Application of Object Contrast for Forming Images Used in Technical Vision Systems for Navigation of Mobile Robots

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Abstract. The purpose of the article is to substantiate the feasibility of using object contrast as an informative feature for the formation of images used in technical vision systems. This goal is achieved by studying the dependence of the contrast of objects in images on the viewing geometry and determining the conditions under which the greatest similarity of the compared images is ensured. The solution to the first problem is based on the presentation of reference information about sighted objects, taking into account the navigation parameters of mobile robots. By modeling in the MATLAB software environment for typical viewing conditions, selective images were obtained using randomly selected fragments from Google Earth Pro, the distribution of contrast values and the cross-correlation function of the original and selective images. The influence of viewing angles on the distribution of contrasts and the formation of the decisive function was determined. The studies were performed for viewing angles of -60˚, -80˚ and -90˚ for altitudes in the range from 500 to 600 meters. The most significant result is a model of a set of reference images, taking into account the influence of navigation parameters on the contrast of objects, as well as experimentally established dependences of the distribution of contrasts for typical viewing conditions. The novelty of the work lies in the fact that the procedure for generating images and the decision function using the contrast of objects has been further developed. This will significantly increase the efficiency of selection of objects with insignificant brightness characteristics.
Keywords: mobile robot, object contrast, navigation parameters, image quantization, decision function.
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Aplicarea contrastului obiectelor pentru formarea imaginilor utilizate în sistemele tehnice de viziune pentru navigarea roboților mobile

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Rezumat. Scopul articolului este argumentarea fezabilității utilizării contrastului obiectelor ca caracteristică informativă pentru formarea imaginilor utilizate în sistemele tehnice de viziune. Acest obiectiv este atins prin studierea dependenţei contrastului obiectelor din imagini de geometria vizualizării şi determinarea condiţiilor în care se asigură cea mai mare similitudine a imaginilor comparate. Soluția primei probleme se bazează pe prezentarea informațiilor de referință despre obiectele văzute, ținând cont de parametrii de navigare ai roboților mobili. Prin modelarea în mediul software MATLAB pentru condiții tipice de vizualizare, imaginile selective au fost obținute folosind fragmente selectate aleatoriu din Google Earth Pro, distribuția valorilor de contrast și funcția de corelare încrucișată a imaginilor originale și selective. S-a determinat influența unghiurilor de vizualizare asupra distribuției contrastelor și a formării funcției decisive. Studiile au fost efectuate pentru unghiuri de vizualizare de -60˚, -80˚ și -90˚ pentru altitudini în intervalul de la 500 la 600 de metri. Rezultatul cel mai semnificativ este un model al unui set de imagini de referință, luând în considerare influența parametrilor de navigare asupra contrastului obiectelor, precum și dependențele stabilite experimental ale distribuției contrastelor pentru condițiile tipice de vizualizare. Noutatea lucrării constă în faptul că procedura de generare a imaginilor și funcția de decizie folosind contrastul obiectelor a fost elaborată în continuare. Acest lucru va crește semnificativ eficiența selecției obiectelor cu caracteristici de luminozitate nesemnificative.
Cuvinte cheie: robot mobil, contrast obiect, parametri de navigare, cuantizare imagini, funcție de decizie.

Применение контраста объектов для формирования изображений, используемых в системах технического зрения для навигации мобильных роботов

