Study of the efficiency of data preprocessing in multispectral devices for detecting oil spills

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Abstract. The paper presents the results of study of various methods for preprocessing of images obtained using a multispectral system for detecting oil spills on the sea surface in areas of oil production and drilling platforms. Based on the comprehensive analysis of a large number of heuristic methods for processing and improving the quality of images obtained in different spectral ranges, a classification of these methods is proposed in relation to the problem being solved. The method of expert evaluation was used to reveal a feasible hardware of the spill detection system and determine the most effective methods for preprocessing of multispectral images.

1. Introduction
One of the relevant tasks of ensuring the rational use of natural resources is monitoring the state of the environment in oil production sites [1–4]. This task is urgent for oil production at offshore oil platforms. In the event of oil spill in the area of the platform location, it should be identified immediately after the event. In this case, the task of detecting spills should be solved round-the-clock in any weather conditions [5]. To fulfill this requirement, the use of radar systems seems to be most rational [1]. In recent years, numerous studies of radar systems for detecting oil spills [6–14] have revealed advantages and disadvantages of various types of radar systems. With regard to the results of these studies, in our opinion, one of the promising areas of effective and prompt acquisition of data on oil spills is combined multispectral detection systems, including radars of millimeter (35 GHz) and centimeter (10–11 GHz) wavelength ranges combined with medium (3–5 μm) and long wavelengths (8–13 μm) thermal imaging systems, and video cameras of different spectral ranges, which can be installed as a single integrated device directly on the offshore oil platform. Such systems are designed to obtain images of the observed zone of the estimated oil spill in different parts of the spectrum, which will significantly increase the detection efficiency based on the results of their joint processing.

2. Data preprocessing methods
One of the essential stages of processing images obtained in detecting oil spills is the preliminary analysis to improve the image quality, filtering noise, and segmentation into zones. Algorithms for improving the quality of multispectral images are a combination of various special mathematical operations for a more accurate interpretation of the image composition or its transformation into a format appropriate for subsequent digital computer processing. These image processing operations do not solve the problem of achieving an 'ideal' image. Sometimes, an observer perceives a noticeably
distorted image as much more informative than the original (unprocessed) image, for example, a processed image with the highlighted contours of the object or detected boundaries. In a broad sense, image enhancement operations are special cases of data extraction. For example, a high-frequency filtering algorithm of the original image enables detecting the boundaries of sharp changes in brightness (object boundaries) on the image. Their subsequent logical linking into contours identifies important informative features of the processed image.

Modern science does not have a generalized methodological and theoretical apparatus for solving problems of improving the quality of images. This can be explained by the fact that it is impossible to choose a quality indicator (system of indicators) common for various information situations, which could be a criterion for creating systems to enhance the quality or improve images. According to these prerequisites, the study considered a set of different algorithms that could be used to improve the efficiency of retrieving the required information and facilitate thematic processing in the integrated systems for monitoring oil spills on the sea surface. At the same time, practical recommendations for possible application of the algorithms in various situations were developed.

The task of improving images can be divided into three components:

1. selection of algorithms for enhancing the quality of images that take into account the specifics of detecting oil spills on the sea surface;
2. evaluation and selection of algorithms for improving the quality of images obtained in different spectral ranges;
3. study of the efficiency of using traditional algorithms for improving the quality of images for multispectral images.

To date, a huge number of empirical algorithms for improving the quality of images have been developed [16–20], some of these algorithms can be used to improve the quality of both individual spectral components of the image and the multispectral image. The selection of algorithms for enhancing the quality of images that take into account the specifics of detecting oil spills on the sea surface resulted in the classification shown in Fig. 1. To determine the feasibility of certain algorithms, they were investigated in order to develop recommendations on the use of certain algorithms for filtering certain spectral components of images. The proposed classification is of a generalized nature and is intended for assessing the quality of these algorithms, since it includes only the studied algorithms numbered for subsequent processing.

3. Study of the effectiveness of methods for preprocessing of multispectral images of oil spills

The applicability and efficiency of the algorithms shown in Fig. 1 should be studied in the following sequence:

1. Selection of the most suitable algorithms for improving the quality and a set of spectral components (images) for subsequent analysis. First, individual images obtained in different spectral regions are studied, and then multispectral images representing various combinations of the original spectral components are investigated.

2. Evaluation of the image quality improvement. The method of collective expert survey is used for assessment. Experts (25 people with experience in the visual detection of oil spills are involved in the study) are shown an original image from sources [18–20], which is then processed using this algorithm, and the results are used to assess the image according to a 6-point scale: 0 – no improvement in the image quality, 1 – negligible improvement in the image quality, 2 – insignificant improvement in the image quality, 3 – noticeable improvement in the image quality, 4 – significant improvement in the image quality, 5 – very significant improvement in the image quality. Then, the consistency of the expert group is determined and the total score for the processing method and image type is calculated. After that a decision is made on the feasibility of this algorithm for processing images of the corresponding spectral range.
3. Formation of proposals on using the studied algorithms for processing multispectral images.

