The method of spatial-temporal reconstruction of dynamic images based on a geometric model with contour and texture analysis

R R Ibadov¹, V P Fedosov¹ and S R Ibadov²
¹Southern Federal University, Taganrog, Russia
² Don State Technical University, Rostov-on-Don, Russia

Abstract. The article presents a method for image restoration based on a geometric model. The object of research is methods of image removal and restoration. The research is aimed at creating a high-speed and highly efficient system for recovering the lost zones of the underlying surface map image. An algorithm for removing objects and restoring images of lost areas is investigated and its software implementation is developed. The efficiency of the developed algorithm was evaluated on a test example using a statistical criterion.

1. Introduction
The history of the successful use of unmanned aerial vehicles (UAVs) goes back almost eight decades, especially in the most developed countries of the world. Recently, interest in UAVs has increased significantly. The scope of the UAV is quite wide. According to some experts, unmanned aerial vehicles are the most promising direction for the development of aviation. They can monitor the traffic situation, both urban and in remote areas, monitor the fire situation in forests or flood waters in the regions, and much more. [1]. This is explained not only by the fact that mass production and use of UAVs turns out to be cheaper and easier than manned aircraft, but also by the fact that some types of UAVs are capable of solving problems that are inaccessible to manned aircraft, for example, short-range reconnaissance tasks in dense urban areas. For a long time, UAVs found only military applications. Nevertheless, in recent decades, the need for civilian UAVs has been growing: for monitoring oil and gas pipelines, collecting meteorological data, and timely detecting foci of forest fires. Carrying the service, the UAVs transmit the footage to a laptop, with which you can control the unmanned vehicle [2-5].

In many of the above-described UAV applications, tasks are required: Removing unnecessary moving objects from the frame; constant monitoring of the object; restoration of the background and objects in the overlapping area, i.e. when the object is covered by another object (for example, a car). Difficulties arise when a swarm of UAVs is used in urban infrastructure for surveillance in areas that are difficult or unsuitable for humans to access. There are situations when it is necessary to track, control, escort only one of the drones in the UAV swarm, and for this you need to remove the rest of the drones. And in this case, the modified method proposed in the work can remove the object and restore the lost information by predicting its movement [6-10].

2. Proposed method
In this paper, we propose a modification of the method of spatio-temporal reconstruction of dynamic images based on a geometric model, based on the use of a set of descriptors that allow us to extract information about the periodic motion of objects [11-15]. The block diagram of the modified method is
shown in Figure 1. At the stage of preprocessing, a video sequence model is built. The main goal is to separate the input sequence into background and foreground objects. After that, each component is processed separately. A simple and potentially effective way to simulate and automatically analyze footage is to represent a scene as a set of layers. For the purpose of further segmentation into moving objects / stationary segmentation background, the optical flux is calculated, to which the thresholding is then applied. Optical flow is a set of motion vectors for each pixel at intervals \( t \) and \( t + \Delta t \). There are fast methods for calculating optical flux using partial derivatives with respect to spatial and temporal coordinates.

For pixel with coordinates \((i, j, t)\) with intensity \(Y'_{i,j}\) there is a shift \(\Delta i\), \(\Delta j\), \(\Delta t\) between two frames, while the image can be represented as the following expression (1):

\[
Y'_{i,j} = Y_{i+\Delta i, j+\Delta j}^{t+\Delta t}.
\]

It is assumed that the shift is not large and the image can be expanded into a Taylor series \(Y''_{i,j}\) (2):

\[
Y''_{i+\Delta i, j+\Delta j, t+\Delta t} = Y'_{i,j} + \frac{\partial Y}{\partial i} \Delta i + \frac{\partial Y}{\partial j} \Delta j + \frac{\partial Y}{\partial t} \Delta t + H.O.T.
\]

From the equation follows (3-4):

\[
\frac{\partial Y}{\partial i} \Delta i + \frac{\partial Y}{\partial j} \Delta j + \frac{\partial Y}{\partial t} \Delta t = 0,
\]

or

\[
\frac{\partial Y}{\partial i} \Delta i + \frac{\partial Y}{\partial j} \Delta j + \frac{\partial Y}{\partial t} \Delta t = 0,
\]

as a result, we write:

\[
\frac{\partial Y}{\partial i} V_i + \frac{\partial Y}{\partial j} V_j + \frac{\partial Y}{\partial t} I = 0,
\]

where \(V_i, V_j\), \(i\), \(j\) optical flux magnitude components \(Y'_{i,j}\), and \(\frac{\partial Y}{\partial i}\), \(\frac{\partial Y}{\partial j}\) and \(\frac{\partial Y}{\partial t}\) partial derivatives of the point image \((i, j, t)\) in the respective directions.