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Аннотация. Целью статьи является обоснование целесообразности применения контраста объектов в качестве информативного признака для формирования изображений, используемых в системах технического зрения. Поставленная цель достигается путем исследования зависимости контраста объектов на изображениях от геометрии визирования и определения условий, при которых обеспечивается наибольшее сходство сравниваемых изображений. Решение первой задачи основано на представлении эталонной информации об объектах визирования с учетом навигационных параметров мобильных роботов в виде многомерных матриц, в которых для каждого отдельного элемента i-го эталонного изображения формируется своя соответствующая p-мерная матрица. Дальнейшая процедура выделения искомого объекта на текущем изображении включает этап бинаризации с последующим квантованием в выбранном диапазоне контрастов. Путем моделирования в программной среде MATLAB для типовых значений высоты получены селективные изображения района привязки с использованием случайно выбранных фрагментов из Google Earth Pro, распределения значений контрастов и взаимная корреляционная функция исходного и селективного изображений. Установлено, что использование контраста объектов в качестве информативного параметра позволяет формировать унимодальную решающую функцию. Путем моделирования определено влияние углов визирований на распределение контрастов, а, соответственно, на формирование решающей функции. Исследования выполнены для углов визирования -60˚, -80˚ и -90˚ для высот в диапазоне от 500 до 600 метров. Наиболее существенным результатом являются модель совокупности эталонных изображений с учетом влияния навигационных параметров на контраст объектов, а также экспериментально установленные зависимости распределения контрастов для типовых условий визирования. Новизна работы заключается в том, что получила дальнейшее развитие процедура формирования изображений и решающей функции с использованием набора изображений, построенных с использованием информативного параметра – контраста объектов. Это позволит значительно повысить эффективность селекции объектов с незначительными яркостными характеристиками.

Ключевые слова: мобильный робот, контраст объектов, навигационные параметры, квантование изображений, решающая функция.

INTRODUCTION

Mobile robots (MR) equipped with technical vision systems (TVS) are extensively used for various objects monitoring on the line of sight (LOS), for assessing the condition of objects during the search and rescue operations [1]. The solution to monitoring tasks is primarily determined by the quality of information provided, which depends on the informational features (IF) used for image formation. These are measured by the TVS sensors and used in the formation of current images (CI) [1]. At the same time, reference images (RI) used for forming the decisive function (DF) must correspond to CI [2]. One possible feature for the image formation is an object contrast, which depending on the background type, can be sufficiently informative, allowing for the formation of selective images and the extraction of the required object on them. Methods and algorithms for the image formation have been developed in many recent publications [3–7]. This is associated with the widespread development and application of unmanned aerial vehicles (UAVs) in many fields, including the military sphere. Known works explore the influence of geometric distortions on the formation of the DF [8], as well as the possible appearance of false objects [9]. In this regard, the task is typically solved using a single informational feature - signal intensity. A significant number of publications are devoted to the development and improvement of methods for object extraction from images [10–13]. However, as the analysis has shown, these works do not pay sufficient attention to the use of various informational features for describing the images. Typically, the object brightness is used. In the work [14], a method for forming DF in determining an unmanned aerial vehicle (UAV) using radiometric and optoelectronic channels for obtaining information is proposed. To form images the brightest objects in the line of sight are offered. The advantage is the increased accuracy of UAV localization by adapting them to perspective and scale distortions of images, while the disadvantage is the inability to use the method for the UAV localization in conditions of developed infrastructure with the presence of small-sized and low-contrast objects. Issues related to the extraction of small and elongated objects are considered in works [15-25]. The application of adaptive thresholds followed by the application of different operators has been investigated.

Thus, as the analysis has shown, despite the significant number of methods for image formation, object selection on images, and the exploration of using contrast as an informative feature for image formation, as well as studying changes in contrast depending on geometric conditions of measurement, attention has been scarcely paid to the latter, which necessitates further research to address this gap.

The aim of the article is to justify the feasibility of using object contrast as an informative feature for forming RI used in TVS for the navigation of mobile robots.

To achieve this goal, the following tasks are needed to be addressed:
- define the problem and investigate the dependence of object contrast of typical surfaces on the viewing geometry of TVS;
- determine the conditions under which the RI fragment exhibits the greatest similarity to CI.

METHODS, RESULTS, AND DISCUSSION

1. Problem statement and investigation of the dependence of object contrast of typical surfaces on the viewing geometry of TVS.

