VILNIUS UNIVERSITY

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CLASSIFICATION-BASED COMPRESSION SOLUTIONS OF DIGITAL IMAGES

Summary of Doctoral Dissertation

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1. Introduction

1.1. Relevance

At present, digital data and information are an integral part of life and the surrounding world. Today, the tasks of storage and processing of digital data and presentation of information are of particular importance. Digital images refer to particular information, which is presented (represented) by processing specific data sets. The presentation and storage of image information requires enormous computer resources. In order to be able to meet ever increasing users' demands, image capturing and representation software developers are making efforts to provide more and more advanced solutions, however, they require more and more resources. The storing of one photograph captured by a modern camera requires more physical storage than the storing of the text of the whole book.

Hundreds of millions of images are daily uploaded to social networks and specialised data storage facilities of digital images by internet users. Internet search engines allow finding easily the data published by many popular social networks on quantities of images at their possession. The numbers of images captured and uploaded by mobile phones alone total trillions annually. Despite the fact that the price of data storage is decreasing over time, the quantities of uploaded data are increasing more rapidly. The increasing quantities of uploaded data have an effect on the increase of energy consumption, which is a problem. Expansion, development and optimisation of network and data storage facilities are only part of the measures of tackling the problem. Therefore, the development of more advanced digital image compression solutions and improvement of the currently available ones is necessary. The development and improvement of algorithms for the compression, storage and presentation (representation) of digital image data has been an object of scientific research for as long as a few decades. The image compression solutions, analysed in this thesis, are of relevance to and could be applied by hosting and cloud storage services, social networks, e-commerce platforms, etc.

1.2. Object of research

The object of research in the thesis refers to different digital images and compression of groups of those images considering of storage resources.

1.3. Objective of the thesis

The objective of the thesis is the development of compression technology for groups of digital images aimed at saving the space, occupied by the images, and maintaining the desired quality.

1.4. Tasks of the thesis

To achieve the objective of the thesis, the following tasks are set:

1. Analysis of currently available methods used for the objective assessment of quality of digital images and their adaptation for the assessment of quality of large[1] images;
2. Analysis of methods used for the extraction of features of images and determination, which features describing images have to be used to classify those images in accordance with their quality;
3. Creation of a technology for compression of groups of images, which would apply the classification of images prior to their compression in order to be able to choose the most appropriate algorithm for the compression based on the classification results;

[1] Subjective Image Quality Databases intended for the analysis of objective quality assessment methods are comprised of low-resolution test images. This thesis examines different images captured by digital cameras. In this thesis, the concept "large image" shall be defined as a digital image of the size of at least 1024×768 pixels. Images larger than 6144×4096 pixels are not subject to research in this thesis.

4. Development and research of an approach for the compression of images by the JPEG algorithm applying of the proposed technology, which would allow saving the space, occupied by the images, compared to the standard JPEG algorithm, and make an assessment of the proposed approach from the point of view of costs.

1.5. Statement of the problem

Working with large groups of images as well as with other large data sets, we face problems related to data processing, uploading, and storing. In view of the fact that the displayed image refers to a specific representation of data and this image is perceived by people subjectively, we face the problem of image quality assessment.

The dissertation analyses groups of different content independent images captured by different digital cameras, therefore, it is impossible to set parameters for compression algorithms so that images could be modified in a targeted way with consideration of image quality assessment measures. The thesis demonstrates that even in cases where images are captured by the same camera with identical settings the quality of the images, depending on the scene of the image, is not the same as the quality of the images is assessed by using different image quality assessment measures.

Another problem is that objective methods of image quality assessment are developed considering the specific character of human visual perception, whereas lossy image compression methods and algorithms are developed seeking to store, decode and represent the maximal possible amount of information. There is no direct correlation between the amount of stored information and the quality of the image received since they are different paradigms. Currently, certain modifications of compression algorithms are under development seeking to achieve that the result corresponds to a certain measure of quality, however, this is not universal as the result meets only the requirements of the selected measure of quality.

To achieve the specified objective, one more problem is addressed in the thesis, i. e. identification, which features describing initial images have to/can be used in the classification of these images in accordance with their quality after they have been processed by compression algorithms.

In view of the character of the research, the general problem is analysed in three aspects: compression of images; image quality assessment; classification of images. There is no universal performance model to achieve the specified objective and to accomplish the tasks, therefore, knowledge and methods of the interdisciplinary areas, such as data mining, computer vision as well as other areas related to presentation of information have to be used.

1.6. Author‘s position and the methodology of research

The objective of the thesis was defined taking into consideration the currently available and widely used digital data management processes (processing, storing, representation, etc.). In the thesis, clear and measurable results are sought while the proposed technological solutions have been developed, based on the pragmatic point of view, i. e. in the consideration of the habits of the public, which are relevant today (use of social networks, cloud solutions, etc.) and technologies used by the public (smartphones, tablet PCs, etc.).

From the scientific point of view, there is no principal philosophical position selected for the dissertation, however, certain clearly defined provisions are observed:

- the work was carried out within the framework of existing paradigms; well-established methods are not disputed. This is particularly important when subjective issues are analysed, for example, how the quality of an image is perceived by a person;
- assumptions, hypotheses and ideas, that are put forward in the thesis, are falsifiable and are based on empirical research. The intention was to achieve better results than the existing ones according to one or several criteria.

Scientific achievements are assessed with the application of the methods of information search, analysis, comparative analysis, systemising and summarising.

The statistical analysis of experimental research results and their summarising were made based on the experimental research method.

Multidisciplinary knowledge and theories were used in the thesis to achieve the specified objective: quality assessment, data classification, and digital image analysis. To quantify the perceived quality of images the Mean Opinion Score (MOS) is used. Objective, full-reference methods of MOS are analysed and used in the thesis. Supervised classification methods are used in the thesis for image classification. The image analysis is made within the framework of the paradigm of computer vision (as a discipline). The image analysis methods are used for the preparatory image filtering and processing of interim results. Geometric Transformations, Region and Image Properties, Texture Analysis are used to quantify features describing images. Considering the fact that non-specific groups of images (different images captured by different cameras are used), are analysed, the object analysis methods are not used in the thesis. Major ideas are presented through modelling processes.

1.7. Scientific novelty of the thesis

A technology for compression of groups of digital images, which can be applied for developing other technologies and obtaining new knowledge, is proposed in the thesis. Based on this technology, an approach is proposed for the compression of groups of different content independent images, captured by digital cameras, using JPEG algorithm thus saving the space, occupied by the images while maintaining the pre-defined quality (the quality is assessed by objective quality assessment measures).

A hypothesis was advanced in the thesis: when the classification is used and the classifier is trained in feature describing images, the impact of the compression algorithm on the compressed images can be predicted when the images are grouped into classes in accordance with the quality of the images, which will allow saving the space occupied by the images. The new approach towards the identified problem of storing data seeking to save the space occupied by images is applied in the thesis: the intention is to choose adequate settings for algorithms for different groups of images instead of improving the existing compression algorithms in order to save as much information about the image as possible.

The particularity of the solutions, presented in the dissertation, is that the images obtained after compression meet the selected quality threshold (the quality of the received images is not lower than a specified value of the quality measure), although the quality of images is not assessed in the process of compression, which is different from the approach applied in the works of other authors. The classification of images prior to selecting a compression algorithm is also useful because the compression algorithm with appropriate settings is used only once for one image.

The achievement of the optimal solution (the quality of all the received images is equal to the selected quality measure), where an appropriate algorithm is selected for each image, is possible by checking each image with the use of the quality assessment measure, however, it is a very time-consuming process. A compromise between the above solution and the conventional approach is proposed in the dissertation where a single compression algorithm is applied to all images.

The research results have showed that the proposed solutions are feasible in the cases where the desired quality value for each image of the analysed group of images is no less than the specified quality threshold. The proposed solutions, where the impact of the algorithm on the image is determined using the Intelligence-based Approach, are of particular relevance when large groups of images are stored.

1.8. Practical value of the thesis results

The technology is proposed in the thesis as well as the approach, based on this technology, for processing groups of images by the JPEG algorithm and for storing them by saving the space, occupied by the images, and maintaining the pre-defined quality. In view of the fact that most manufacturers and users of photography equipment *de facto* use the JPEG compression algorithm and image format, this kind of solution is of relevance for social networks, different hosting and cloud storage services, e-commerce platforms, etc. The image compression approach for provision of the above services, proposed in the dissertation, can be used without any additional modifications. A trained classifier can be used for an indefinite period of time without any additional retraining.

The technology proposed in the dissertation can be used for developing other technologies and obtaining new knowledge. The application of this technology can be useful for work with specific content images: medical images, satellite images, and images obtained by different specific image capturing devices, etc.

1.9. Statements to be defended

1. The approach for computing and selection of feature describing images, used for a maximally precise classification of images in accordance with their quality after they have been processed by compression algorithms, is defined in the thesis.
2. The universal technology for compression of groups of digital images, proposed in the thesis, saves the space occupied by the images while maintaining the pre-defined quality. The main idea of the technology is: with the application of classification, a possible impact of the compression algorithm on the quality of the image is predicted, where the quality is assessed by objective quality assessment methods.
3. The approach for processing groups of different images (captured by digital cameras) by the JPEG algorithm, proposed in the thesis, saves more than 20% of the space occupied by the images while maintaining the pre-defined quality. The quality of images is assessed by the SSIM index and PSNR measures.