\(Y', T\) and \(I\) can be represented in derivatives in the following form (5-6):

\[
YV_i + YV_j = -Y_t,
\]

\[
\nabla Y^T \cdot \nabla = -Y_t.
\]

This uses the same approach as the method based on the search for similar blocks. To restore the background component, it is proposed to use separate restoration of texture and structure. To this end, each frame is segmented based on the geometric model of the active contour, by solving the problem of minimizing the energy functional (7):

\[
E^{CV}(c_1, c_2, C) = \mu \cdot \text{Length}(C) + \lambda_1 \cdot \int_{\text{inside}(C)} |u_0(x, y) - c_1|^2 \, dx \, dy + \lambda_2 \cdot \int_{\text{outside}(C)} |u_0(x, y) - c_2|^2 \, dx \, dy,
\]

where \(\mu\), \(\lambda_1\) and \(\lambda_2\) are positive constants, usually fixed \(\lambda_1 = \lambda_2 = 1\), \(c_1\) and \(c_2\) - average intensity values \(u_0\) inside \(C\) and beyond \(C\), respectively.

A modification of the method of spatio-temporal reconstruction of dynamic images based on a geometric model is proposed, based on the use of a set of descriptors that allow one to extract information about the periodic movement of objects.
preprocessing

- static background

Splitting into groups of frames

Calculating priority

- Finding a similar global video descriptor on adjacent frames
- Searching on a group of 3D block frames
- Copying the 3D block to the area with the highest priority
- Updating the priority value for the next iteration

Reconstruction of dynamic objects

Reconstructing a static background

- Temporarily copy 3D blocks or Synthesis of textures within the frame

Computing the global video descriptor

Repeat the procedure until all pixels are filled

Repeating this block for all frames

Figure 1. Block diagram of the modified method of space-time reconstruction of dynamic images.
The proposed approach makes it possible to delete or restore objects using the spatial and temporal information of neighboring scenes. The algorithm iteratively performs the following operations: frame preprocessing; getting a scene model; calculating a set of descriptors that provide information needed to recover a frame; reconstruction of frames using the space-time domain of pixels - 3D blocks (Figure 2).

This approach is used to estimate the values of the descriptors. The global video descriptor is calculated by convolution of space-time filter banks (Figure 3). This descriptor allows you to extract information about the movement and structure of the scene and classify various actions [15-16].

![Figure 2. Space-time domain of pixels](image)

The bandpass nature of the filters eliminates the need for motion compensation. The frequency spectrum of video sequences can be estimated by computing a 3D discrete Fourier transform (DFT). The first step in reconstruction is to reconstruct moving foreground objects that do not cross the reconstructed area [17].

![Figure 3. The response spectrum of the 3D space-time filter.](image)

If such areas are absent in adjacent frames, then the standard procedure for searching for a similar block within the frame area is used for reconstruction [18].

Below is the result of processing by the proposed method on a test image with a swarm of UAVs. Figures 4, 5 show the result of processing by the proposed method.
Figure 4. The results of applying the method: a) the original image, b) the image with the UAV swarm, c) the drone being monitored is highlighted in the red frame, d) the image after removing unnecessary drones.

Figure 5. The results of applying the method: a) the original image, b) the image with the UAV swarm, c) the drone being monitored is highlighted in the red frame, d) the image after removing unnecessary drones.

3. Efficiency of method operation

For quantitative evaluation of the work of a method is used the random mean square error (RMSE) [19]. This quality criterion (8) is fairly common to determine the differences between a pair of data. The input data used are the observed image and the original image. The expression RMSE shows how to get the numeric value of a given quality criterion.

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (X_{o,i} - X_{n,i})^2}{n-1}},
\]

(8)

where \(X_{o,i}\) is observed image, \(X_{n,i}\) is original image. In this case, for Figure 5, the random mean square error is: \(RMSE = 10.5\), for Figure 6: \(RMSE = 13.2\). Recovery error percentage is calculated [20]:

For Figure 4:

\[
R = \frac{RMSE}{Pell_{all}} \cdot 100 = \frac{10.5}{68.719.476} \cdot 100 = 15.2\% ;
\]

For Figure 5:

\[
R = \frac{RMSE}{Pell_{all}} \cdot 100 = \frac{13.2}{68.719.476} \cdot 100 = 19.2\%
\]
Studies have shown that this method works effectively in image analysis tasks when no strict requirements are imposed on the shape of the boundary between statistically homogeneous areas.

4. Conclusion
The paper presents a method for image restoration based on spatial-temporal reconstruction of dynamic images. The presented examples demonstrate the effectiveness of the developed algorithm in reconstructing areas of the terrain map with lost pixels. A quantitative assessment of the effectiveness of the method based on the standard deviation of pixels for images of terrain in the presence of a single UAV and a swarm of identical UAVs has been made.

