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Alexey Podlasov and Eugene Ageenko

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Morphological reconstruction of semantic layers in map images

Alexey Podlasov, Eugene Ageenko

Department of Computer Science, University of Joensuu, Box 111, FIN-80101 Joensuu, Finland

Abstract

Map images are composed of semantic layers depicted in arbitrary color. Often images require separation into layers for storage and processing. Separation results in severe artifacts because of layer overlapping. In the current work, we design the technique to restore semantic layers after separation. The designed restoration technique alleviates compression deficiency of reconstructed layers versus corrupted ones with lossless compression algorithms (ITU Group 4, PNG, JBIG and IBIG2 with optimized context templates), and provides better visual quality of images in operations with selective layer removal/extraction.

1 Introduction

1.1 Digital Spatial Libraries

Real-time cartography imaging applications provide user with the view of geographic map for the area surrounding the user's location. The geographical map image is obtained from *Digital Spatial Library* and transmitted via network to user's mobile device such as pocket computer (*PDA*) or a mobile phone. *Digital Spatial Library* is an electronic archive of geographic imagery data [F+95, S89]. The images forming the archive are the color (or grayscale) raster images or multi-layer map images. The multi-layer map images consist of the set of semantic layers, each containing the data with distinct semantic content, e.g. roads, elevation lines, state boundaries, water areas, etc. The layers are combined and displayed to the user as a generated color image, in which the data of each type is usually depicted using its own color (see Figure 1).

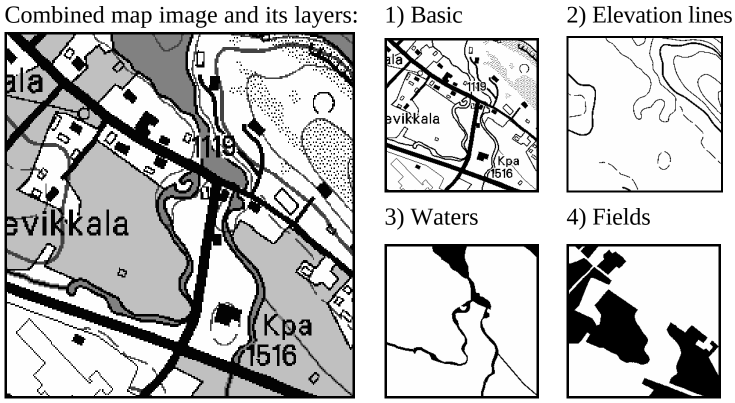


Figure 1: Illustration of a multi-layer map image from NLS Topographic database.

The main problem of DSL is the huge storage size of the images. Especially it is apparent in applications requiring the use of mobile hardware such as mobile phones or pocket computers. Even though during the last decade the technology demonstrated significant progress in the development of hardware, mobile devices are still hardly restricted in memory and computational resources. Another problem resultant of large image sizes is that larger image size takes longer to transmit and/or require faster (expensive) transmission channels as well as appropriate hardware equipment. The use of compression for saving storage space is therefore obvious. It has been shown that the best compression results for the map images can be achieved if the images are decomposed into binary semantic layers, which are consequently compressed by the algorithm designed to handle binary data (e.g. JBIG) [AF00a, FKA02] (see Figure 2). Layer separation allows utilizing more efficient context-base compression techniques which benefits in high compression performance. Separation also gives the ability to select specific layers at the time of viewing [FAKGB02, FKV02].

Often though, the original vector or semantic data are not available. In such (still prevailing) situations we have only raster color image as the original map. The semantic layers must be obtained from the color image through the *color separation* process (see Figure 3). The map image is divided into binary layers so that each layer represents one color in the original image [FKA02]. This color separation process however leads to appearance of severe artifacts in places when information in one layer overlaps another. These artifacts affect statistical properties and consistency of the layers and result in degraded visual quality and compression performance. The Figure 4 illustrates the corruption of semantic layers.

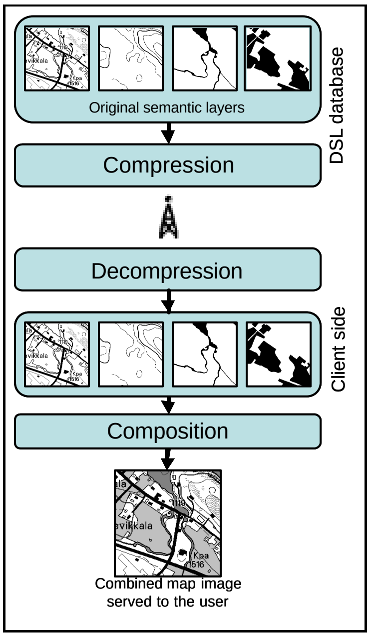


Figure 2. Operation on multi-layer map images.

