The Creation of the Database for Mobile Robots Navigation under the Conditions of Flexible Change of Flight Assignment

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Abstract - The necessity to find a rational way of creating a database regarding the sighting surface taking into consideration the features of construction and functioning of correlation-extreme navigation systems (CENS) of aerial mobile robots (MR), including in particular the conditions of flexible change of flight assignment, is shown in the article. It is proposed to use invariants, which have been obtained based on a correlation analysis of the scene according to the brightness index with the subsequent and allowing to form selective images, as a database information content. The results of the evaluation of the quality of formed selective reference image (RI) for scenes with various object impletion under conditions of limitations in time and number of calculations are given.

Key words - Aerial Mobile Robot, Reference Area, Selective Image, Correlation Analysis, Database.

I. INTRODUCTION

The principles of autonomous navigation of mobile robots, based on the application of correlation-extreme navigation systems, are widely used in various branches of industry, healthcare and the military affairs. However, the implementation of these principles may be distinctly different depending on the purpose of the information retrieval system and the type of tasks it performs. These principles impose constraints upon both the retrieval system and the preparation of the reference information required for its operation. An essential feature of MR navigation is the need to reconfigure the flight route in real time, which imposes constraints upon the formation of reference images of the reference area in time and upon the associated selection of reference objects on the sighting surface. This necessitates the identification and tracking of those information features whose use ensures the required accuracy of the navigation system, especially in the event of interference that causes the degradation of operation of the secondary processing system.

The complication of the problem can be caused by the need of application of combined navigation systems, which use different information attributes (invariants) embedded in the RI, as well as high flight speeds or the need to bind over steep MR trajectories. The combination of these factors substantially adds complexity to the flight assignment preparation process, based on the information stored in the database regarding the MR location, and requires these factors to be taken into account during the creation of corresponding databases. In other words, the specifics of the MR flight causes the need to create the special database, which helps to prepare RI in a timely manner taking into consideration the imposed constraints without compromising the accuracy and reliability of the navigation system. The object structure of the sighting surface with different informative features, which can be unstable due to various external factors, as well as the instability of the conditions for the formation of the images, are of great importance. Considering these factors, it is required to carry out research and find a rational way of creating a database on the sighting surface for MR navigation taking into consideration the features of construction, functioning and current tasks of correlation-extreme navigation systems (CENS) [1, 2, 3].

II. ANALYSIS OF LITERATURE DATA AND PROBLEM STATEMENT

In [1], the results of constructing matrix CENS are presented. The analysis of sensors used for primary signal processing is presented. Algorithms for comparing RI and CI are considered. At the same time, the initial data for describing the sighting surfaces and filling the database were not discussed.

In [2], the results of the development of a method for localizing a referenced object on current images (CI) in the event of false objects caused by geometric distortions are presented.

The studies were carried out without taking into account the object composition of the sighting surface and the geometrical sighting conditions.

In [3], the results of the development of secondary image processing methods based on adaptation to the quantization threshold are presented. The results were obtained without taking into account the object composition and changes in the image structure depending on the sighting geometry.

In [4], the synthesis results of the optimal reference image for vehicle navigation systems are presented. The synthesis of the optimal image is based on the use of the concepts of the theory of the measurement scale. It is proposed to formalize the brightness component of the image, as well as its shifts and rotations relative to the CI in terms of the theory of large images. Relationships are given for describing the models of current and reference images. However, it is not shown how to use the luma component to generate the database.

In [5], models of radiometric CI and RI are presented, the possibility of reducing the influence of geometric distortions on the accuracy of positioning CENS is shown, algorithms for the formation of RI and a decisive function are proposed, the concept of an equivalent reference object is introduced, a method for forming the decision function of a combined CENS is developed, which is based on the implementation of preliminary processing CI consists in its stratification in accordance with the quantization threshold relative to the average value of the background radio brightness temperature and the construction of a set of selective images of a group of geometrically related objects with the determination of their average values of the brightness temperatures within the introduced equivalent object. At the same time, the authors disregarded the issues of using these informative features to fill the database of sighting surfaces.

In [6], the results of RI synthesis in strong and ordinal scales are given. The filling of the database in accordance with the results obtained was not reflected.