Acknowledgments
This work was supported by the Russian Ministry of Education and Science in accordance to the Government Decree № 218 from April 9, 2010 (project number № 074-11-2018-013 from May 31, 2018 (03.G25.31.0284)).

References
[1] Minsan M, Arshad N, Shauri R, Abd Razak N, Thamrin N, and Mahmud S 2013 Real-time vision based sensor implementation on unmanned aerial vehicle for features detection technique of low altitude mapping IEEE Conf. on Sys. Proc. and Con. (Kuala Lumpur: ICSPC) pp 289-294
[2] Wang H, Wang L, Guan H, and Geng Z 2014 Automated mosaicking of UAV images based on SFM method IEEE Geo. and Rem. Sen. Sym. (Quebec City: IEEE) pp 2633-2636
[3] Iqbaal A, and Saleem F 2018 Monitoring application for Unmanned Aircraft Systems IEEE Wor. on Ele. and Net. Tech. (Moscow: MWENT) pp 1-5
[4] Le Meur O, Gautier J, and Guillemot C 2011 Examplar-based inpainting based on local geometry IEEE Int. Con. On Ina. Proc. (Brussels: IEEE) pp 3401-3404
[5] Guo Y, Li L 2013 Examplar-Based Image Inpainting Under Smoothness Constraint IEEE Int. Con. on Com. and Inf. Sci. (Shiyang: IEEE) pp 163-166
[6] Ebdelli M, Guillemot C, and Le Meur O 2012 Examplar-based video inpainting with motion-compensated neighbor embedding IEEE Int. Con. on Ina. Proc. (Orlando, IEEE) pp 1737-1740
[7] Ebdelli M, Le Meur O, and Guillemot C 2012 Loss concealment based on video inpainting for robust video communication IEEE Conf. Proc. (Bucharest, EUSIPCO) pp 1910-1914
[8] Daisy M, Buyssens P, Tschumperlé D, and Lézoray O 2014 A smarter exemplar-based inpainting algorithm using local and global heuristics for more geometric coherence IEEE Int. Con. on Inma. Proc. (Paris: ICIP) pp 4622-4626
[9] Voronin V, Marchuk V, and Egiazarian K 2011 Images reconstruction using modified exemplar based method //Ima. Proc. Int. Soc. for Opt. and Pho. vol. 7870 (San Francisco: SPIE)
[10] Voronin V, Shraifel I, Marchuk V, Tokareva S, and Sherstobitov A 2012 Image inpainting with structure and texture propagation IEEE 12th Int. Con. on Sig. Proc. (Hangzhou: ICSP)pp 658-661
[11] Jin X, Su Y, Wang Y, and Wang Z 2018 Image Inpainting Detection Based on a Modified Formulation of Canonical Correlation Analysis IEEE 20th Int. Wor. on Mul. Sig. Proc. (Vancouver: MMSP) pp 1-5
[12] Zhang L, Shen P, Song J, and Zhu G 2016 Depth enhancement with improved exemplar-based inpainting and joint trilateral guided filtering IEEE Int. Con. on Ina. Proc. (Phoenix: ICIP) pp 4102-4106
[13] Voronin V, Zelensky A, and Agaian S 2019 The quaternion-based anisotropic gradient for the color images. Electronic Imaging, 11 pp 277-1-277-6
[14] Gapon N, Voronin V, Sizyakin R, Zhdanova M, and Zelensky A. 2020 Depth-map inpainting using learned patch-based propagation. 12 Int. Conf. on Mach. Vis. (Amsterdam: ICMV 2019) Vol. 11433, pp 1143338

[15] Fedosov V, Ibadov R, Ibadov S and Voronin V 2019 Restoration of the Blind Zone of the Image of the Underlying Surface for Radar Systems with Doppler Beam Sharpening Conf. Proc. (Divnomorskoe: RSEMW) pp 424-427

[16] Ibadov R, Ibadov S, Voronin V and Fedosov V 2018 J. Rad. Sys. Spec. and Civ. (Moscow: Radio engineering) 1 Edited by Yu.I. White 381-385

[17] Ibadov R, Fedosov V, Voronin V and, Ibadov S 2019 J.S.F.U. Tec.sci. 5(207) 16-25

[18] Ibadov R, Fedosov V, Ibadov, S and Kucheryavenko S 2019 Recovering lost areas of the underlying image surface using a method based on similar blocks Conf. Proc. (Rostov-on-Don: AIP)

[19] Ibadov R, Fedosov V, Ibadov S, Gapon N and Sizyakin R 2019 Restoration of the Lost Map Area of the Underlying Image Surface Using the Reconstruction Method EPJ Web of Conf. vol. 224 (Moscow: MNPS)

[20] Ibadov R, Ibadov S, Gapon, N, Tokareva O and Alepko A 2018 Research the textures synthesis method based on the neural network MATEC Web of Conf. vol. 224 (Rostov-on-Don: DTS)