In TVS, one of the options for representing standard information about viewing objects is the use of multidimensional matrices. This is due to the need to account for the navigation parameters of MR (altitude h, latitude α, longitude β), as well as the angular orientation parameters (roll, yaw, pitch), leading to the formation of *N*-dimensional matrices, where for each individual element of the *i*-th RI, its corresponding p-dimensional matrix is formed. Based on this, the set of RI fragments $RI \rightarrow S = \left(S_{i_1 i_2 ... i_p}\right)$ can be represented as follows:

$$\begin{gathered} RI \rightarrow S = \left(S_{i_1 i_2 ... i_p}\right), \\ i_\alpha = \overline{1,n_\alpha};\ \alpha = \overline{1,p};\ i = \left(i_1, i_2, ..., i_p\right) = \left(l,s,c\right); \\ l = \left(l_1, l_2, ..., l_k\right);\ \ s = \left(s_1, s_2, ..., s_\lambda\right);\ c = \left(c_1, c_2, ..., c_\mu\right). \\ S = S_{(k,\lambda,\mu)} = \left(s_{l,s,c}\right). \end{gathered} \quad (1)$$

The multi-indices in (1) traverse their range of values depending on the selected discretization steps and the size of the RI fragments, chosen not less than the size of the control or reference object. Thus, the set of RI constitutes a multidimensional matrix, the structural diagram of which is shown in Fig. 1.

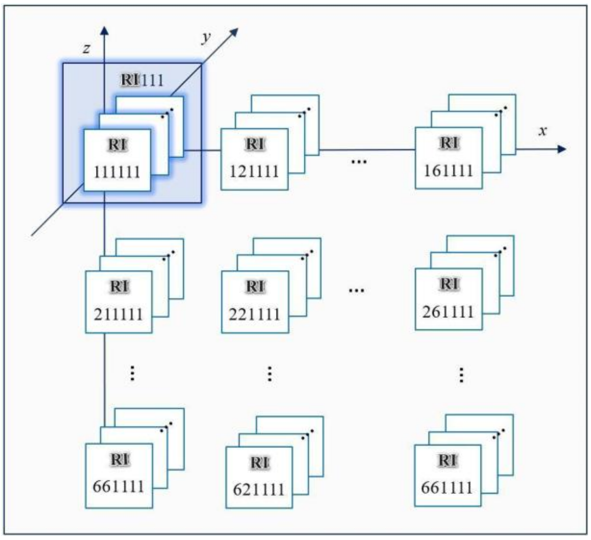

Fig. 1. The structure of the scheme of the matrix describing the set of fragments in the reference images.

<u>Problem statement.</u> For the considered model of the set of RI, it is necessary to solve the problem of forming the set $S = S_{(k,\lambda,\mu)} = \left(s_{l,s,c}\right)$ using object contrast ΔB as an informative feature, which will subsequently ensure the formation of a unimodal DF:

$$R(\mathbf{r},t) = F_{SP}\left(S_{CI}(\mathbf{r},t_k), S_{RI}(h,\alpha,\beta,\Delta B,t_\rho)\right) \rightarrow max, \quad (2)$$

where $S_{CI}(\mathbf{r},t_k)$ - CI formed by TVS; $S_{RI}(h,\alpha,\beta,\Delta B,t_\rho)$ - RI fragment corresponding to the navigation parameters of MR h,α,β at the current time t_ρ.

At the same time, the accuracy characteristics of TVS will be determined according to the following formula:

$$\sigma_R = \sqrt{-\frac{1}{\frac{\partial^2 \mathbf{R}(\mathbf{r},t)}{\partial \mathbf{r}^2}}}. \quad (3)$$

The solution to this problem necessitates investigating the dependence of the contrast ΔB of LOS objects on the geometric viewing conditions by altitude h and orientation angles α,β.

Solution of the problem.

In TVS, the classical correlation algorithm serves as the basis for forming the DF, in accordance with (1). Therefore, to determine the closest RI fragment to CI, we will use the coefficient of cross-correlation (CCC), which for each coordinate value and change in altitude $(i, j, \Delta h)$ is determined according to the expression [1, 2]:

$$K_K(i,j) = \frac{1}{M_2 N_2} \sum_{m=1}^{M_2} \sum_{n=1}^{N_2} \begin{matrix} [S_{RI}(m,n) - \bar{S}_{RI}] \times \\ \times [S_{CI}(m+k-1, n+l-1) - \bar{S}_{CI_{kl}}] \end{matrix}, \quad (4)$$

where $i = 1 \ldots M_1 - M_2,\ j = 1 \ldots N_1 - N_2$;

$$\bar{S}_{RI} = \frac{1}{M_2 N_2} \sum_{m=1}^{M_2} \sum_{n=1}^{N_2} S_{RI}(m,n);$$

$$\bar{S}_{CI_{kl}} = \frac{1}{M_1 N_1} \sum_{i=1}^{M_1} \sum_{j=1}^{N_1} S_{CI}(m+k-1, n+l-1).$$