1.10. Approbation and publications of the research

The main results of the dissertation were published in 10 research papers: four papers are published in periodicals, reviewed scientific journals; one paper is published in conference proceedings; five papers are published in conference abstracts. The main results have been presented and discussed at three national and six international conferences.

1.11. Organisation of the thesis

This thesis is organized as follows. The JPEG image compression algorithms, image quality assessment measures, and image classification concepts are outlined in Section 2. The technology for efficient storage of the compressed images using the image classification is proposed in Section 3. The approach for image storage in JPEG format, based on the classification into three classes, is also described here. In Section 4, the proposed approach is experimentally investigated on benchmark image sets, the efficiency of the proposed approach and the conventional JPEG algorithm as well as a precise quality selection technique is also compared. Finally, conclusions are drawn in Section 5.

2. Image classification in accordance with their quality after compression

Before introducing the proposed technology for efficient storage of the compressed images, some concepts and fundamentals should be described. Therefore, the works and researches on the efficiency of image compression by the JPEG algorithm are reviewed in this section. Measures for image quality assessment are also described, and the background of image classification tasks is presented here as well. Moreover, the researches on image storage while taking into account the image quality are reviewed below.

2.1. Image compression by JPEG

The basic principles of the wide-used JPEG image compression standard were proposed more than 25 years ago, however, it remains most popular for image compression. There are many studies to compare various modifications of the JPEG algorithm. This format is commonly used for cloud storage, and the recent JPEG improvements for online upload of a large number of photos were proposed in (Liu, et al., 2016) (Wu, et al., 2016).

The JPEG compression algorithms allow varying many settings. There are many research works, dedicated for analysis of the JPEG algorithm, where different compression settings are investigated. In JPEG procedures, it is possible to select a sub-sampling way, to apply different DCT methods, to use Hoffman optimization, progressive storage, etc. By changing setting values, different results with various characteristics can be obtained. The JPEG algorithm is a lossy compression algorithm, thus, the image quality after compression is reduced. The main setting influencing the image quality after compression by JPEG is the quality factor (QF), which defines a compression ratio. It is the integer number between 0 and 100 used to parametrize the quantization matrix, the higher the number, the less information is lost. It has been shown that when compressing various images by the JPEG algorithm with the same quality factor (QF), the different compression efficiency as well as different quality of the compressed images are obtained. To determine the compression efficiency, the amount of space occupied by the compressed images and the changes of images are evaluated. Usually, the image changes are evaluated by the following measures: CR (Compression Ratio), SNR (Signal to Noise Ratio), PSNR (Peak Signal to Noise Ratio), and MSE (Mean Square Error).

2.2. Image quality assessment

After compression of an image by lossy compression algorithms, not only image size, but also its quality reduces. The image size can be measured by bytes, however, there is no unique measure to assess the image quality. The Mean Opinion Score (MOS) is a *de-facto* metric, used to quantify the perceived image and video quality. The metric is standardized by a Telecommunication Standardization Sector (ITU-T) of the International Telecommunication Union (ITU). The image quality can be evaluated subjectively based on opinions of the observers – subjective MOS. The following methods are provided in ITU-T recommendations for this purpose:

- In the Absolute Category Rating method, the images are presented to an observer by one at a time and they are rated independently on a category scale – the five-point scale (excellent, good, fair, poor, bad).
- In the Degradation Category Rating method, the images are presented in pairs: the first image in each pair is always the original one, while the second image is the distorted (compressed) one. The five-level scale (imperceptible, perceptible but not annoying, slightly annoying, annoying, very annoying) for rating the distortions is used.
- In the method of Pair Comparisons, the distorted images are presented in all the possible pairs, and an observer indicates the preferred image from each pair.

Such an image quality assessment indicates the level of image distortion. However, it has negative aspects: it is impossible to rate the image size and resolution; the observers' motivation is subjective and their backgrounds are different; the image is influenced by lighting and monitor quality, etc. Moreover, such assessment procedures are very expensive and time-consuming.

The algorithms that evaluate the image distortion automatically provide objective measures for the image quality assessment or objective (predicted) MOS. When developing the objective measures, researchers aim to achieve a high correlation of the measure with the subjective MOS. The objective quality assessment measures can be classified into three categories (Moorthy, et al., 2011) (ITU, 2001):

- In No-Reference (Blind) approaches, the quality of the distorted image is evaluated without its comparison with the original one.
- In Reduced-Reference (Partly Comparative) approaches, the quality of the distorted image is evaluated according to a part of information about the original one.
- In Full-Reference (Comparative) approaches, the distorted image is compared with the original one.

The Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR) is are the most popular objective image quality assessment measures. MSE is a mean of the squared differences between pixels of the original and compressed images. PSNR is directly related to MSE, it evaluates the possible highest difference between the original and compressed images. However, not always a small value of MSE and a high value of PSNR guarantee a high quality of the compressed image. The Structural Similarity (SSIM) index (Wang, et al., 2004) method better reflects the human visual perception characteristics compared with other popular measures (Ponomarenko, et al., 2009a) and is also widely used in image and video processing, image classification and restoration (Rehman, et al., 2012) (Fernando, et al.). The method is based on three image characteristics: luminance, contrast, and structure. Let X be a fragment of the original image and Y be a fragment of the distorted image. The SSIM index is calculated by the formula:

$$\boldsymbol{SSIM}(\boldsymbol{X},\boldsymbol{Y}) = [\boldsymbol{l}(\boldsymbol{X},\boldsymbol{Y})]^{\boldsymbol{\alpha}} \cdot [\boldsymbol{c}(\boldsymbol{X},\boldsymbol{Y})]^{\boldsymbol{\beta}} \cdot [\boldsymbol{s}(\boldsymbol{X},\boldsymbol{Y})]^{\boldsymbol{\gamma}}), \tag{1}$$

where $l(X,Y)$ is a luminance, $c(X,Y)$ is a contrast, $s(X,Y)$ is a structure, $\alpha > 0$, $\beta > 0$, and $\gamma > 0$ are parameters used to control relative importance of each characteristic. The SSIM index value is calculated for each local fragment of the image. In such a way, a SSIM index map is constructed. The SSIM index value of the whole image is obtained by calculating the mean of SSIM index values of local fragments. The possible values of SSIM are in interval [-1, 1].

Taking into consideration the fact that PSNR assesses an image in the pixel level and SSIM estimates an image in a higher level, it is purposeful to apply a combination of both measures to assess the quality of the compressed images versatilely.

2.3. Image classification tasks

Image classification is a part of computer vision that is related to a theory of developing artificial systems required to receive and perceive the information from images. The process of solving computer vision problems usually consists of three stages: preprocessing filtering, image processing/analysis, and decision making. It is difficult to set strict boundaries between these stages. Some image analysis methods are used for both preprocessing filtering and image processing. Usually, image processing is performed by detecting particular objects in an image. In this case, image classification is formulated as an object recognition problem. When solving computer vision problems, it is necessary to indicate information classes, and here classification methods should be applied.

Image classification is a process where information classes are extracted from a multiband raster image. The function $Y' = f(X')$ is formed which assigns each feature vector X' of the image to the class Y'. The function f is called a classifier which divides the feature space into some regions.

Taking into account that there is no reason to use the specific Machine Learning algorithm to achieve the objectives, the classification algorithms based on different principles can be chosen: Linear Discriminant Analysis (LDA), Decision Tree Learning and the Support Vector Machine (SVM).

2.4. Image storage considering the image quality

When considering the image quality, image storage always copes with assessment of the quality by objective methods. In (Forczmanski, et al., 2014), an adaptive JPEG algorithm was proposed which allows compressing images efficiently according to their content. Smoothness of images was assessed, and smoother images are compressed stronger, while images with many edges – weaker. MSE, SSIM, and Image Fidelity (Daly, 1993) were considered as image quality assessment measures. To set the values of quality thresholds, Laplace edge detection filter was applied. Using this adaptive approach, the JPEG algorithm must be processed ones or several times, and each time the compressed image has to be compared with the original one.

The paper (Coulombe, et al., 2010) proposed a system that optimizes the quality of images processed by JPEG according to QF and a scaling parameter, while the maximal image size and resolution were predefined. The image quality is assessed by the SSIM index method. The system requires many transcoding operations per image to determine the optimal solution. The approach predicts neither resulting file size nor quality, but the transcoding parameters maximizing quality under the constraint of file size. Some improvements of the system were introduced in (Pigeon, et al., 2012) by the usage of k-means (Lloyd, 1982) based on prediction of the transcoded JPEG file size and the SSIM index.

In the aforementioned approaches, to determine the best QF value, the compression algorithm is usually repeated more than one time.

The paper (Kozhemiakin, et al., 2017) described a method to predict MSE (and/or PSNR) for grayscale images, compressed by JPEG with uniform quantization and by the advanced DCT-based coders called AGU and ADCT. The proposed method can predict the quality of a compressed image with appropriately high accuracy using a limited number of the analysed blocks. This prediction is based on a hypothesis that MSE of distortions, introduced due to quantizing DCT coefficients in blocks, is equal to MSE of distortions, observed in decompressed images. In this case, the quality is predicted when its assessment is performed in a pixel level.

