values corresponding to each area of the segmentation; $\chi_{Gi}(x,y)\in\{0,1\}$ is the characteristic function of ith illumination region.

Set of images of one form of frame segmentation G in this case constitutes a convex and closed subspace $F\subseteq L^2(\Omega)$:

$$G = \left\{ g(x,y) = \sum\nolimits_{i=1}^{n} g_i \chi_{Gi}(x,y), g\in R^n \right\}. \qquad (2)$$

Forms create the algebraic structure of the “grid” type, in which for any two forms F and G, more complex form $F\wedge G$ and less complex form could be specified.

More complex forms can be obtained from less complex segmentation and less complicated from more complex – regions dilation [2].

For any image $f(x,y) \in L^2(\Omega)$ projection on the form *G* could be determined:

$$f_G(x,y) = P_G f(x,y) = (\chi_{Gi}, f)/\|\chi_{Gi}\|^2,$$
$$f_{Gi} = (\chi_{Gi}, g)/\|\chi_{Gi}\|^2, i = 1, \ldots, n. \quad (3)$$

Morphological comparison of images *f*(*x*, *y*) and *g*(*x*, *y*) is performed using morphological quasidistance $d_M(f,G) = \|f - P_G f\|$ and normalized morphological correlation coefficients:

$$K(f,G) = \frac{\|P_G f\|}{\|f\|}. \quad (4)$$

The set of images, whose form is not more difficult than the form *f*, is a uniform linear space

$$\nu_f = \{g = kf, k \in (-\infty, \infty)\} \subset L^2_\mu(X). \quad (5)$$

This set consists of images obtained from *f* as homogeneous linear transformations of brightness. Set V_f is convex and closed so there is only one projection of the image on the form, which is obtained by solving the corresponding problem of the best approximation

$$\|g - kf\| \sim \min_{k \in (-\infty, \infty)}. \quad (6)$$

In the correlation analysis, similarity of images is characterized by the measure

$$|\text{cor}(f,g)| = \frac{|(f,g)|}{\|f\|\|g\|}. \quad (7)$$

To select from a set of images $\nu_f \subset L^2_\mu(X)$ image $g_0 \in L^2_\mu(X)$ the closest by the form to $f \in L^2_\mu(X)$, it is necessary to minimize $\rho_{\text{morph}}(f, g)$ by choice $g \in \nu_f$.

Condition of maximum is

$$|cor(f - P_0 f, g - P_0 g)| = \frac{|(f - P_0 f, g - P_0 g)|}{\|f - P_0 f\|\|g - P_0 g\|}. \quad (8)$$

Morphological correlation coefficient corresponds to each pair "image-projection". It takes maximal value for the images that belong to the total subform $F \wedge G$: here projection is equal to image itself [3].

III. Proposed Technique of Realization of Morphological CEN Operation

A. Image segmentation

Image segmentation is a mid-level processing technique used to analyze the image and can be defined as a processing technique used to classify or cluster an image into several disjoint parts by grouping the pixels to form a region of homogeneity based on the pixel characteristics like gray level, color, texture, intensity and other features.

It is performed for separating the good BLOBs (binary large object) from the background and each other as well as eliminating everything else in the image that is not of interest [4]. If *R* represents an image, then the image segmentation is simply division of *R* into subregions $R_1, R_2, \ldots, R_n$ such that

$$R = \bigcup_{i=1}^{n} R_i \quad (9)$$

and is governed by following set of rules:

a) R_i is a connected set, $i = 1, 2, \ldots, n$.

b) $R_i \cap R_j = \varnothing$ for all *I* and *j*, $i \neq j$

c) $Q(R_i) = \text{True}$ for $i = 1, 2, \ldots, n$.

d) $Q(R_i \cup R_j) = \text{False}$ for adjoint regions, R_i, R_j,

where $Q(R_k)$ is a logical predicate.

The rules described above mention about continuity, one-to-one relationship, homogeneity and non-repeatability of the pixels after segmentation respectively. There are many knowledge based approaches to segment an image and the most important are listed as

– discontinuity based methods;
– similarity based methods;
– intensity based methods.

Discontinuity based method is based on the principle of intensity variations among the pixels. If the image consists of two or more objects boundaries exist and hence it can be applied to segment of the image. The boundaries of the objects lead to formation of edges. Edges are usually found by applying masks over the image [5]. One of the methods is evaluating the gradients generated along two orthogonal directions:

$$\nabla f = G[f(x,y)] = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}. \quad (10)$$

Direction of gradient is given by

$$\alpha = \tan^{-1}\left[\frac{g_y}{g_x}\right]. \quad (11)$$

Disadvantage of such method is the fact that no single operator can fit for all variety of images and the computational complexity increases with the size of operator.