Taking into account that we are interested in RI fragments $S_{RI}(h, \alpha, \beta, \Delta B, t_\rho)$ constructed using object contrast for various geometric conditions, to extract the desired object from CI using contrast as an informative feature, it is necessary to perform binarization of RI and subsequent quantization based on selected contrast values K_K. By choosing quantization levels within $0.5 < K_K \leq 1$, we will highlight the RI fragment the closest to CI.

It is obvious that in each specific case, viewing objects and backgrounds will have different brightness values, and consequently, different contrast values will occur. Therefore, we will utilize modeling of selective images constructed in the MATLAB software environment using randomly selected LOS fragments from Google Earth Pro (Fig. 2–10).

Figures 11, 12, and 13 show the results of modeling the cross-correlation function (CCF), which effectively represents the DF. They demonstrate that using object contrast as an informative feature allows for the formation of a unimodal DF.

Fig. 2. The original image from a height of 1000 meters.

Fig. 3. Selective images (Fig. 1) by contrast.

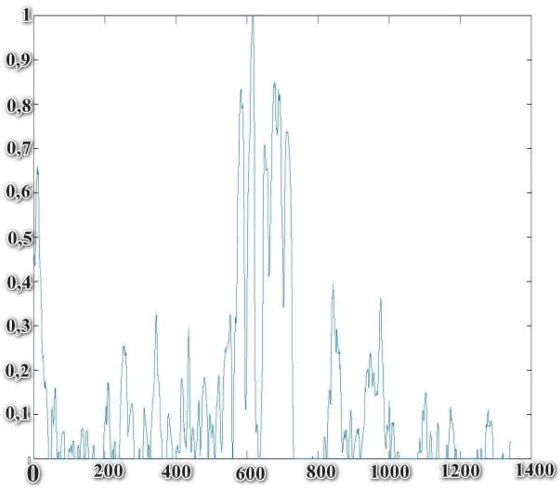

Fig. 4. Contrast distribution in the image (Fig. 1).

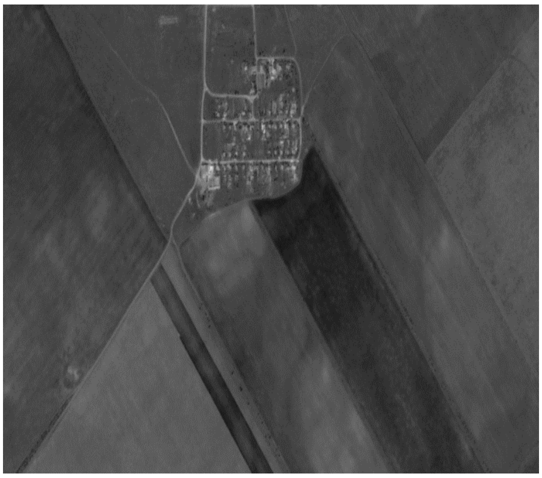

Fig. 5. The original image from a height of 2000 meters.

Fig. 6. Selective images (Fig. 4) by contrast.

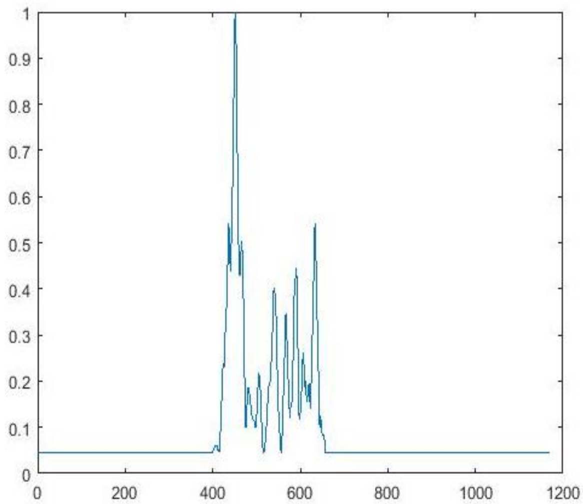

Fig. 7. Contrast distribution in the image (Fig. 4).