In (Laua, et al., 2003), the JPEG influence on image recognition was investigated by applying the Iterative Self-Organizing Data Analysis Technique (ISODATA). The authors aimed to recognize four classes in satellite images: water, vegetation cover, urban land use, and barren land. They concluded that the effect of compression on the image quality depends on the content.

A classification problem was solved in (Venkatesh Babu, et al., 2006) to predict the image quality, i.e., to indicate a relation between HVS-based features and MOS. The aim was to develop a measure that closely correlates with human perception without usage of the original image. The sequential learning algorithm called Growing and Pruning Radial-basis Function (GAP-RBF) network was applied. To train a neural network, the following image features are used: edge amplitude, edge length, background activity, and background luminance (Karunasekera, et al., 1995). The edges were detected along horizontal and vertical directions by the corresponding Prewitt edge operators (Maini, et al., 2009). The smallest error of the MOS prediction was obtained by the GAP-RBF network as compared to other measures.

In summary, two groups of approaches for effective storage of the compressed images considering the image quality can be identified:

1. Precise Quality Selection Approach (PQSA) – a precise quality of the compressed image is predefined and, considering this quality, the settings for compression are identified (see Figure 1).
2. Computational Intelligence-based Quality Selection Approach (CIQSA) – the quality of the compressed image is predicted by classification, and the settings for compression are identified considering the classification results (see Figure 2).

It is obvious that usage of PQSA allows getting the maximally effective results (preferable image quality and size combination) when compressing images. However, the storage of large image groups is very time-consuming. Thus, in practical usage, it is reasonable to apply the method of CIQSA group with a low prediction error level that is much faster. Moreover, small errors will not affect the representation of images essentially.

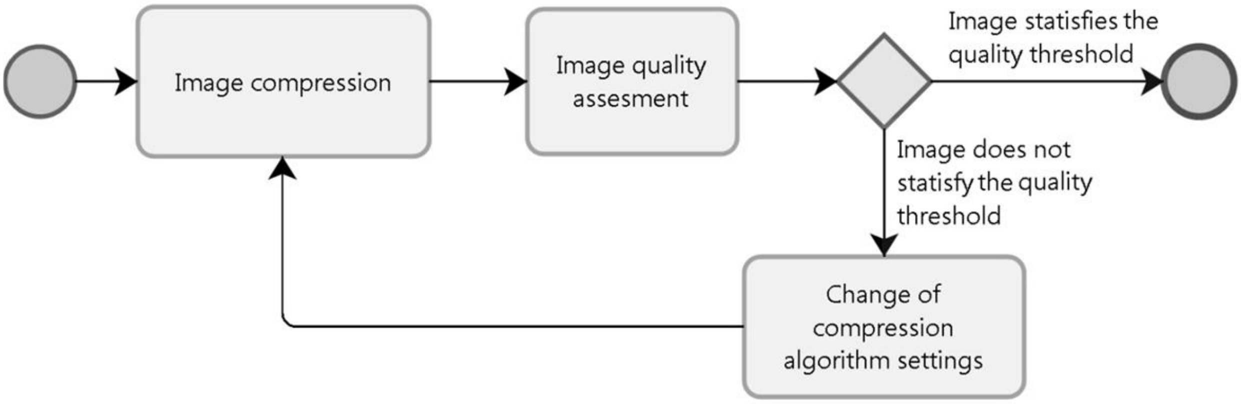

Figure 1: Process of PQSA for image compression.

Figure 2: Process of CIQSA for image compression.

In many image processing methods, each image is assigned to a class according to its content, and then the same predefined processing settings are applied to all the images from the class. On the contrary, we aim to develop a contentžindependent image classification, based on grouping according to the image quality.

3. Experimental investigation of image quality

In the thesis, the SSIM index method when assessing the quality of high-resolution images with small distortions after compression has been investigated. The experimental investigation has shown that it is necessary to use image data downsampling in the algorithm for calculating the SSIM index value, otherwise, the

SSIM index values are very dependent on the sizes of images, especially if their structure was changed. Moreover, it has been determined that execution of the algorithm without data downsampling is slower, and it takes much more time when the sizes of images are large.

After the experimental investigation, where high-resolution images were processed by different variants of the algorithms for calculating the SSIM index value, a new algorithm has been proposed, where image data downsampling in the SSIM index method is implemented by the nearest-neighbour interpolation. In this case, the obtained SSIM index values better reflect the differences between the original and distorted images. The proposed algorithm will enable us to properly evaluate the quality of huge high-resolution image sets automatically if distortions after applying compression algorithms are hardly noticeable.

4. Proposed technology for image compression

In the thesis, an effective technology is proposed to compress digital images in order to save storage space, while maintaining the desirable image quality. The advantage of this method is especially revealed when dealing with large volumes of content independent images. It should be noted that the proposed method belongs to the group of CIQSAs (see Subsection 2.4).

4.1. Storage process of the image group

The main idea of the proposed method is based on the classification of images before compression considering the quality and selection of the settings for the compression algorithm according to the classification results. The values of the settings should be selected that the predefined thresholds of the image quality were satisfied.

The storage process of the image group is presented in Figure 3 and described hereafter:

- U1 – A group of images is transferred from the local storage place or image capture device.

- U2 – Numerical value(s) of the desired image quality are selected.
- S1 – Image classification is performed (details of classifier creation are described in Subsection 3.2).
- S2 – The values of compression settings are selected for each class so that the image quality of each class after compression would satisfy the predefined quality measure thresholds.
- S3 – The images of each class are compressed using the settings selected for this class.
- S4 – The compressed images are saved to the storage.

It should be noted that the process of classifier creation is performed once, and the compression – on demand.

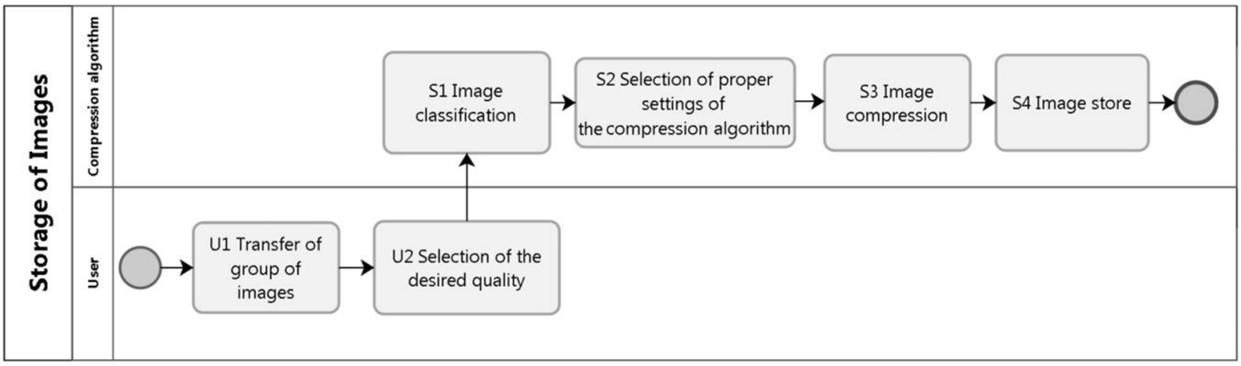

Figure 3: Storage process of the image group.

4.2. Classifier creation

Let an image be described by a d-dimensional vector $S = (s_1, s_2, \dots, s_d)$, and $Y'_1, Y'_2, \dots, Y'_l$ be class labels, where l is the number of classes. The general classification problem is solved in two stages:

1. Considering the vector S, the features $(x_1, x_2, \dots, x_p)$, describing the image, are determined and the p-dimensional vector $X' = (x_1, x_2, \dots, x_p)$ is formed, usually, $p \leq d$. The aim is to find the minimal number of image features without losing a lot of information about the image. A set of the vectors $X'_1, X'_2, \dots, X'_n$, corresponding to a set of the images, is formed, where

$X'_i = (x_{i1}, x_{i2}, \dots, x_{ip})$, and n is the number of images. Each vector is assigned to one of the classes Y'_k, $k \in [1, \dots, l]$.

2. The classifier is trained using the vectors $X'_1, X'_2, \dots, X'_n$, i.e. vectors $X'_1, X'_2, \dots, X'_n$ are mapped to the set of class labels $Y'_1, Y'_2, \dots, Y'_l$. Considering to the trained classifier, any new image X'_{n+1}, can be assigned to one of the known classes Y'_k, $k \in [1, \dots, l]$.

Thus, with a view to create a classifier, three main problems should be solved: (1) to set feature vectors describing the images, (2) to define a class of each image for classifier training, and (3) to train the classifier. As a result, using the created classifier, each new image can be assigned to a class.

Due to the fact that we do not solve object recognition problems, but cope with image classification based on the image quality, to set the feature vectors $X'_1, X'_2, \dots, X'_n$, geometric transformations, region and image properties, texture analysis can be applied.

The general process of the classifier creation is presented in Figure 4 and described below:

- C1 – A representative image group is selected (medical images, GIS images, ordinary photographs, etc.).
- C2 – The images are processed by a compression algorithm. The settings of the compression algorithm are selected such that the algorithm differently affected the image quality. In such a way, a larger range of values of image quality measure is obtained, which will facilitate the formation of classes.
- C3 – The image quality is assessed by the selected full-reference measures.
- C4 – The features describing the images are extracted.
- C5 – Correlation coefficients between the numerical values of the features are calculated.
- C6 – The weakest correlated features are selected for classifier training.
- C7 – The number of classes is selected. A class label is defined to each image according to the predefined thresholds of quality measures.