Some results of these studies are shown in Tables 1–2 and Fig. 2–3. The analysis of these results made it possible to develop recommendations on the use of certain algorithms for processing both individual multi-spectral images and their combinations. If the average score is higher than 3, the algorithm can be recommended for use in this situation, and if the score is higher than 4.5, the use of the algorithm is highly recommended. If the score is less than 2, the use of the algorithm is not recommended.

After obtaining a set of images in different spectral ranges, it is necessary to form a complex multispectral image, which is a combination of the original images. The solution to this problem was carried out in three stages:

- mutual linking of images;
- combining images;
- obtaining a combined image.

![Figure 1. Classification of algorithms for improving image quality](image-url)
Table 1. Rating assessment of the algorithms for improving the quality of individual images obtained in different spectral ranges.

| Algorithm # (Fig. 1) | TV-1 (0.2–0.4 µm) | TV-2 (0.4–0.8 µm) | IR-1 (0.9 µm) | IR-2 (3–5 µm) | IR-3 (8–13 µm) | RAD-1 (8 mm) | RAD-2 (3 cm) |
|----------------------|------------------|------------------|-------------|-------------|-------------|-------------|-------------|
| 1                    | 4.2              | 3.8              | 3.7         | 3.8         | 3.6         | 3.5         | 3.9         |
| 2                    | 3.2              | 3.6              | 2.7         | 2.4         | 2.9         | 4.2         | 4.4         |
| 3                    | 2.3              | 2.6              | 1.8         | 2.2         | 2.3         | 1.6         | 1.8         |
| 4                    | 2.6              | 2.7              | 2.7         | 2.7         | 2.9         | 1.9         | 1.8         |
| 5                    | 3.7              | 3.4              | 2.9         | 3.3         | 3.8         | 4.1         | 4.2         |
| 6                    | 2.6              | 2.7              | 3.2         | 3.5         | 3.3         | 3.4         | 3.7         |
| 7                    | 2.0              | 1.9              | 3.1         | 3.2         | 3.3         | 3.5         | 3.8         |
| 8                    | 4.1              | 3.8              | 2.9         | 2.7         | 2.6         | 1.8         | 1.2         |
| 9                    | 3.2              | 2.7              | 3.1         | 3.3         | 4.0         | 2.7         | 3.1         |
| 10                   | 2.9              | 2.6              | 3.0         | 2.9         | 3.3         | 3.0         | 2.6         |
| 11                   | 3.3              | 4.2              | 2.1         | 1.9         | 1.7         | 2.1         | 2.4         |
| 12                   | 3.2              | 3.1              | 2.3         | 2.6         | 2.2         | 3.3         | 3.4         |
| 13                   | 3.9              | 4.1              | 4.2         | 4.3         | 4.1         | 3.7         | 2.2         |
| 14                   | 2.1              | 2.4              | 2.7         | 2.2         | 3.0         | 4.1         | 3.9         |
| 15                   | 3.8              | 3.7              | 3.4         | 2.6         | 2.3         | 2.1         | 1.9         |
| 16                   | 1.7              | 1.4              | 1.6         | 1.3         | 1.5         | 1.2         | 1.1         |
| 17                   | 2.3              | 2.4              | 2.6         | 3.1         | 3.3         | 2.8         | 3.1         |
| 18                   | 1.6              | 1.3              | 1.4         | 1.7         | 3.3         | 1.4         | 1.5         |
| 19                   | 2.3              | 3.0              | 3.1         | 2.4         | 2.5         | 3.3         | 2.9         |
| 20                   | 1.2              | 1.4              | 1.8         | 1.3         | 1.6         | 1.5         | 3.1         |

Figure 2. Results of evaluating algorithms for noise reduction on images of different spectral ranges.

The mutual linking of images of different spectral components was carried out by searching for their peak values of cross-correlation, and the alignment was carried out by weight processing of the spectral components. The obtaining of image combinations was carried out using the method of principal components, a well-known method for obtaining linear combinations of multidimensional
measurements. In this case, the axes of the new coordinate system are selected parallel to the axes of the scattering ellipsoid of the initial multispectral measurements, that is, the original \( n \)-dimensional measurement space is rotated so that the new coordinates are mutually uncorrelated. This transformation leads to preserving the Euclidean distances between points in space. In the general case, the matrix \( W \), which determines the transformation of the image by the method of principal components, is calculated as follows.