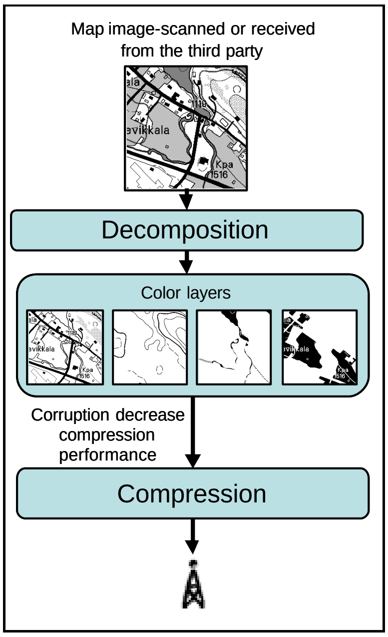


Figure 3. Operation on map images using color separation.

Elevation lines layer Waters layer Fields layer

Figure 4: Corrupted layers after separation.

Secondary problem arises in situations where some of the layers must be extracted or, opposite, removed from the image. Lower layers in hierarchy will suffer more from degradation as well as top-level layers will cause more degradation on under-laying imagery data if being removed.

In this paper we present a technique to restore semantic layers resulting from decomposition of the map image using color separation process. The main restriction for that technique is that once combined reconstructed layers form the map image identical to the original. Restoration technique is expected to provide better compression performance for reconstructed layers than for corrupted ones when using popular compression algorithms (ITU Group 4, PNG, and JBIG). Reconstructed layers have to perform good visual appearance, which is useful for removal or extraction of layers from the original map image for further processing.

When designing algorithms for use in real-time cartography, one should take into account the capabilities of modern mobile devices. The technical level of the most widely used mobile terminals at the moment represents the processing power of the computers in the nineties. Therefore the complexity and memory requirements of the algorithms must be as less as possible to make algorithm applicable and we have to restrict our research with that factors. Thus we decided to avoid too complicated techniques of restoration and chose *Mathematical Morphology* as a base tool to construct our restoration technique.

The compression performance could be improved by the using of nonlinear filters for improving of the image (known as image enhancement). In the early sixties investigations of Matheron and Serra led to a new quantitative approach in image analysis, nowadays known as *mathematical morphology* [S82, M75]. One of the primary applications of morphology is noise removal, which is established in the classical works on mathematical morphology such as [S82, M75], and continues to develop nowadays [PV90, H94, DA97]. The standard (so called 'crisp') morphology has been also extended to 'soft' morphology, which is more tolerant to noise and has advantages in image filtering [KA94]. The idea of using nonlinear filtering for improving compression performance of the image is known as image enhancement and was investigated in [W86, ZD96]. Most filtering techniques improve compression performance by degrading the image which results in loss of image content (e.g. smoothing). However, in our task we can not use that kind of enhancement techniques because we agreed that the content of the map image is critically important and can not be degraded.

A variety of other methods utilizing global (semantic) and statistical properties was developed [AF00b, FAKK02, RS01, PL00]. Some of these methods are not directly applicable to the context of map images, others (as in the case of latter techniques) require significant computational or memory resources which are not available for mobile devices.

2 Mathematical morphology – the background

Mathematical morphology refers to a branch of nonlinear image processing and analysis developed initially by Georges Matheron [M75] and Jean Serra [S82] that concentrates on the geometric structure within an image. The main idea is to analyze the shapes of objects in an image by "probing" the image with a small geometric template (e.g. line segment, disc, square) known as the *structuring element*. The choice of the appropriate structuring element strongly depends on the particular application at hand.

Basic definitions

Consider E is an Abel group and $E = \mathrm{E}^d$ is the d-dimensional product $\mathrm{E}\times\ldots\times\mathrm{E}$. We denote by $\mathrm{P}(E)$ the power set of E comprising all subsets of E.