- C8 – The classifier is created by some classification method using the training image set with the class labels. The classification accuracy is evaluated by a cross-validation strategy.
- C9 – If the classification accuracy is low and does not satisfy a user's preferences, new values of image quality thresholds are selected.
- C10, C11 – The number of image features is reduced by selecting various combinations of features till the desirable classification accuracy is obtained. Here the classification accuracy is also evaluated by the cross-validation strategy.
- C12 – Considering the most appropriate set of features, the final classifier is created, which will be used in the storage process of the compressed images, presented in Figure 3.

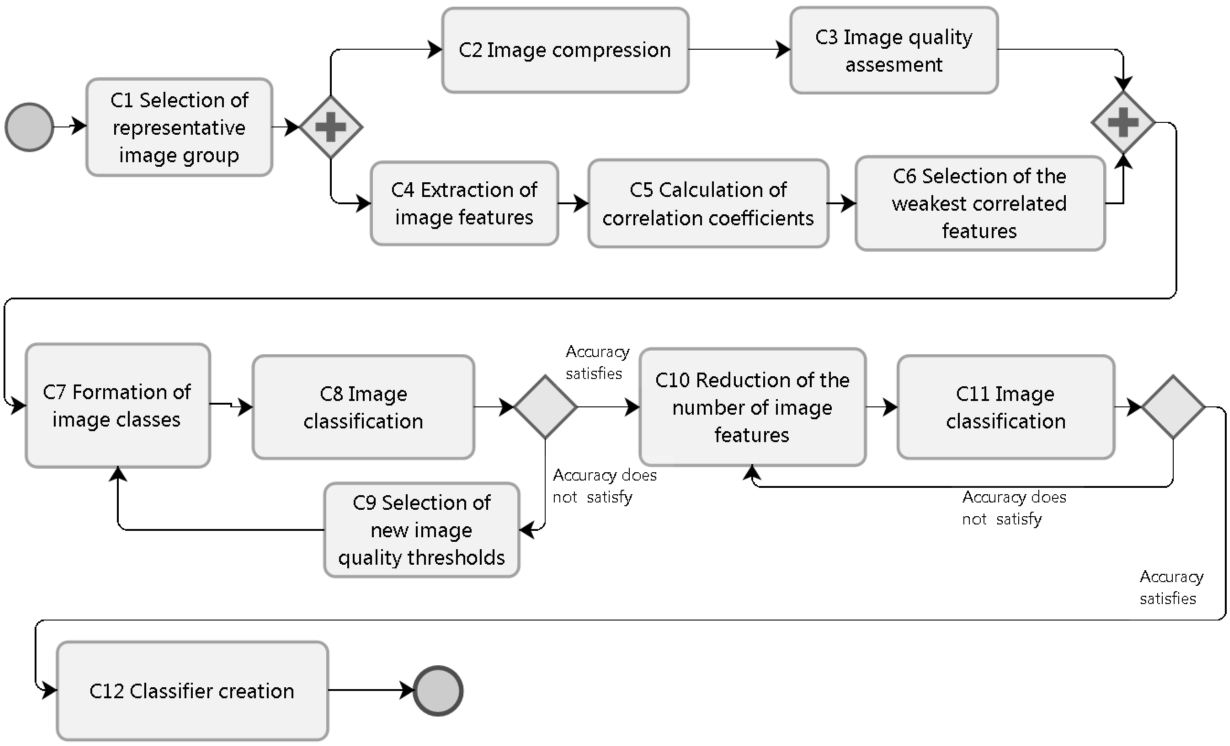

Figure 4: Classifier creation.

4.3. JPEG compression approach

In this subsection, a JPEG compression approach based on the described technology is presented. In the approach, a content independent image group is processed by the JPEG algorithm so that all the compressed images would satisfy the minimal quality thresholds, and the QF value would be selected automatically. The process of the proposed approach is presented in Figure 5. The classification-based approach allows predicting how the JPEG algorithm will affect the image quality after compression. The experimental investigation, where the proposed approach has been compared with the conventional JPEG algorithm, has shown that the approach allows us to save 15% of image storage space, when classifying only into two classes. With a view to save more image storage spaces, the investigation with a larger number of classes should be performed.

In the thesis, the effective image storage technology is applied to the JPEG algorithm, where the images are divided into three classes. Classification into more than three classes does not make sense for the JPEG algorithm, as the values of the image quality measures after compression are distributed in a narrow range. Thus it is very complicated to form more distinct classes.

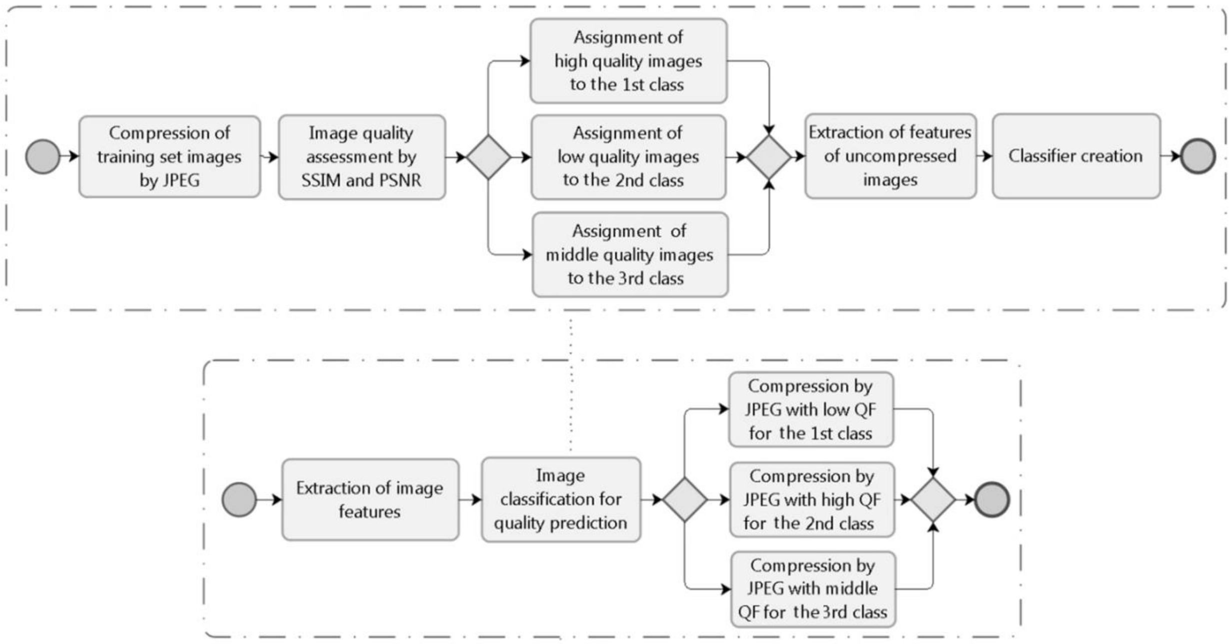

Figure 5: The proposed JPEG-based approach for image group storage.

The image quality thresholds are calculated by using the objective full-reference quality assessment measures. The quality is assessed by two weak-correlated measures (Forczmanski, et al., 2014): in the pixel level by PSNR and general image changes by the SSIM index. The quality thresholds are set at the intersection of the values of these measures (see Figure 6).

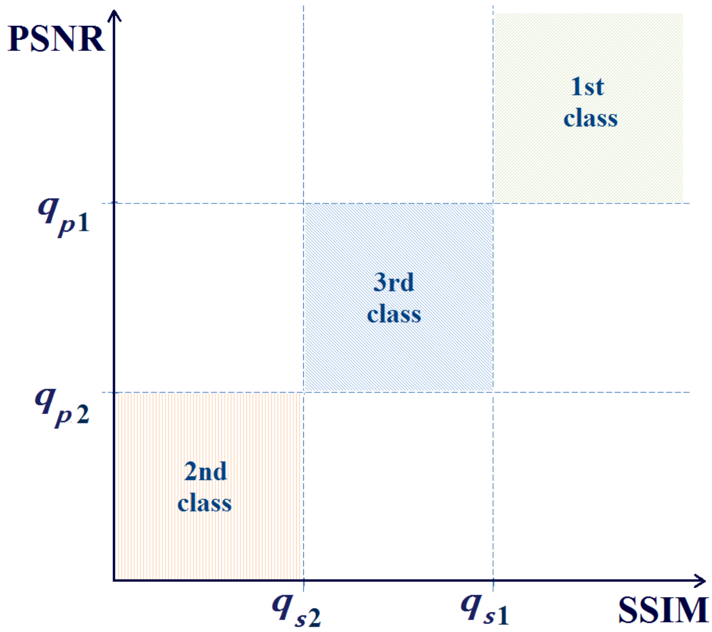

Figure 6: Assignment of the images to classes.

To form classes for classifier training, the following rules are complied with:

- the images, the quality of which has changed least after the compression, are assigned to the 1st class ($SSIM > q_{s1}$ and $PSNR > q_{p1}$);
- the images, the quality of which has changed most, are assigned to the 2nd class ($SSIM < q_{s2}$ and $PSNR < q_{p2}$);
- the images, the quality of which has changed an average, are assigned to the 3rd class ($q_{s2} < SSIM < q_{s1}$ and $q_{p2} < SSIM < q_{p1}$).