Fig. 8. The original image from a height of 3000 meters.

Fig. 9. Selective images (Fig. 7) by contrast.

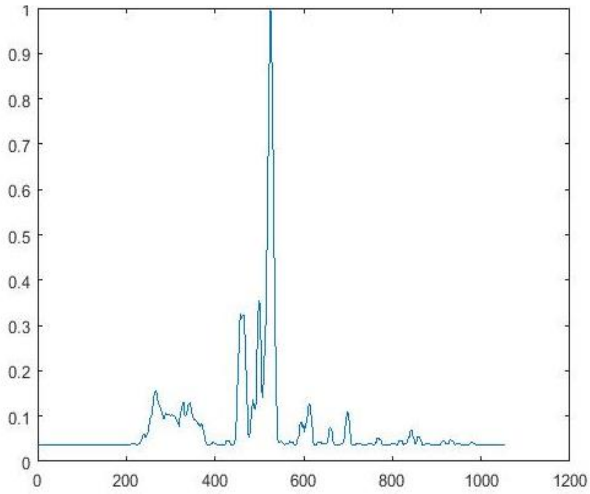

Fig. 10. Contrast distribution in the image (Fig. 7).

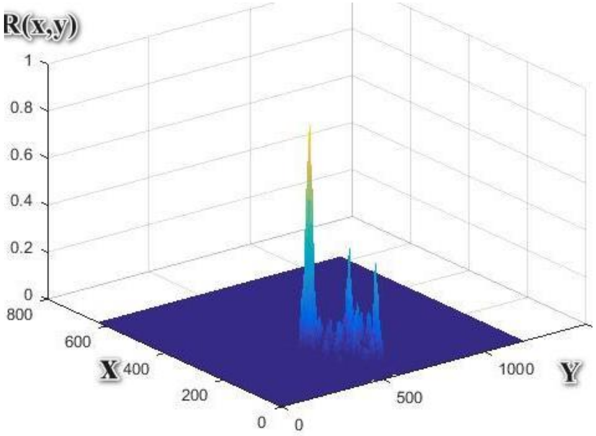

Fig. 11. Cross correlation function of the original image (Fig. 2) and the selected image (Fig. 3).

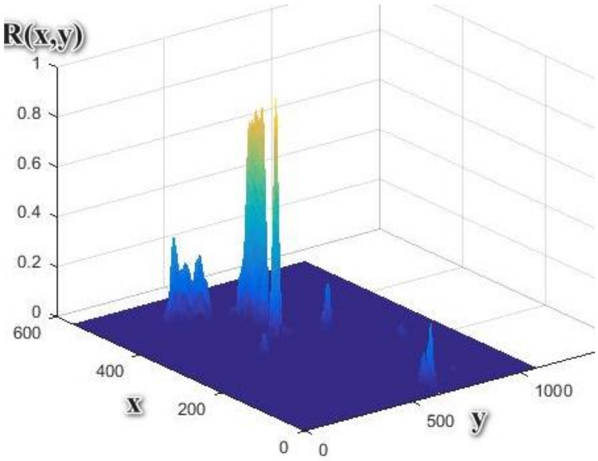

Fig. 12. Cross correlation function of the original image (Fig. 5) and the selected image (Fig. 6).

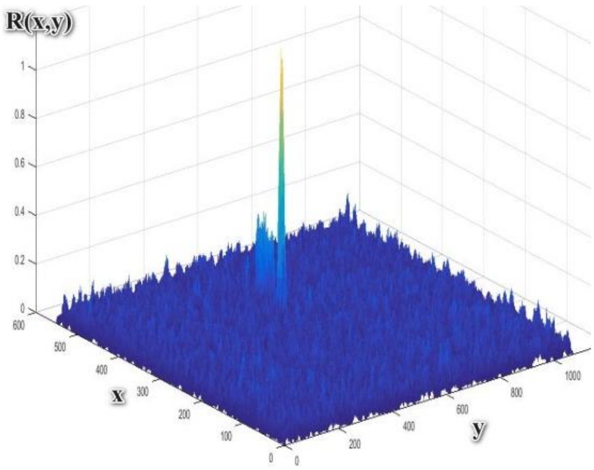

Fig. 13. Cross correlation function of the original image (Fig. 8) and the selected image (Fig. 9).