In case of discrete binary images E is defined as $E = \mathbf{Z}^2$ and *binary image* X – as a set $X \subseteq E$:

$$X = \{z \mid f(z) = 1, z = (i, j) \in \mathbf{Z}^2\}$$

The function f is called *characteristic function* of X. For a set $A \subseteq E$ and element $h \in E$ we define the *translate of A along the vector h* as $A_h = \{a + h \mid a \in A\}$. Operator $y : \mathrm{P}(E) \to \mathrm{P}(E)$ is called *morphological operator* if it is *increasing* (if $X \subseteq Y \Rightarrow y(X) \subseteq y(Y)$, for $X, Y \in \mathrm{P}(E)$) and t*ranslation invariant*, ($y(X_h) = [y(X)]_h$, for $\forall X, h$)

Dilation, erosion and rank operators

Given a fixed set $A \subseteq E$ called in morphology the *structuring element*, we define the *dilation of X by A*, denoted by $d_A(X)$, as an operator on $\mathrm{P}(E)$ such as

$$d_A(X) = \bigcup_{a \in A} X_a = \{h \in E \mid \tilde{A}_h \cap X \neq \varnothing\}.$$

The *erosion by A*, denoted by $x_A(X)$, is the operator

$$e_A(X) = \bigcap_{a \in A} X_{-a} = \{h \in E \mid A_h \subseteq X\}.$$

Here $\tilde{A} = -A = \{-a \mid a \in A\}$ – is the reflectance of A with respect to the origin.

Define the translation invariant operator $r_{A,n}$ called *rank operator*:

$$r_{A,n}(X) = \left\{h \in E \,\middle|\, card\left(X \cap A_h\right) \geq n\right\}.$$

One finds that $r_{A,n}(X)$ sets the pixel to the foreground if amount of pixels on the image in a neighborhood defined by the structuring element is greater than *n*. Otherwise pixel is set to be background.

From Matheron's representation theorem [M75] follows that rank operator can be treated as the base operator of mathematical morphology. In particular, $d_{\tilde{A}}(X) = r_{A,1}(X)$ and, $e_A(X) = r_{A,n}(X)$.

Conditional dilation

A common form of conditioning restricts the union-forming translations to a superset of the input image: if image A is a subimage of T, and B is a structuring element, then the conditional dilation of A by B relative to T is defined by restricting the translations to T, the result being

$$d_B(A|T) = \bigcup_{a \in A} B_a \cap T$$

Where notation $d_B(A|T)$ instead of $d_B(A)$ indicates there is conditioning. Keep in mind that to appreciate the meaning of $d_B(A|T)$ in any particular context, one must recognize the type of conditioning being employed.

Soft morphology

Soft morphological filters are less sensitive to additive noise and small variations in the shapes of the object to be filtered than standard morphological filters. The definitions of the soft morphological operators are similar to crisp operators but incorporate a factor, r, of how well the structuring element fits within the image.

Given a fixed set $A \subseteq E$ called the *structuring element* and a number r called a *factor* (or *rank parameter*), define the *soft dilation by A with factor r*, denoted by $d_A(X,r)$, as an operator on $\mathrm{P}(E^d)$ defined by an expression

$$d_A(X,r) = \left\{ h \,|\, card(X \cap A_h) \geq r \right\}.$$

The *soft erosion by A with factor r*, denoted by $e_A(X,r)$, is the operator given by

$$e_A(X,r) = \left\{ h \,|\, card(X \cap A_h) \geq card(A) - r \right\}.$$

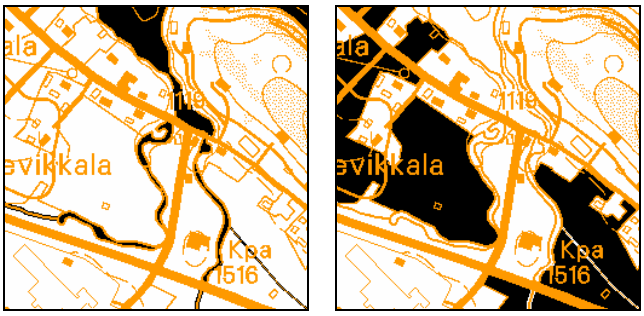
The factor r represents the minimum acceptable overlap between X and the displaced structuring element A.

3 Layer reconstruction technique

3.1 The base restoration algorithm

The task of restoration consists of three stages. First we decompose the combined map image into a set of corrupted layers. Then, for every corrupted layer, the *conditioning mask* is created. Conditioning mask defines the area where the restoration of layer could be performed keeping the combination of restored layers untouched. Typically, the mask for every layer is a union of all upper-laying layers. Obviously, all modifications performed in mask area will be overlapped when combined color image will be presented to the user.