The assignment of images to classes by quality thresholds are presented in Figure 6. It should be noted that not all the images fall into one of these classes (for example, if $SSIM < q_{s2}$ and $PSNR > q_{p1}$). However, such strict boundaries of thresholds are defined to get more accurate training of the classifier.

4.4. Experimental investigation

The digital image database SUN2012 (Xiao, et al., 2010) is used in the experimental investigation with a view to demonstrate the efficiency of the proposed computational intelligence-based approach for storage of large image groups. The database consists of 16783 different images. There selected such images the dimensions of which are not smaller than 1024×768 pixels to form a test image database (the total number is equal to 2963).

A desktop computer with the Intel Core i-7-5500U processor and 8 GB RAM is used in the experimental investigation. The approach is coded and evaluated in Matlab R2015a.

4.4.1. Image feature extraction

Before the image classification, the features that describe the images must be identified. To simplify the feature extraction, the sizes of images are reduced to 256×192 by using the nearest-neighbour interpolation. For such a kind of image classification problem, different information describing the image should be considered. Therefore, for each image, the following features are evaluated:

- Pixel and histogram entropies, means, standard deviations, calculated for each colour component in different colour spaces (*RGB, YCbCr, HSV*);
- The ratio between the number of pixels and file size, which shows physical memory required to save a pixel;
- The means and standard deviations of pixels of the images in grayscale, processed by global image thresholding (Otsu, 1979);
- The number of different regions of similar colour areas (black and white) in the images, processed by global image thresholding (see Figure 7). Such regions of the following areas are selected (in a number of pixels): from 1 to 10, from 11 to 50, from 51 to 200, from 201 to 1000, from 1001 to 5000, from 5001 to 10000, from 10001 to 25000, from 25001.

In totally, 55 features are identified. The correlation coefficients between image features are calculated. Then less correlated features are selected for a further analysis – if the correlation coefficient between two features is larger than 0.7, only one of them is selected. After such a selection procedure, 27 less correlated image features are identified.

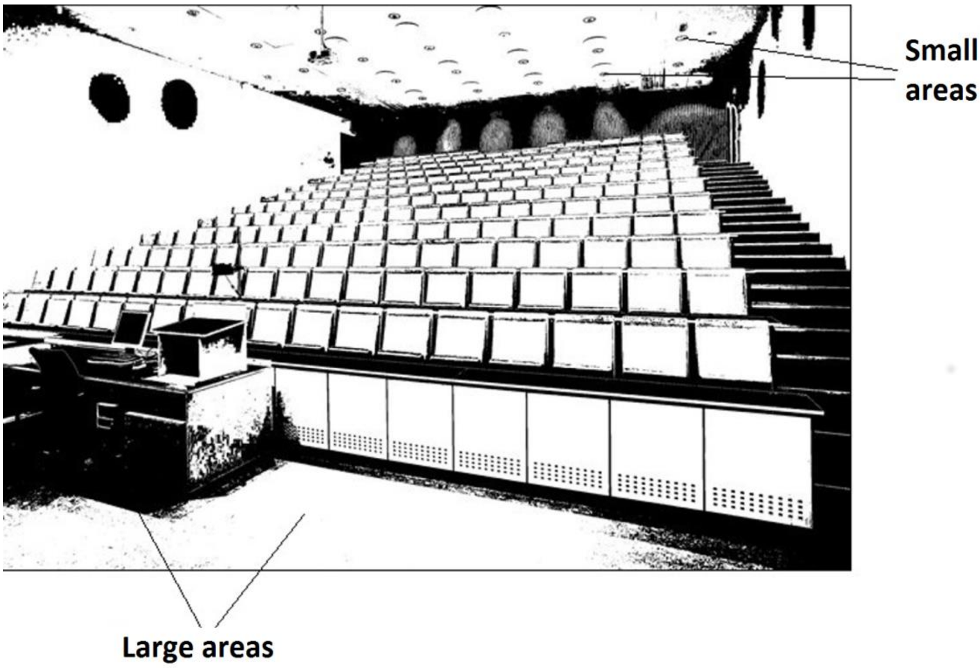

Figure 7: Regions of similar colours.

4.4.2. Image classification

For the initial assignment of images to classes (formation of the training set), the images are processed by the JPEG algorithm, and the quality of the compressed images are computed. The obtained SSIM values range from 0.69 to 0.999, PSNR – from 20.3 to 57.3. For further classification, 450 images are selected (150 images for each class). Various classification methods can be applied to classify images considering to their quality after compression. Regarding the previous investigations, in the case of such image classification, the proper features describing images influence the classification results more than the classification method used. Taking into account that there is no reason to use the specific Machine Learning algorithm to achieve the set of objectives, the algorithms for computing are chosen, based on different principles: LDA, Decision Tree Learning and SVM. The classification accuracy is evaluated by the 10-fold cross validation strategy. The numerical values of the quality thresholds $q_{s1}, q_{s2}, q_{p1,} q_{p2}$ are defined in the way described above (see Figure 4 and Figure 6). In the experimental investigation, the values q_{s1} = 0.94, q_{p1} = 37, q_{s2} = 0.92, q_{p2} = 32 were set so that representativeness of the classes were maintained.

4.4.3. Image feature reduction

27 image features can be used to train a classifier, however, such a number of features is too high for constant usage of the trained classifier. Thus, only the essential features must be identified to reduce the computational time. It is very time consuming to examine all possible combinations of features, therefore we select the features by an empirical iterative procedure. The steps of procedure are as follows:

Step 1. 1000 combinations of randomly selected 4 features are formed.

Step 2. The classification accuracy is calculated, and the combination of the features with the most accurate classification results is fixed. If there are unused features go to Step 3, otherwise stop the procedure.

Step 3. 1000 combinations of randomly selected 4 unused features are formed and added to the previously fixed features. Go to Step 2.

The classification results, obtained by selecting combinations of the features, are presented in Table 1. The best classification accuracy is equal to 76% (using LDA and SVM). Due to the fact that SVM with a higher content of classes is extremely slow, LDA is used for further calculations.

Table 1: Classification accuracy with the different number of features.

The number of features	**Decision Tree Learning**	**LDA**	**SVM**
4	57 – 65%	61 – 70%	61 – 71%
8	58 – 65%	61 – 71%	62 – 71%
12	60 – 69%	64 – 73%	65 – 74%
16	62 – 70%	70 – **76%**	70 – **76%**
27	71%	**76%**	**76%**
55	69%	73%	72%

Table 2: Selected features ($x_5, \ldots, x_{16}$) for each colour component.

Colour component	Std	Colour component	Std	Colour component
R	-	-	-	-
G	+	-	-	-
B	+	-	-	-
Y	+	-	-	-
Cb	+	-	-	-
Cr	+	-	-	-
H	+	-	+	-
S	-	+	-	-
V	+	+	-	-
Binarizavimas	+	+	-	-

For a further experimental investigation the set with the minimal number of features was selected while maintaining this accuracy. Finally, the essential 16 features are identified that should be used to train the classifier:

- x_1 - the ratio between the amount of pixels and file size;
- x_2, x_3, x_4 - the number of black regions of pixels from 1 to 10, the number of white regions of pixels from 1 to 10 and from 11 to 50;
- $x_5, \ldots, x_{16}$ - the means, standard deviations and entropies of pixels. The statistical characteristics selected as image features are marked by "+" in Table 2. It should be noted that entropies of histograms are not essential with the view of image classification, investigated in this research.

4.4.4. Classification results

The problem of classifying images into three classes has been solved with the selected 16 image features. The obtained values of classification precision and recall are presented in Table 3, and the confusion matrix is shown in Table 4.

Table 3: Classification accuracy (LDA).

	(Precision)	**(Recall)**
1st class	0.93	0.72
2nd class	0.85	0.72
3rd class	0.61	0.84

Table 4: Confusion matrix (LDA).

		Predicted class		
Actual class		**1st class**	**2nd class**	**3rd class**
	1st class	108	3	39
	2nd class	0	108	42
	3rd class	8	16	126

We can see that the1st (high-quality after compression) and 2nd (low-quality after compression) classes are not intermixed. And this fact is relevant, if the compression algorithm with settings for the images of the 1st class were applied to the images of the 2nd class, the low-quality images would be obtained instead of high-quality ones.

4.4.5. Comparison of the proposed approach and the conventional JPEG algorithm

The proposed JPEG compression approach, based on the developed method, is compared with the conventional JPEG algorithm in order to investigate the storage space, required for compressed images. 150 images were randomly selected from each class to train the classifier (450 in total). 500 other random images were selected to examine the efficiency of the proposed approach.

Two cases are investigated, where a different resulting image quality is desired. In the first case, it is aimed to obtain high-quality images after the compression, and the following quality requirements are defined: $SSIM > 0.94$ and $PSNR > 37$. In the second case, it is desired to obtain middle-quality images after the compression, and the following $SSIM > 0.92$ and $PSNR > 32$ are defined.

It is experimentally identified that, to achieve the predefined quality thresholds by using the conventional JPEG algorithm, it is necessary to apply QF=95 in the first case, and QF=85 in the second case. To achieve the predefined thresholds by using the proposed approach, the values of QF are defined depending on the image class and they are presented in Table 5.