The results of the research on the dependence of image object contrast on shooting height show that using object contrast as an informative parameter allows obtaining a unimodal DF. At the same time, changes in viewing angles can significantly affect the formation of the DF.

2. Viewing conditions of TVS ensure the closest resemblance of RI fragments to CI.

The task of determining the angular viewing conditions will be accomplished by modeling in the MATLAB software environment using the selected typical surfaces mentioned above.

The results of forming the DF for viewing angles of -60˚, -80˚, and -90˚ at a height of 500 m are presented in Figs. 14–16, and for a height of 600 m in Figs. 17–19.

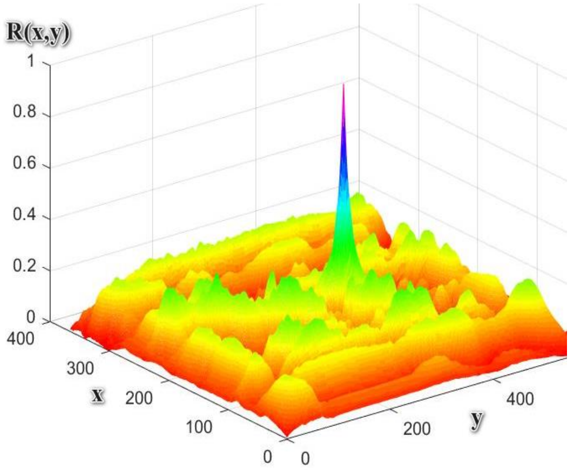

Fig. 14. Decisive function for viewing angle 90˚ (600 m).

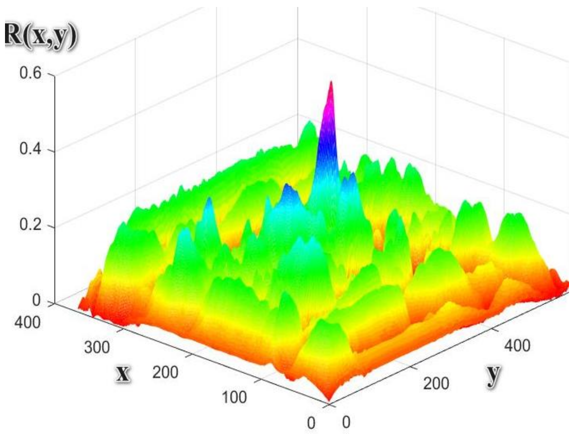

Fig. 15. Decisive function for viewing angle 80˚ (600 m).

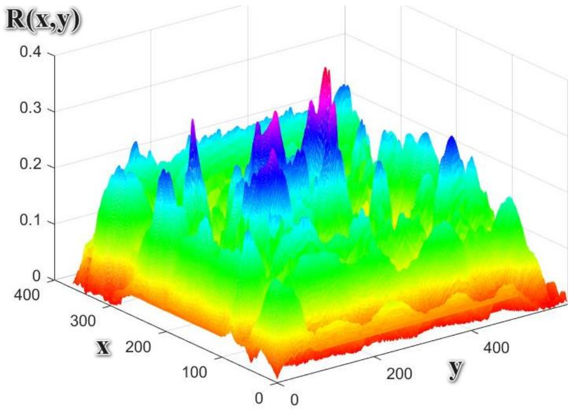

Fig. 16. Decisive function for viewing angle 60˚ (600 m).