Similarity based methods work on the principle of homogeneity by considering the fact that the neighboring pixels inside a region possess similar characteristics and are dissimilar to the pixels in other regions. The objective of region based segmentation is to produce a homogeneous region which is bigger in size and results in very few regions in the image. Region based methods are fundamentally divided by region growing methods and region split and merge methods.

Region growing method gives reliable output compared to its other counterparts. It is basically extracting a region from the image using some pre-defined criteria. The simplest procedure is to compare the candidate pixel to its neighbors to check the homogeneity criteria allocated to the class to which its neighbor belongs.

If complete image is denoted as region *R*, then segmentation compose it into *n* disjoint regions $S_1, S_2, ..., S_n$ such that

$$\left.\begin{array}{lll} \cup S_i = S, & S_i \cap S_j = \varnothing, \text{ if} & i \neq j \\ \Pr\text{op }(S_i) = \text{True}, & \text{if} & i = 1,2,3,...,n \\ \Pr\text{op }(S_i \cup S_j) = \text{False}, & \text{if} & i = 1,2,3,...,n \end{array}\right\} \quad (12)$$

Region Split and Merge method is the most similar method to segment the image based on homogeneity criteria. This method works on the basis of quadtrees and main objective is to distinguish the homogeneity of the image.

But there are such disadvantages

1. Formulation of Stopping rule for segmentation is a tedious task.

2. A good segmentation result depends on a set of "correct" choice for the seeds and can lead to erroneous segmentation results if user specifies a noisy seed.

Intensity based segmentation. This work relates with such method. It is one of the simplest approaches to segment an image based on the intensity levels and it is called threshold based approach. Threshold based techniques classify the image into two classes and works on the postulate that pixels belonging to certain range of intensity values represent one class and the rest of the pixels in the image represents the other class [7]. For global thresholding:

$$g(x,y) = \begin{cases} 1 & \text{for} \quad i(x,y) \geq t, \\ 0 & \text{for} \quad i(x,y) < t. \end{cases} \quad (13)$$

where $g(x,y)$ is the output image; $i(x,y)$ is the input image and *t* is the threshold value.

For local thresholding the procedure is following.

Let us consider an image with two different objects, then identify two thresholds T_1 and T_2 such that

$$\left.\begin{array}{l} T_1 \leq g(x,y) \leq T_2 \quad \text{for one object,} \\ g(x,y) \geq T_2 \quad \text{for the other object,} \\ g(x,y) \leq T_1 \quad \text{for the background.} \end{array}\right\} \quad (14)$$

Threshold value can be modified and are categorized as band thresholding, multi-thresholding and semithresholding. Either the global thresholding or local thresholding yields the result depending on the value of threshold chosen. Hence the choice of threshold is crucial and complicated.

So, this method was chosen because of computationally simplicity and speed of operation.

But this paper also deals with **auto tracking method**. Having an image $f(x,y)$, the task is to find positions on the image that best fit to set subimage $w(x,y)$. On the initialization phase, initially the target was chosen based on a small tracking window.

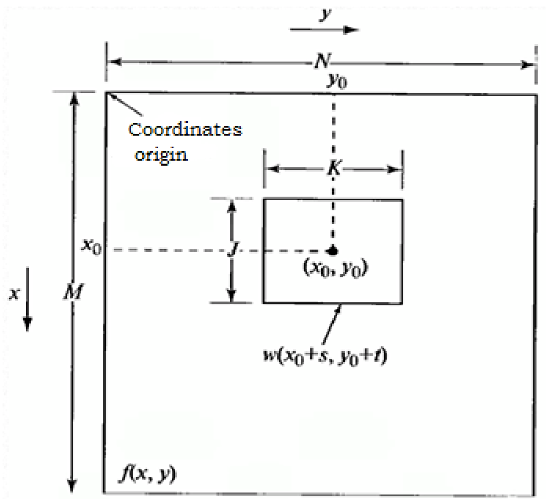

Fig. 1. Scheme of tracking start [8]

Based on the new position of the object the updating is done.

In practice, this method uses regions of interest (ROIs). A region of interest is a portion of an image that we want to perform some other operation on. We define an ROI by creating a binary mask, which is a binary image that is of the same size as the image we want to process with pixels that define the ROI set to 1 and all other pixels set to 0.

B. Binary large object analysis

Binary large object (BLOB) is an area of connecting pixels with the same logical state. All pixels in an image that belong to BLOB are in a foreground state. All other pixels are in a background state.

The next step is now to classify the different BLOBs. Each BLOB is represented by a number of characteristics, denoted features. Feature extraction is a matter of converting each BLOB into a few representative numbers. That is, to keep the relevant information and to ignore the rest. The main parameters of BLOB analysis are the following [9].