Mask is defined with respect to the assumption that layers in multi-layer map are combined one over another in a predefined order. Depending on the particular case, it is possible to simplify the mask structure by taking into account the nature of objects represented on the map. For example, we can expect that *Waters* and *Field* layers could not overlap in reality, and therefore could not overlap on a combined map image. So, when implementing, we can exclude that kind of layers from the conditioning mask (see Figure 5).



Waters and its mask   Fields and its mask

Figure 5: Waters and Fields with a mask. Objects are black, mask is in light color and background is white.

After the conditioning mask is created, the actual reconstruction of the layer is performed. The restoration is performed using *conditional dilation with mask erosion* operator. This operator establishes the following iterative process:

Repeat	
Layer **= Dilate(** Layer, Mask **)**	$L = d_A(L \mid M)$
Mask **= Erode(** Mask **)**	$M = e_B(M)$
Mask **= Union(** Mask, Layer **)**	$M = L \cup M$
Until Restoration is complete	

The erosion of a mask is applied in order to avoid disadvantages of standard conditional dilation, such as creation of artifacts on the borders of objects which corrupt visual appearance and statistical consistency. Figure 6 illustrates the algorithm.

Compare results of application of conditional dilation with mask erosion operator for *Waters* and *Fields* layers with original layers as presented on Figure 7. You can see that restoration significantly improves the consistency and visual appearance of objects. All inner artifacts (holes made by text and other symbols) were completely filled. Borders of objects smoothed and became more natural. Restored layer is very close visually to the original.

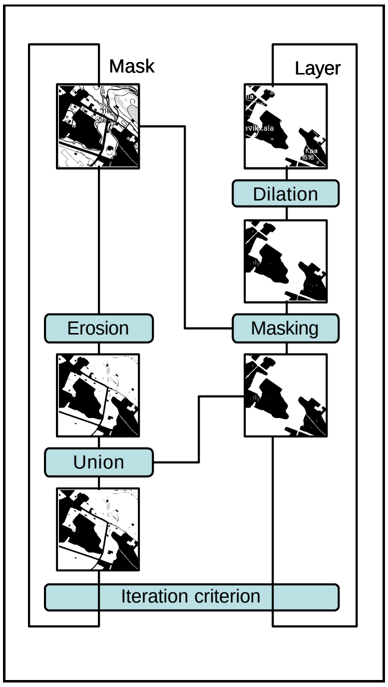


Figure 6: Dilation with mask erosion algorithm

Waters original | Waters reconstructed | Fields original | Fields reconstructed

Figure 7: Waters and Fields layers reconstructed with dilation with mask erosion operator

3.2 Algorithm modifications

Different layers have different morphological structure. Therefore reconstruction operator has to be "tuned" for every layer in order to achieve better performance. Parameters which could be modified are: the criterion controlling the amount of iterations in a process; the structuring element of erosion and dilation operator; dilation and erosion operators could be replaced by other (similar) operators (e.g. soft dilation and erosion). Besides that, so called "smoothing approach" (an operator which "smoothes" objects borders in order to improve visual appearance) was considered. Modifications are briefly discussed below.

Criterion of iterations

Criterion of iterations determines how long iterative process should be performed. There are two approaches: *Iterate until stability* and *Iterate fixed amount of times*. We investigated that the most efficient approach is to determine the average size of artifacts to be reconstructed and iterate that amount of times. For example, if average artifact size is 4 pixels, than we can be sure that 2 or 3 dilations with block 3x3 are enough for restoration.

Using alternative structuring elements

There are two structuring elements in our algorithm: in objects dilation and in mask erosion. By changing the first element we can control how fast objects expand over the mask. Changing of the second allows controlling how fast mask shrinks. Essential thing also is the relation between speeds of dilation and erosion.

Using soft erosion and dilation

Dilation and erosion operators could be replaced with their soft counterparts. They are relaxed versions of their crisp analogues, and therefore can manage with objects and mask more smoothly. Also, by varying the factor parameter of soft dilation and erosion we can control the speed of expanding and shrinking.