In [7], the results of a generalized assessment of the performance of ground detection systems based on the tracking and comparison method are presented. A generalized relation has been obtained for determining the probability of detecting ground objects without reference to a specific type of sensor of the detection system. The results of modeling the detection of ground objects by radiometric systems under conditions of a decrease in radio-thermal contrasts are presented. However, the initial data for filling the database was not discussed.

In [8], the results of using one-to-one and hypermonotonic transformations for the synthesis of the optimal image necessary for the functioning of the CENS MR are presented. At the same time, it is not shown how to use the results obtained to populate the database. In addition, the relationship between the object saturation of the sighting surface and the image models is not shown.

In [9], the results of evaluating the efficiency of decision making as a result of comparing images in the navigation systems of mobile robots are presented. It is proposed to use a probabilistic measure as a criterion for assessing efficiency. The expediency of the formation of RI in strong scales is shown. However, no attention was paid to the formation of a database for MR navigation.

In [10], the results of a study of the method of iterative formation of selective reference images of the CENS of aircraft by the "sliding window" method based on the use of correlation analysis of images in terms of brightness are presented.

In [11], the results of studies of the adaptive image comparison algorithm in CENS are presented. It is shown that it is possible to reduce the influence of impulse noise arising on the sighting surfaces of the reference area by means of algorithmic processing. The results of statistical tests of the adaptive algorithm, which makes it possible to select target objects under conditions of impulse noise, are presented. At the same time, the issues of filling the database for MR navigation remained not touched upon.

In [12], a solution to the problem of determining the accuracy of the information retrieval system under conditions of a stochastic change in the state of the propagation path of working signals and a priori uncertainty about the informative parameters of objects on the sighting surface is proposed.

It is shown that for the signal-to-noise $q \approx 3$ ratio, the navigation accuracy will be at least 10 m.

In [13], the results of the development of a method for planning the flight route of an unmanned aerial vehicle (UAV) for searching for a dynamic object in the forest-steppe zone are presented. Imaging issues were not considered.

Thus, in the well-known works devoted to the study of ways to improve the CENS MR, improve the quality of generated PW images with various object content, the issues of forming and filling the database for MR navigation have not received proper development.

The object of the article is to develop principles for the formation and filling of a database for navigation of MR under conditions of flexible change of flight assignment.

III. MAIN MATERIAL

1) Analysis of common approaches to creation of the database for information extraction systems

The creation of a database on the SS object composition involves the use and processing of background images in order to extract the informative features of SS objects required for the operation of the information extraction systems. Regardless of the type of sensors used for remote sensing, the resulting source information is the set of informative parameters measured by sensors of different physical nature (SDPN).

Whereupon, the useful information obtained by remote sensing is determining bright, contrasting, structural (geometric) informative parameters, the distribution of which within the limits of SS is represented in the form of corresponding informative fields. These informative fields are analyzed after the SS images are formed by comparison with the information available in the SS database. The database is filled with reliable information that prevents the entry of information that is random. The ageing of information is taken into account.

The central position in the resulting SS database belongs to the rules that determine the order of interpretation of the information obtained from the SDPN and the filling of the database.

In order to efficiently solve SS object classification problems, information is pre-processed, which can be used in an integrated manner if necessary.

Image preprocessing is well understood and covered in many monographs on digital image processing. Therefore, we will not dwell on this issue within the framework of this article. We only note that the preprocessing of images includes the following stages:

- noise filtering to remove insignificant elements in the image;
- Scaling (thinning and interpolation);
- Improvement of visual quality through sharpening;
- Improvement of the visual quality by highlighting the contours of image objects;
- Fusion and imposition of multi-spectral images.

Depending on the conditions for obtaining the initial images, as well as the object composition of the SS, some stages of image preprocessing may not be applied. So, for example, with a small number of objects in the image and high contrast, filtering noise, improving visual quality based on sharpening, as well as improving visual quality based on highlighting the outlines of image objects can be omitted. In the case of high object saturation, with low and blurry contrasts of individual SS objects on the backgrounds under consideration, these processing steps should be mandatory. The decision should be made based on the results of a preliminary analysis of the quality of the available images. After the preliminary processing of the images, the stage of formation of selective images begins. Further, the selection of informative features, which are selected as invariants, is carried out, and then the filling of the database.