1. **Area** of BLOB is the number of pixels the BLOB consists of. This feature is often used to remove BLOBs that are too small or too big from the image.
2. **Bounding box** of BLOB is the minimum rectangle which contains the BLOB. It is defined by going through all pixels for a BLOB and finding the four pixels with the minimum *x*-value, maximum *x*-value, minimum *y*-value and maximum *y*-value, respectively. From these values the width of the bounding box is given as $x_{\max} - x_{\min}$ and the height as $y_{\max} - y_{\min}$.
3. **Convex hull** of BLOB is the minimum convex polygon which contains the BLOB.
4. **Bounding box ratio** of BLOB is defined as the height of the bounding box divided by the width.
5. **Compactness** of BLOB is defined as the ratio of the BLOB's area to the area of the bounding box

$$\text{Compactness}=\frac{\text{Area}}{\text{width}\cdot\text{height}}. \tag{15}$$

6. **Center of mass** (or center of gravity or centroid). It is the average *x*- and *y*-positions of the binary object. It is defined as a point, whose *x*-value is calculated by summing the *x*-coordinates of all pixels in the BLOB and then dividing by the total number of pixels. Similarly for the *y*-value. In mathematical terms the center of mass is calculated as

$$x_c = \frac{1}{N}\sum_{i=1}^{N} x_i, \quad y_c = \frac{1}{N}\sum_{i=1}^{N} y_i, \tag{16}$$

where *N* is the number of pixels in the BLOB.

7. **Perimeter** of BLOB is the length of the contour of the BLOB.
8. **Eccentricity** of BLOB defines how circular BLOB is

$$\text{Circularity}=\frac{\text{Perimeter}}{2\sqrt{\pi\cdot\text{Area}}}. \tag{17}$$

C. Images matching

Normalized morphological cross correlation has been commonly used as a metric to evaluate the degree of similarity between two compared images. The normalized correlation for two time series can be defined as

$$\varphi'_{xy}(t) = \frac{\varphi_{xy}(t)}{\sqrt{\varphi_{xx}(0)\varphi_{yy}(0)}}. \tag{18}$$

The normalized quantity $\varphi'_{xy}(t)$ will vary between "0" and "1". A value of $\varphi'_{xy}(t)=1$ indicates that at the alignment *t*, the two time series have the exact same shape (the amplitudes may be different). A value of $\varphi'_{xy}(t)=0$ shows that they are completely uncorrelated [10]. In practice when one applies this normalization to real discrete signals, one will find that a correlation coefficient greater than about 0.7 or 0.8 indicates a pretty good match.

IV. Results of Images Comparison

Series of experiments on images of different informative levels were performed based on thresholding method and following figure shows results of checking robustness characteristic.

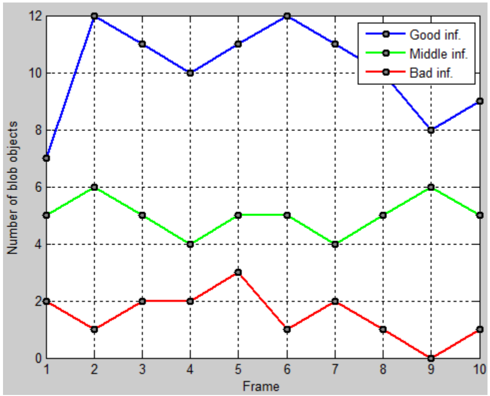

Fig. 2. Characteristic of robustness of intensity based method obtained by images with different informative levels

Such characteristic shows some instability in comparison to another observed auto tracking method, which is shown in Fig. 3.

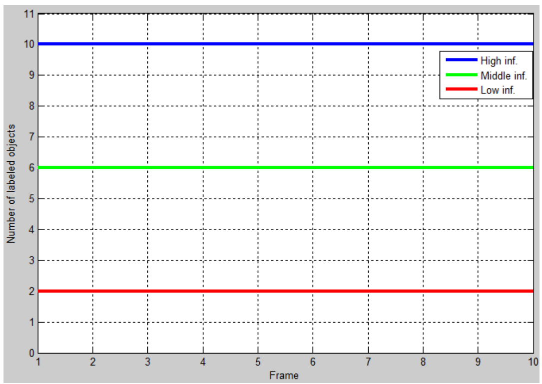

Fig. 3. Characteristic of robustness of auto tracking method obtained by images with different informative levels

The second method shows ideal characteristic at this stage of observation. The reason being that when we start to process images we have to process each pixel, i.e., perform some math on each pixel. And, due to the large number of pixels, that quickly adds up to quite a large number of mathematical operations, which in turn means a high computational load on computer.