1. For the set of multidimensional values obtained during measurement, the sample covariance matrix \( \Sigma \) is calculated (it determines the scattering ellipsoid parameters: dimensions of the semi-axes and their orientation in the measurement space). After solving the system of eigenvalues for the matrix \( \Sigma \), its eigenvalues \( \lambda_i \) and the matrix of eigenvectors \( W \) are calculated, which is the required transformation that determines the rotation of the coordinate system.

2. The eigenvalues of the components \( \lambda_i \) specify the variances of the new variables along the new coordinate axes. The vector \( \omega_1 \) that corresponds to the maximum eigenvalue \( \lambda_1 \) determines the first principal component with the largest variance, the vector that corresponds to the next largest eigenvalue \( \omega_2 \) is the second principal component, etc. Thus, each subsequent principal component has a lower variance. The analysis of eigenvalues reveals the number of principal components that can be excluded from consideration and those that can be left. For this purpose, the relative fraction of the total variance of each main component of the image is calculated, and the information content of the newly obtained observation vector is determined.

After the matrix \( W \) is obtained, the linear combinations of the image spectral components should be determined. Computationally, this is a matrix-vector multiplication. The results of the expert assessment of the quality and efficiency of algorithms for processing multispectral images are presented in Table 2 and Fig. 3.

**Table 2.** Rating assessment of the algorithms for improving the quality of multispectral images

| Algorithm # (Fig. 1) | TV-1 + TV-2 | TV-1 + IR-1 | TV-1 + IR-2 | IR-1-3 (3-5 \( \mu \)m) | TV-1 + IR-3 + RAD-1 | RAD-1 + RAD-2 |
|----------------------|-------------|-------------|-------------|------------------------|---------------------|--------------|
| 1                    | 4.2         | 3.8         | 3.7         | 2.3                    | 3.1                 | 2.9          |
| 2                    | 3.2         | 3.3         | 3.0         | 2.0                    | 2.0                 | 4.0          |
| 3                    | 2.4         | 2.6         | 2.4         | 2.1                    | 1.9                 | 2.3          |
| 4                    | 2.6         | 2.4         | 2.3         | 2.2                    | 1.6                 | 2.7          |
| 5                    | 3.6         | 2.2         | 2.0         | 2.4                    | 2.3                 | 2.0          |
| 6                    | 2.7         | 2.7         | 2.2         | 2.6                    | 2.0                 | 1.6          |
| 7                    | 2.1         | 2.0         | 1.7         | 1.9                    | 1.9                 | 1.6          |
| 8                    | 3.9         | 1.9         | 1.9         | 1.9                    | 1.6                 | 1.8          |
| 9                    | 3.1         | 1.8         | 2.2         | 1.7                    | 1.4                 | 1.6          |
| 10                   | 2.8         | 2.3         | 2.0         | 1.1                    | 1.7                 | 1.4          |
| 11                   | 3.2         | 3.9         | 3.8         | 1.2                    | 1.9                 | 1.6          |
| 12                   | 3.1         | 2.6         | 2.9         | 1.4                    | 2.1                 | 2.0          |
| 13                   | 3.6         | 2.3         | 2.2         | 3.9                    | 3.0                 | 2.4          |
| 14                   | 2.7         | 2.7         | 2.4         | 2.9                    | 2.3                 | 3.6          |
| 15                   | 2.5         | 2.2         | 2.3         | 2.2                    | 2.5                 | 2.3          |
| 16                   | 2.3         | 2.9         | 2.8         | 2.3                    | 2.4                 | 2.1          |
| 17                   | 2.8         | 2.7         | 2.8         | 2.6                    | 2.3                 | 2.0          |
| 18                   | 2.1         | 2.0         | 1.9         | 2.4                    | 2.8                 | 2.3          |
| 19                   | 1.0         | 1.3         | 1.4         | 2.5                    | 1.0                 | 1.6          |
| 20                   | 1.2         | 2.3         | 1.9         | 2.1                    | 2.0                 | 1.7          |
4. Conclusion

The analysis of the results yielded the following conclusions: 1. The most informative hardware for detecting oil spills is a high-resolution television system; however, in terms of solving the problem of round-the-clock observation in any weather conditions, a combination of radar and thermal imaging channels is the most appropriate. 2. The most feasible image preprocessing algorithms in oil spill detection systems are median and threshold filtering, as well as Sobel filtering. 3. The method of principal components is the most efficient method for combining detection systems of different spectrum ranges. All in all, it should be noted that the technical implementation of the potential for solving the problems of data preprocessing in spill detection systems is determined mainly by the capacity of the hardware of the processing systems.

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