Such approach to the acquisition, processing and filling of the database enables us to view the analysis of SS information as a single problem consisting of interrelated procedures, ensures that uniform requirements for the production of a wide range of data can be established to meet the required image processing procedures, and that the similar approach is used during the analysis of informative fields describing the results of remote sensing that in various tasks involve the use of information on the current state and changes in the background.

However, the implementation of these procedures does not take into account the possible limitations, based on the specifics of operation and solved problems of the information extraction system, in particular in case of changing the flight assignment of MR equipped with CENS.

2) Database Information Content Concept for MR navigation under the conditions of flexible change of flight assignment

2.1) Main database information content requirements

The database for MR navigation under the conditions of flexible change of flight assignment should meet the requirements in accordance with the general principles of database construction, such as:

- the max volumes of data, which can be stored, is unlimited;
- independence of the data – separate elements can be used;
- guarded data access;
- providing protection against unauthorized access to information contained in the database;
- support of transactions with a guarantee of the corresponding properties;
- guaranteed no failure;
- user authorization system.

These requirements do not take into consideration the specific problems assigned to the navigation system, and it determines the need to develop further the database information content concept.

2.2) General Principles of Navigation Systems Database Information Content provisioning under the conditions of flexible change of flight assignment

Database provisioning should be based on existing best practices in CENS development and upgrading. Therefore, the development and information content provisioning should take into account the following:

- Existing effective models and methods for describing of SS based on the type of parameters measured by the sensors or a combination of CENS sensors;
- Criteria and methods for forming RI under stochastic conditions of information extraction;
- Methods of forming the decision function as the MR trajectory correction command.

IV. RESULTS AND DISCUSSION

In the work [10] the results of studies of formation of binary selective RI are given. Let us consider in more detail the research results in [10]. On the basis of experimental verification with the use of real images of the sighting surface (SS), the ways of forming selective RI, preserving the correlation with the original image, are proposed. The paper proposes to carry out the correlation analysis of the image using the "sliding window" method.

The essence of the "sliding window" method consists in the general analysis of image pixels, which are "covered" by some two-dimensional, usually square, area of finite size. All image pixels that fall into the comparison sector are processed in accordance with the classical correlation algorithm. The result of processing is the brightness of a pixel of the original image or an element of the two-dimensional matrix of transformation results, which corresponds to the center of the window. Then the window is shifted by one pixel and the processing is repeated. The processing process ends when the window has been shifted by all possible values within the image. If fragments of the input image itself are alternately used as a "sliding window" to perform correlation analysis of an image in terms of brightness, then the result of such processing will be a set of values of joint correlation function (JCF) of image fragments and the image as a whole. This is necessary to obtain a selective RI, which will include only those image fragments that are important from the point of view of maintaining the correlation relationship between the original image and the generated RI. Thus, in order to carry out the correlation analysis of the image in terms of brightness, it is alternately proposed to use fragments of the original image as a "sliding window" with the size, $M_w \times N_w$ (M_w , N_w are the dimensions of the sliding window in pixels). Each next fragment of the image ("window") is displaced relative to the previous one by one pixel horizontally (vertically). This approach to the formation of selective SS images can be applied in the interests of forming a set of initial data filling the database taking into account both the sighting geometry and the features of the object composition of the scene itself.

However, the influence of the SS object implemation on the quality of the RI has not been properly highlighted, nor has the degree of necessary correlation between the database content to form the RI population for the MR navigation process been shown. In order to determine the usefulness of the proposed approach to the formation of selective reference images, the dependence of the quality of the image on the object implemation of the scene is analyzed.

We will use the joint correlation function (JCF) of current image (CI) and the generated binary selective image as the criteria for assessing the quality of the reference information:

$$K_{CCF}(i,j)_{mn} = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} [S_{OI}(i,j)S_W(i+m,j+n)], \quad (1)$$

where K_{CCF} is the discrete two-dimensional JCF;
 M , N are the measurements of CI in pixels;
 M_w , N_w are the measurements of "sliding window" (SW) in pixels;

$m = [0, \dots, M-M_w]$, $n = [0, \dots, N-N_w]$ is the shift of SW relative to CI;

$S_{OI}(i,j)$, $S_W(i,j)$ is the brightness (grey intensity) of CI and SW in the position with coordinates (i, j) .