Table 5: The image quality requirements and QF values.

	First case		**Second case**	
	Conventional JPEG	**Proposed approach**	**Conventional JPEG**	**Proposed approach**
Aim	High-quality		Middle-quality	
JPEG parameters	QF=95	QF=50 (1st class) QF=95 (2nd class) QF=85 (3rd class)	QF=85	QF=40 (1st class) QF=85 (2nd class) QF=65 (3rd class)
Requirements	*SSIM* > 0,94 *and* *PSNR* > 37		*SSIM* > 0,92 and *PSNR* > 32	

The experiment is repeated 10 times for each case using different sets of images. Each time 500 images are randomly selected from the image test database (different from the training set). The image storage space after the compression and the number of images which do not satisfy the predefined quality requirements (misclassified images) are calculated and presented in Table 6 and Table 7. The results show that approximately 26% of storage space can be saved. In the first case, the space required was reduced from 4114 MB to 3029 MB; in the second case – from 2446 MB to 1805 MB. Although approximately 4% of images do not satisfy the predefined quality thresholds, however, the quality of these images is very close to the quality thresholds.

Next it was investigated the proposed approach with the decreased QF values. In brief, the average results of 10 reps are presented in Table 8. With a view to get the high-quality images (the first case), 35.3% of storage space is saved, and 9.7% of images do not satisfy the quality thresholds. With a view to get the middle-quality images (the second case), 31.7% of storage space is saved, and 7.1% of images do not satisfy the quality thresholds.

Table 6: Comparison of the results of the first case (high quality).

Exp. No	**Conventional JPEG**		**Proposed approach**		**Saved storage space (MB)**
	Storage space (MB)	Misclassified images	Storage space (MB)	Misclassified images	
1	399	6 (1.2%)	276	20 (4.0%)	123 (30.1%)
2	445	8 (1.6%)	346	23 (4.6%)	99 (22.2%)
3	403	6 (1.2%)	287	18 (3.6%)	116 (28.8%)
4	443	10 (2%)	351	21 (4.2%)	92 (20.8%)
5	403	3 (0.6%)	279	22 (4.4%)	124 (30.1%)
6	382	5 (1%)	291	18 (3.6%)	91 (23.8%)
7	410	4 (0.8%)	293	20 (4.0%)	117 (28.5%)
8	421	7 (1.4%)	307	17 (3.4%)	114 (27.1%)
9	376	5 (1%)	280	22 (4.4%)	96 (25.5%)
10	432	6 (1.2%)	319	24 (4.8%)	113 (26.2%)
Total:	**4114**	**60 (1.2%)**	**3029**	**205 (4.1%)**	**1085 (26.4%)**

Table 7: Comparison of the results of the second case (middle quality).

Exp. No	Conventional JPEG		Proposed approach		Saved storage space (MB)
	Storage space (MB)	Misclassified images	Storage space (MB)	Misclassified images	
1	233	5 (1.0%)	166	10 (2.0%)	67 (28.9%)
2	266	5 (1.0%)	209	24 (4.8%)	57 (21.4%)
3	238	6 (1.2%)	165	23 (4.6%)	73 (30.7%)
4	262	8 (1.6%)	209	15 (3.0%)	53 (20.2%)
5	237	4 (0.8%)	165	21 (4.2%)	72 (30.4%)
6	227	3 (0.6%)	170	18 (3.6%)	57 (25.1%)
7	251	4 (0.8%)	181	17 (3.4%)	70 (27.9%)
8	256	5 (1.0%)	186	19 (3.8%)	70 (27.3%)
9	232	4 (0.8%)	176	20 (4.0%)	56 (24.1%)
10	244	6 (1.2%)	178	17 (3.4%)	66 (27.1%)
Total:	**2446**	**50 (1.0%)**	**1805**	**184 (3.7%)**	**641 (26.2%)**

After the analysis of the results of four (QF/quality thresholds) combinations, the proposed approach enables us to save the storage space considerably. It is obvious that the increase of the QF values will lead to the decrease of the number of images that do not satisfy the predefined quality thresholds. However, in this case, the saving of the storage space will decrease.

Table 8: The image quality requirements and QF values.

	First case		**Second case**	
	Conventional JPEG	**Proposed approach**	**Conventional JPEG**	**Proposed approach**
Aim	High-quality		Middle-quality	
JPEG parameters	QF=95	QF=40 (1st class) QF=95 (2nd class) QF=75 (3rd class)	QF=85	QF=30 (1st class) QF=85 (2nd class) QF=55 (3rd class)
Requirements	$SSIM > 0{,}94$ *and* $PSNR > 37$		$SSIM > 0{,}92$ and $PSNR > 32$	
Storage space	4114	2663	2446	1671
Saved storage space	-	1451 (35.5%)	-	775 (31.7%)
Misclassified images	60 (1.2%)	485 (9.7%)	50 (1%)	355 (7.1%)

4.4.6. Run-time analysis

In the previous subsection, the advantages of saving more storage space, using our proposed effective JPEG approach, have been demonstrated. However, it is also important to estimate time expenditure in comparison with other JPEG approaches. As mentioned before, there exist two possible ways for effective storage of images: by predefining the image quality precisely (PQSA), and by predicting the image quality applying proposed computational intelligence-based approach. PQSAs allow getting optimal results, i.e. to use the minimum amount of storage space while all the images meet the quality thresholds. However, PQSAs are not suitable for storage of large image groups due to high time expenditure. In this subsection, we aim to compare time expenditure of PQSA, the proposed approach, and the conventional JPEG algorithm.

When evaluating the run-time in the proposed approach, the time expenditure for creating the classifier is not estimated, as it is performed only once, and the trained classifier is constantly used for the effective image storage. Moreover, it is not possible to evaluate unambiguously the time expenditure for a part of the classifier creation process as the time depends on the user (see Figure 4, block C9). The run-time of conventional JPEG is estimated according to compression with QF=95. However, the process of the proposed approach consists of three main tasks that influence the runtime: image feature extraction, image classification, and image processing by the JPEG algorithm with one of the QF values predefined for the class. The averaged runtime expenditure for randomly selected 500 images is presented in Table 9.

Table 9: Run-time of tasks in the conventional JPEG and the proposed approach.

Task	**Average runtime (sec) 500 images**	**Average runtime (sec) 1 image**
Compressing by JPEG, QF=50	128	0,256
Compressing by JPEG, QF=85	136	0,272
Compressing by JPEG, QF=95 (Conventional JPEG)	163	0,326
Feature extraction	75	0,15
Classification	0.01	2×10^{-5}
Proposed approach (CIQST)	**219**	**0.446**

To estimate the runtime of PQSA, the process is simulated using the Bizagi Modeler software. It is assumed that the images will be processed by JPEG, using

PQSA no more than two times. When the image, obtained with the predefined minimal QF value, does not satisfy the quality requirements, the appropriate QF value will be selected. In Figure 8, the simulation process is presented aimed to get a high quality of the compressed images (the first case). Probabilities that the compressed images meet the quality requirements must be estimated and provided for the model. Using 10 randomly selected sets of 500 images it is experimentally estimated that the probability for the images to meet the requirements as QF=50 is equal to 0.32. The probability that the remaining images meet the requirements as QF=85 is equal to 0.84. The runtime of the simulated process is presented in Table 10.

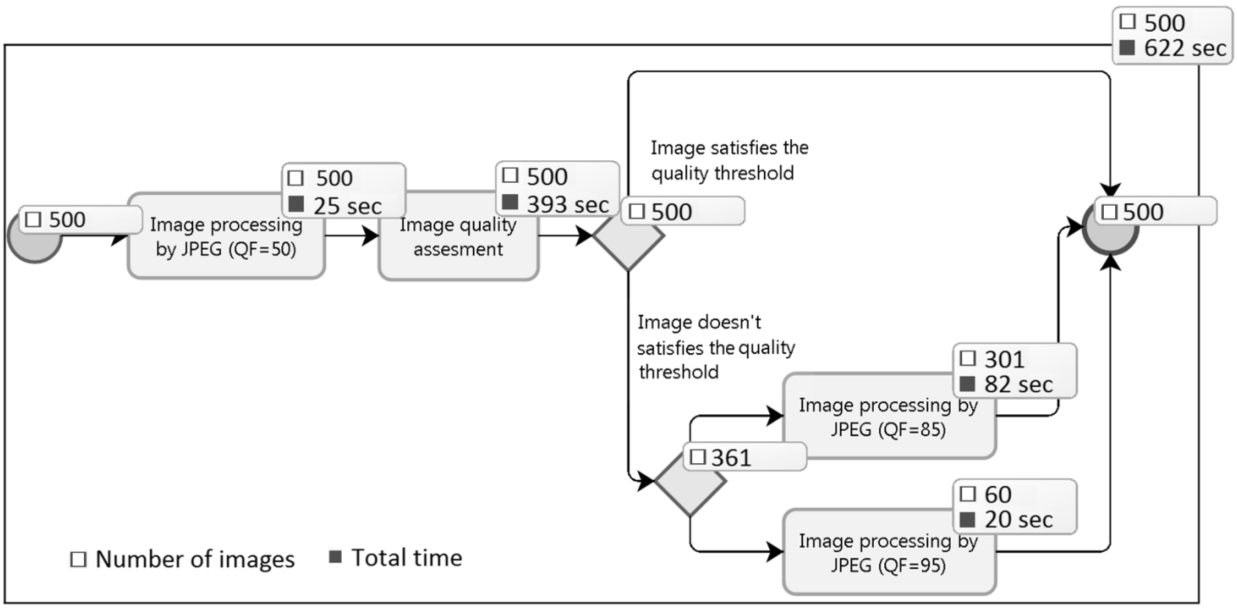

Figure 8: Simulation of PQSA process for the first case (high quality).