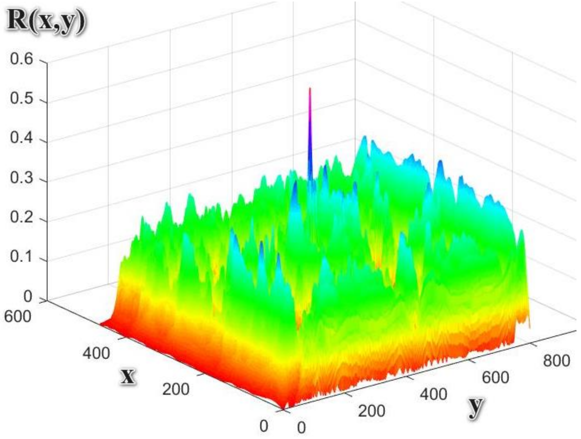

Fig. 17. Decisive function for viewing angle 90˚ (500 m).

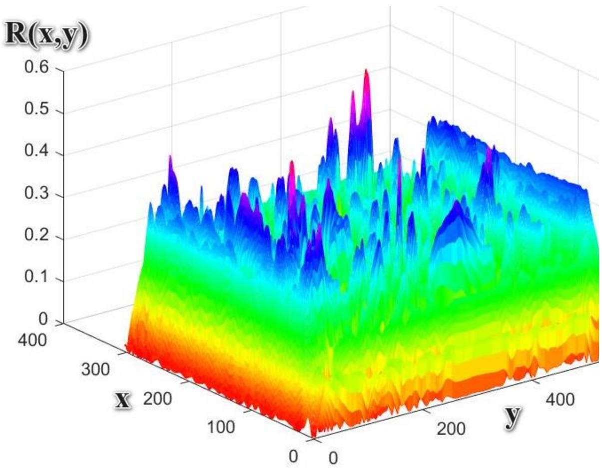

Fig. 18. Decisive function for viewing angle 80˚ (500 m).

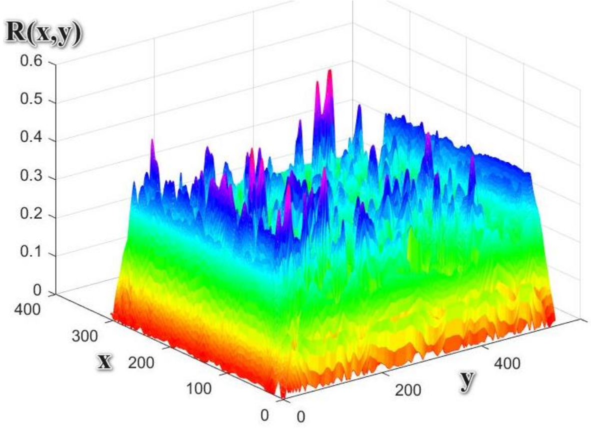

Fig. 19. Decisive function for viewing angle 60˚ (500 m).

Analysis of the modeling results indicates that with decreasing altitude and deviation of the viewing angle from the normal, the decisive function increasingly exhibits a multi-extremal nature. This is due to the growing influence of small-scale objects, which, due to spatial smoothing, are not taken into account in the contrast distribution and formation the selective images. At the same time, the appearance of side outliers, with the amplitudes lower than the main lobe, can be mitigated through quantization to form a unimodal DF. Thus, the presented research results show that in MR equipped with TVS, object contrast can be used as an informative parameter for monitoring the condition of objects in hard-to-reach areas. However, at low altitudes, the use of contrast alone may be insufficient for image formation and DF, requiring the complexity of the TVS secondary processing system and, consequently, the application of additional informative features.

CONCLUSIONS

Thus, the feasibility of using object contrast as an informative feature for forming both RI and CI used in TVS for the navigation of mobile robots has been justified as a result of the conducted research.

A new problem statement for image formation in TVS has been proposed, and the dependence of object contrast of typical surfaces on TVS viewing geometry has been investigated. Modeling has shown that object contrast can be used as an informative feature of viewing objects under certain conditions. Selective images constructed using contrast allow TVS to form a unimodal DF. However, at low altitudes (less than 500 m) and with an increased deviation of the viewing angle from the normal (-60˚), the formation of a unimodal decision function becomes challenging due to the increased influence in the small-scale objects. This will require the complexity of the TVS secondary processing system and, consequently, the application of additional informative features.

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