The resulting matrix $|K|$ with the size of elements

$(M_1 - N_1) \times (M_2 - N_2)$ characterizing the distribution of the maximum JCF value in the plane of the analyzed image is called the field of correlation analysis (FCA). Provided that the dimensions of the original image and the sliding window do not change in the process of evaluating the information content, the maximum JCF value used as an element of the FCA uniquely characterizes the severity of the JCF peak in the region of the maximum. The FCA formed on the basis of the brightness estimate will be called the field of brightness correlation analysis (FBCA).

Modelling will be based on the images with rich object implemation of SS, which corresponds to the typical urban infrastructure and heterogeneous landscape imagery.

The influence of random factors on the formation of images is taken into account by choosing the degree of correlation between CI and selective RI at a level of 0.5 to 0.7.

The original images are given in Fig. 1, 4, 7, 10, 13; the binary RI derived from these CI (Fig.1, 4, 7, 10, 13) are given in Fig. 2, 5, 8, 11, 14, and their JCF are given in Fig. 3, 6, 9, 12, 15.

Since the initial data put into the database should take into account not only the features of the SS itself, but also different angles at which the problem of locating the MR using the CENS should be solved, we investigate the formation of selective images of two highly saturated areas from two angles (Fig. 1, 4). Let us construct selective images for two values of the FBCA cross sections: 0.6 and 0.7 (Fig. 2, 5).

Fig. 1 CI of densely populated area

Fig. 2 The binary selective image at the FCA section level of 0.7 to the Fig. 1

Fig. 6 JCF of CI (Fig. 4) and its selective image (Fig. 5)

Fig. 3 JCF of CI (Fig. 1) and its selective image (Fig. 2)

The results of constructing the JCF for the cases under consideration are shown in (Fig. 3, 6). Obviously, if the correlation between the original images and their selective images, lying in the range of 0.6 ... 0.7, there will be a unimodal JCF, as a result of image comparison. This means that for the operational formation of the RI with changes in the angles of sight, it is sufficient to put into the database not the original SS images themselves, but their selective images. In this case, the spread in the correlation between the selective images to eliminate anomalous errors in the positioning of MR using CENS can be from 0.6 to 1. To generalize the results obtained and their distribution to other types of SS, we will perform similar estimates of the JCF using other initial images in terms of structure (Fig. 7, 10, 13). In this case, to construct selective images, we will use a correlation from 0.5 to 0.6.

Fig. 4 CI at sighting angle 30 degrees

Fig. 7 CI of the landscape with large homogeneous zones

Fig. 5 The binary selective image at FCA section level 0.6 to the Fig. 4

Fig. 8 The binary selective image at FCA section level 0.5 to Fig. 7

Fig. 9 JCF of CI (Fig. 7) and its selective image (Fig. 8)

Fig. 10 CI of standard landscape

Fig. 11. The binary selective image at FCA section level 0.6 to Fig. 10

Fig.12 JCF of CI (Fig. 10) and its selective image (Fig. 11)

Fig. 13 CI of standard landscape with buildings

Fig. 14 The binary selective image at FCA section level 0.6 to Fig. 13

Fig. 15 JCF of CI (Fig. 13) and its selective image (Fig. 14)

It can be seen that a decrease in the degree of correlation between the images under study, as well as the use of weakly saturated types of SS in terms of the object composition, leads to an increase in the level of lateral emissions of the JCF. At the same time, the unimodality of the JCF remains, which emphasizes the possibility of using informative parameters obtained on the basis of their selective images, not the original ones, to fill the database.

The analysis of the results of the numerical modeling presented graphically on Fig. 1...15 shows the possibility of using the database of invariants based on the collection of binary selective images, which results in substantial reduction of the volume of the database, ensures, when using the information in the proposed format, the high accuracy characteristics of the navigation system of the MR, and the reduction of the number of operations when forming a decisive function by the navigation system.

V. CONCLUSION

As a result of the research on the principles of the formation and provisioning of the database for navigation of MP in the conditions of flexible change of the flight assignment, it has been demonstrated that the use of invariants for the information content of the database, derived from a combination of binary selective images, is advisable.

It has been established that the correlation between database content and CI population can be within 0.5... 0.7, which will enable the navigation system to provide a unimodal decisive function and ensure the required accuracy characteristics.

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