Table 11 provides a summary of runtimes of the conventional JPEG, proposed approach, and simulated PQSA process, when the user aims to obtain the high-quality images after compression (the first case). The results show that the proposed approach is approximately 3 times faster than PQSA, and the conventional JPEG exceeds the approach only by 26%.

Table 10: Runtime of the tasks in the conventional JPEG and the proposed approach.

Task	Average runtime (sec) 500 images	Average runtime (sec) 1 image
Compressing by JPEG, QF=50	128,1	0.256
Compressing by JPEG, QF=85	81,81	0.272
Compressing by JPEG, QF=95 (Conventional JPEG)	19,55	0.326
Quality assessment, PSNR	177	0.354
Quality assessment, SSIM	216	0.432
PQST procesas	**622.46**	**1.234**

Table 11: Runtime of the tasks in the conventional JPEG, proposed approach, and simulated PQSA process.

	The first case		
	Conventional JPEG	**Proposed approach (CIQST)**	**PQST**
Aim	High quality		
Requirements	*SSIM* > 0.94 and *PSNR* > 37		
JPEG parameters	QF=95	QF=50 (1st class) QF=95 (2nd class) QF=85 (3rd class)	QF=50 QF=95 QF=85
Total time	163 sec	219 sec	622 sec

It is obvious that more storage space will be saved by using PQSA. However, when the number of images to be compressed and saved is very high, the PQSA is not suitable due to the huge time expenditure. For example, if 5000 images are saved, the conventional JPEG runs 27 min, the proposed approach – 36 min, while PQSA – 1 h 46 min.

5. Conclusions

The technology for compression of groups of digital images, aimed at saving the space occupied by the images while maintaining the pre-defined quality, is proposed in the thesis. This technology can be used for developing other technologies and obtaining new knowledge. Two classification-based approaches for the compression of images in the JPEG format by classifying the stored images into two or three classes prior to the application of the compression algorithm are presented and analysed in the thesis. The proposed approaches enable us to assess of the impact of the algorithm on the quality of images. The proposed approaches are comprised of two parts: training of the classifier and compression of images by JPEG, based on the class to which the image belongs. The application of these approaches allows us process large groups of images by the JPEG algorithm so that the JPEG QF value is automatically selected for each image in view of the desired quality of the image. When the proposed technology is used, the training of the classifier is performed once, since the compression of images on the basis of the trained classifier can be applied for an indefinite period of time according to the need.

Seeking to achieve the objective of the thesis, the SSIM index method was analysed in the thesis and it was applied in the assessment of the quality of high resolution images with small distortions. It has also been established that, in the case of compression of different images by the JPEG algorithm with the same QF values, a different efficiency and quality of the compression are obtained. The research has showed that the classification of images prior to the application of the compression algorithms can be useful to save the space occupied in the data storage.

During the experimental research, a task has been performed to determine which features, describing initial images, have to be used for classifying these images in accordance with their quality after they have been compressed by the JPEG algorithm. Appropriate features describing images were selected.

Based on the research carried out in the dissertation, conclusions were drown and results were summarised:

1. The application of the proposed technology for processing groups of different content independent images, captured by digital cameras by the JPEG algorithm, allows saving about 15% of the space occupied by the images, when the images are classified into two classes, and about 26% of the space occupied by the images, when the images are classified into three classes, as compared to the standard JPEG algorithm. As a result, 95% of the images meet the desired quality threshold when the quality assessment is performed by the SSIM index and PSNR methods. This technology and the image compression approach, based on this technology, allow varying quality settings. When QF values for individual classes are increased, the number of images, which do not meet the quality threshold, decreases, whereas, when these values are reduced the amount of the saved space is increased. The proposed technology is flexible and can be easily adapted to users' needs.
2. A set of features describing images was specified; in the case of using this set of features as a basis for classifying images, the classification accuracy is 0.85 when the images are classified into two classes, and 0.76 when the images are classified into three classes.
3. It has been determined that the compression of images when the quality of the compressed images is defined precisely (PQST) is nearly three times slower than the proposed classification-based image compression (CIQST) with the predicted impact of the JPEG on the quality of images.

List of Publications on the Topic of Dissertation

[1 A] Tichonov J., Kurasova O., Classification of Large Images Before Applying Compression Algorithms, Journal of Young Scientists, 2015, Vol. 1(43): 87–94.

[2 A] Tichonov J., Kurasova, O., Filatovas, E., Classification of Images According their Quality after Compression, Information Science, 2015, Vol. 73: 127–134.

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[4 A] Tichonov J., Kurasova O., Filatovas E., Image Classification for JPEG Compression, Advances in Science and Technology Research Journal, ISSN: 2299-8624 (accepted 2018-03-19).

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[6 A] Tichonov, J., Kurasova, O., Classification of Large Images before Applying Compression Algorithm, 6th International Workshop „Data Analysis Methods for Software Systems“, December 4-6, 2014, Druskininkai, Lithuania.

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[8 A] Tichonov, J., Kurasova, O., Filatovas, E., Decision Tree Classification to Predict Effect of JPEG Compression on Images, EURO 2016, 28th European Conference on Operational Research, July 3–6, 2016, Poznan, Poland.

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KLASIFIKAVIMO METODAIS GRINDŽIAMI SKAITMENINIŲ VAIZDŲ GLAUDINIMO SPRENDIMAI

Darbo aktualumas

Šiuo metu neatsiejama gyvenimo ir mus supančio pasaulio dalis yra skaitmeniniai duomenys ir informacija. Skaitmeninių duomenų saugojimo, apdorojimo ir informacijos pateikimo uždaviniai šiandien yra itin aktualūs. Skaitmeniniai vaizdai – tai ypatinga informacija, kuri pateikiama (atvaizduojama) apdorojant specifinius duomenų rinkinius. Vaizdinės informacijos pateikimas ir saugojimas reikalauja didžiulių kompiuterinės įrangos resursų. Tam, kad būtų galima patenkinti vis didėjančius vartotojų poreikius, vaizdo fiksavimo ir jo atvaizdavimo įrangos kūrėjai stengiasi pateikti vis pažangesnius sprendimus, tačiau jie reikalauja dar didesnių resursų. Vienai šiuolaikiniu fotoaparatu padarytai nuotraukai saugoti reikia daugiau fizinės atminties nei visos knygos tekstui išsaugoti.

Kasdien interneto naudotojai į socialinių tinklų ir specializuotų skaitmeninių vaizdų duomenų saugyklų infrastruktūrą perduoda šimtus milijonų vaizdų. Naudojant interneto paieškos sistemas, galima nesunkiai rasti daugelio populiariausių socialinių tinklų skelbiamus duomenis apie jų valdomus vaizdų kiekius. Vien mobiliaisiais telefonais padarytų ir perduotų vaizdų kiekis skaičiuojamas trilijonais per metus. Nepaisant to, kad diskinė vieta ilgainiui pinga, perduodamų duomenų kiekiai auga sparčiau. Vis didėjantis perduodamų duomenų kiekis daro įtaką didesniam energijos sunaudojimui ir tai yra problema. Tinklo ir duomenų saugyklų infrastruktūros plėtimas, tobulinimas ir optimizavimas – tai tik viena iš priemonių problemai spręsti, todėl būtina kurti pažangesnius ir tobulinti jau esamus skaitmeninių vaizdų glaudinimo sprendimus. Jau kelis dešimtmečius skaitmeninių vaizdų duomenų glaudinimo, saugojimo ir pateikimo (atvaizdavimo) algoritmų kūrimas ir tobulinimas yra mokslinių tyrimų objektas.

Šiame darbe nagrinėjami vaizdų glaudinimo sprendimai aktualūs ir taikytini įvairioms prieglobos ir debesijos paslaugoms, socialiniams tinklams, elektroninės komercijos platformoms ir pan.

Darbo tikslas

Šio darbo tikslas – sukurti skaitmeninių vaizdų grupių glaudinimo technologiją, siekiant taupyti vaizdų užimamą vietą, tačiau išlaikant pageidaujamą kokybę.

Darbo uždaviniai

Darbo tikslui pasiekti iškelti šie uždaviniai:

1. Išanalizuoti esamus skaitmeninių vaizdų kokybės vertinimo metodus ir pritaikyti juos didelių vaizdų kokybei įvertinti;
2. Išanalizuoti vaizdų požymių išskyrimo metodus ir nustatyti, kokie vaizdus apibūdinantys požymiai turi būti naudojami klasifikuojant šiuos vaizdus pagal jų kokybę;
3. Sukurti vaizdų grupių glaudinimo technologiją, kurioje prieš vaizdų glaudinimą būtų taikomas vaizdų klasifikavimas, siekiant pagal klasifikavimo rezultatus parinkti tinkamiausią glaudinimo algoritmą;
4. Pritaikant pasiūlytą technologiją, sukurti ir ištirti vaizdų glaudinimo JPEG algoritmu būdą, kuris leistų sutaupyti vaizdų užimamos vietos kiekį, lyginant su standartiniu JPEG algoritmu. Įvertinti siūlomą būdą laiko sąnaudų aspektu.