TABLE I

TIME OF PARAMETERS COMPUTATION

Parameters	Total time of execution
Area, Centroid, BBox, Count	0.823 s
With additional parameters estimation: Orientation, Eccentricity, Diameter^2, Perimeter, Label	0.914 s

This table shows that computation time is less than one second. Such value means that this algorithm could be used in real-time application.

Following results illustrate values of normalized correlation coefficient for images with different informative levels (Figs 4 – 6).

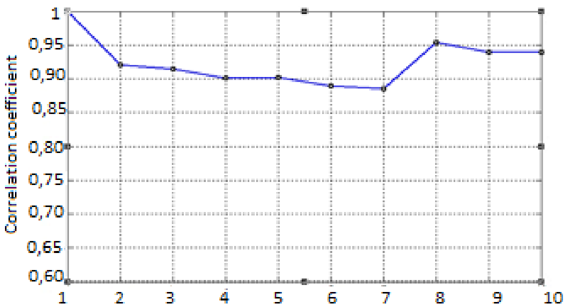

Fig. 4. Normalized correlation coefficient for high informative image

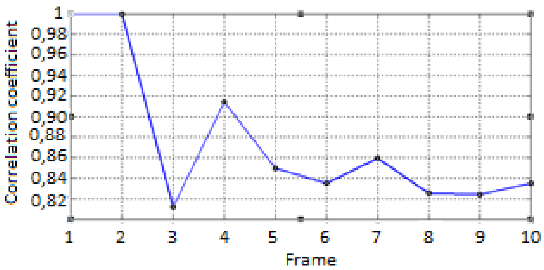

Fig. 5. Normalized correlation coefficient for middle informative image

Previous plots show us that normalized correlation coefficient is less sensitive to registration conditions. And the main advantage of the normalized cross correlation over the ordinary cross correlation is that it is less sensitive to linear changes in the amplitude of illumination in the two compared images.

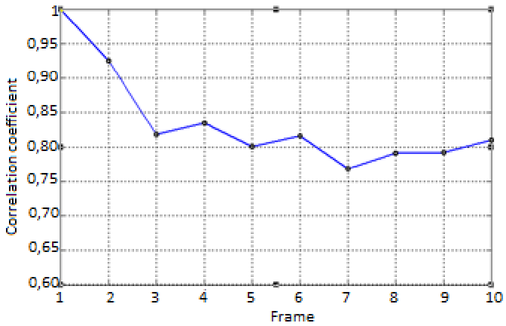

Fig. 6. Normalized correlation coefficient for low informative image

V. CONCLUSIONS

It has been shown that comparison of images only based on the brightness characteristic in not sufficient in some case, but morphological comparison considers also geometric characteristics. Main stages of morphological CEN algorithm of operation were considered. Comparison of characteristics was performed with the help of intensity based and auto tracking methods of images segmentation. The second method shows ideal characteristic at this stage of observation.

Comparison of images was performed using normalized morphological correlation coefficient. For high informative images its value varies in range from 0.88 to 1; for middle informative – from 0.81 to 1; for low informative - from 0.77 to 1. It is good matches and it proves that it is less sensitive to registration conditions and linear changes in the amplitude of illumination in the compared images.

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Received January 28, 2016

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М. П. Мухіна, А. О. Кузьменко. Алгоритм морфологічної кореляційно-екстремальної навігаційної системи

Розглянуто кореляційно-екстремальну навігаційну систему, яка дозволяє більш точно визначити координати безпілотного літального апарату. В якості критеріальної функції обрано нормований морфологічний коефіцієнт кореляції. Зображення оброблені за допомогою методу, який базується на інтенсивності та методу автоматичного відстеження. Порівняння методів за стійкістю та оцінку нормованих морфологічних коефіцієнтів кореляції проведено на серії тестових зображень з різним рівнем інформативності.

Ключові слова: кореляційно-екстремальна навігаційна система, морфологічний аналіз, нормована взаємна кореляція.

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Освіта: Національний авіаційний універститет, Київ, Україна, (2002).
Напрямок наукової діяльності: обробка зображень, навігація та керування.
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М. П. Мухина, А. А. Кузьменко. Алгоритм морфологической корреляционно-экстремальной навигационной системы

Рассмотрена корреляционно-экстремальная навигационная система, которая позволяет более точно определить координаты беспилотного летательного апарата. В качестве критериальной функции выбран нормированный морфологический коэффициент корреляции. Изображения обработаны с помощью метода, который базируется на интенсивности и метода автоматического сопровождения. Сравнение методов по устойчивости и оценку нормированных морфологических коэффициентов корреляции проведено на серии тестовых изображений с разным уровнем информативности.

Ключевые слова: корреляционно-экстремальная навигационная система, морфологический анализ, нормированная взаимная корреляция.

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