Darbo mokslinis naujumas

Disertacijoje pasiūlyta skaitmeninių vaizdų grupių glaudinimo technologija, kuri gali būti naudojama kitų technologijų sukūrimui ir naujoms žinioms gauti. Šios technologijos pagrindu yra pasiūlytas būdas įvairių vaizdų, gautų skaitmeniniais fotoaparatais ir neturinčių specifinio turinio, grupėms glaudinti JPEG algoritmu, taupant vaizdų užimamą vietą, tačiau išlaikant nustatytą kokybę (kokybė vertinama objektyviais kokybės vertinimo matais).

Darbe iškelta ir patvirtinta hipotezė – naudojant klasifikavimą, kai klasifikatorius išmokytas atpažinti vaizdus pagal juos apibūdinančius požymius, galima numatyti, kaip glaudinimo algoritmas įtakos suglaudintus vaizdus, kai jie suskirstomi į klases pagal vaizdų kokybę, kas leistų sutaupyti vaizdų užimamą vietą. Disertacijoje į iškeltą duomenų saugojimo problemą, kai norima taupyti vaizdų užimamą vietą, žvelgiama naujaip – siekiama ne tobulinti esančius glaudinimo algoritmus, norint išsaugoti kuo daugiau informacijos apie vaizdą, o parinkti tinkamus algoritmų nustatymus skirtingoms vaizdų grupėms.

Disertacijoje pasiūlyti sprendimai ypatingi tuo, kad po glaudinimo gauti vaizdai atitinka pasirinktą kokybės slenkstį (gautų vaizdų kokybė ne mažesnė, nei nustatyta kokybės mato reikšmė), nors glaudinimo procese vaizdų kokybė, priešingai nei daroma kitų autorių darbuose, nevertinama. Vaizdų klasifikavimas prieš parenkant glaudinimo algoritmą naudingas dar ir tuo, kad glaudinimo algoritmas su reikiamais nustatymais vienam vaizdui naudojamas vieną kartą.

Pasiekti geriausią sprendimą (visų gautų vaizdų kokybė lygi pasirinktam kokybės matui), kai tinkamas algoritmas būtų parenkamas kiekvienam vaizdui, galima patikrinant kiekvieną vaizdą kokybės vertinimo matu, bet tai labai imlus laikui procesas. Disertacijoje pasiūlytas kompromisas tarp minėto sprendimo ir įprasto, kai visiems vaizdams taikomas vienas glaudinimo algoritmas.

Tyrimų rezultatai parodė, kad pasiūlyti sprendimai turi perspektyvą tais atvejais, kai norima gauti ne mažesnę kokybės reikšmę už nustatytą kokybės slenkstį kiekvienam nagrinėjamos vaizdų grupės vaizdui. Pasiūlyti sprendimai, kai išmaniuoju būdu nustatoma (angl. *Intelligence-based Approach*) kaip algoritmas įtakos vaizdą yra ypač aktualūs, kai saugomos didelės vaizdų grupės.

Ginamieji teiginiai

1. Darbe nustatytas būdas apskaičiuoti ir atrinkti vaizdus apibūdinančius požymius, kurie turi būti naudojami kiek galima tiksliau klasifikuojant vaizdus pagal jų kokybę po apdorojimo glaudinimo algoritmais.
2. Darbe pasiūlyta universali skaitmeninių vaizdų grupių glaudinimo technologija taupo vaizdų užimamą vietą, išlaikant nustatytą kokybę. Pagrindinė technologijos idėja – naudojant klasifikavimą numatyti, kaip glaudinimo algoritmas įtakos vaizdo kokybę, kai kokybė vertinama objektyviais kokybės vertinimo metodais.

3. Darbe pasiūlytas būdas įvairių vaizdų (gautų skaitmeniniais fotoaparatais) grupėms apdoroti JPEG algoritmu, sutaupo daugiau nei 20 % vaizdų užimamos vietos, išlaikant nustatytą kokybę. Vaizdų kokybė vertinama SSIM indekso ir PSNR matais.

Disertacijos struktūra

Disertaciją sudaro 5 skyriai. Pirmasis, įvadinis disertacijos skyrius skirtas pristatyti mokslinio darbo kryptis, aktualumą, tikslą ir uždavinius. Antrajame skyriuje pateikta darbui aktualių mokslinių darbų ir metodų apžvalga. Trečiajame skyriuje pristatomi autoriaus atlikti eksperimentiniai tyrimai, pagrindžiantys disertacijos uždavinius.

Ketvirtasis skyrius skirtas aprašyti autoriaus pristatomus vaizdų glaudinimo sprendimus ir lyginamuosius tyrimus. Disertacijos apibendrinimas ir išvados pateikti penktajame skyriuje. Taip pat disertacijoje pateiktas žymėjimų ir trumpinių sąrašas. Disertacijos apimtis 122 puslapiai, pateikti 35 paveikslėliai, 28 lentelės ir 38 formulės. Literatūros sąrašą sudaro 92 šaltiniai.

Disertacijos apibendrinimas ir išvados

Darbe pasiūlyta skaitmeninių vaizdų grupių glaudinimo technologija, siekiant taupyti vaizdų užimamą vietą, bet išlaikant nustatytą jų kokybę. Taip pat darbe pristatyti ir ištirti du klasifikavimu grįsti būdai glaudinti vaizdus JPEG formatu, klasifikuojant saugomus vaizdus į dvi arba į tris klases prieš naudojant glaudinimo algoritmą. Siūlomi būdai leidžia įvertinti, kaip JPEG algoritmas paveiks vaizdų kokybę. Pasiūlyti būdai sudaryti iš dviejų dalių: klasifikatoriaus mokymo ir vaizdų glaudinimo JPEG atsižvelgiant į klasę, kuriai priklauso vaizdas. Šių būdų taikymas leidžia apdoroti dideles vaizdų grupes JPEG algoritmu taip, kad JPEG QF reikšmė būtų automatiškai parenkama kiekvienam vaizdui, atsižvelgiant į pageidaujamą vaizdo kokybę. Naudojant pasiūlytą technologiją, klasifikatoriaus mokymas vyksta vieną kartą, o vaizdų glaudinimas pagal apmokytą klasifikatorių gali būti naudojamas pagal poreikį, neapibrėžtą laiko tarpą.

Siekiant disertacijoje iškelto tikslo, darbe ištirtas SSIM indekso metodas ir pritaikytas didelės raiškos vaizdų su mažais iškraipymais kokybei vertinti. Taip pat nustatyta, kad spaudžiant skirtingus vaizdus JPEG algoritmu su vienodomis QF reikšmėmis, gaunamas skirtingas glaudinimo efektyvumas ir kokybė. Tyrimai parodė, kad vaizdų klasifikavimas prieš taikant glaudinimo algoritmus gali būti naudingas taupant užimamą vietą informacijos saugykloje.

Eksperimentinio tyrimo metu buvo sprendžiamas uždavinys, siekiant nustatyti, kokie pradinius vaizdus apibūdinantys požymiai turi būti naudojami klasifikuojant šiuos vaizdus pagal jų kokybę po glaudinimo JPEG algoritmu. Parinkti tinkami vaizdus apibūdinantys požymiai.

Remiantis disertacijoje atliktais tyrimais suformuluotos išvados ir apibendrinti rezultatai:

1. Pasiūlytos technologijos taikymas įvairių vaizdų, gautų skaitmeniniais fotoaparatais ir neturinčių specifinio turinio, grupėms apdoroti JPEG algoritmu, leidžia sutaupyti apie 15 % vaizdų užimamos vietos, kai klasifikuojama į dvi klases ir apie 26 % vaizdų užimamos vietos, kai klasifikuojama į tris klases, lyginant su standartiniu JPEG algoritmu. Rezultatas - daugiau kaip 95 % vaizdų tenkina pageidaujamą kokybės slenkstį, kokybę vertinant SSIM indekso ir PSNR metodais. Ši technologija ir ja grįstas vaizdų glaudinimo būdas leidžia varijuoti kokybės nustatymais. Didinant QF reikšmes atskiroms klasėms, mažėja vaizdų, kurie netenkina kokybės slenksčio, o mažinant šias reikšmes, didėja sutaupomos vietos kiekis. Pasiūlyta technologija yra lanksti ir gali būti lengvai priderinama prie naudotojų poreikio.
2. Nustatytas vaizdus apibūdinančių požymių rinkinys, pagal kurį klasifikuojant vaizdus, bendras klasifikavimo tikslumas lygus 0,85, kai klasifikuojama į dvi klases ir 0,76 – klasifikuojant į tris klases.
3. Nustatyta, kad vaizdų glaudinimas, kai tiksliai nustatoma suspaustų vaizdų kokybė (PQST), beveik tris kartus lėtesnis nei pasiūlytas klasifikavimu grįstas vaizdų glaudinimas (CIQST), numatant JPEG algoritmo poveikį vaizdų kokybei, klasifikuojant vaizdus į tris klases.

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Jevgenij Tichonov
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