Smoothing approach

Waters and fields typically do not have sharp edges or thin, one or two-pixel details. Therefore, we can have designed particular morphological operator to smooth borders of objects. Small and sharp artifacts are removed using morphological rank operator. In order to keep final combination of layers untouched, it can only remove pixels from a layer, but not those which originate from the original corrupted layer. Formally it could be expressed following way:

$$y(X) = (r_{C,r}(X) \cap X) \cup L$$

Here X is a layer restored using dilation with mask erosion technique (see Figure 7), L is an original corrupted layer, C is a structuring element of rank operator and k is a rank parameter. We use that operator on every step of iterative process of reconstruction to smooth borders of objects. The algorithm is modified the following way:

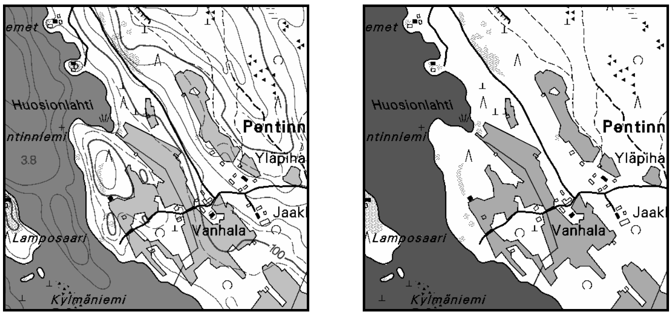
Repeat	
Layer **= Dilate(** Layer, Mask **)**	$L = d_A(L \mid M)$
Mask **= Erode(** Mask **)**	$M = e_B(M)$
Mask **= Union(** Mask, Layer **)**	$M = L \cup M$
Layer **= Intersection(** Layer, **Rank(**Layer**))**	$L = L \cap r_{C,n}(L)$
Layer **= Union(** Layer, CorruptedLayer **)**	$L = L \cup \mathrm{L}$
Until Restoration is complete	

Combined approach

Analysis of restoration techniques for every single layer showed that soft modification of the algorithm presented the best compression improvement for *Waters* layer and modification with smoothing applied – the best improvement for *Fields* and *Elevation* layer. We proposed and evaluate *Combined* algorithm. *Combined* algorithm is the algorithm, where *Elevation* and *Fields* layer is reconstructed with smooth modification and *Waters* layer – with soft modification.

3.3 Removing a single layer from the map

The task of restoration of layers arises also when there is a need for removing a layer (or several layers) from a map. For example some less important layers, like e.g. elevation lines could be unnecessary to the map user driving a car, moreover they can make difficulties for reading a map. It is impossible just to remove that layer because of artifacts it leaves on under-laying layers. Therefore, the restoration technique should be applied to all layers below the one to be removed. Figure 8 illustrates the effect of the removing of *Elevation* layer.



Original map Map with elevation lines removed

Figure 8: Removing elevation lines

4 Evaluation

4.1 Objectives of evaluation

The restoration technique has been evaluated on a set of topographic color-palette map images. These map images were decomposed into binary layers with distinctive semantic meaning identified by the pixel color on the map. The restoration algorithm has been applied for reconstruction of these semantic layers after the map decomposition process. Both the combined color map images and the binary semantic layers composing these color map images were originally available for testing. This fact gave us possibility to compare restored images with their original undistorted counterparts.

The objective of evaluation was to calculate the compression performance in applications were map image is compressed as a set of its binary layers. Restoration method was evaluated against three major compression techniques: LZ (PNG), ITU Group 4 (TIFF) and JBIG. Also optimized binary compression technique presented in [AKF01] was applied. For each of these compression methods we measured the compressed data size for the original semantic layers, similarly for the corrupted binary layers after decomposition, and similarly for reconstructed binary layer using the reconstruction method.

4.2 Test set

The test set includes five randomly chosen images from the "NLS Basic Map Series 1:20000" corresponding to the map sheets *No/No* 431306, 201401, 263112, and 431204. Each map image is of 5000×5000 pixels and consists of four binary component layers. The layer names are following:

- *Basic* – topographic image, supplemented with communications networks, buildings, protected sites, benchmarks and administrative boundaries;
- *Elevation* – elevation lines;
- *Water* – lakes, rivers, swamps, water streams;
- *Fields* – agricultural areas.

4.3 Compression results

Here we evaluate compression results for PNG, TIFF and JBG file formats. Fourth compression technique further denoted as *AKF2* is JBIG2 compression using optimized multi-layer context templates. This method optimizes the size and the ordering of pixels within the context template and provides better compression performance than standard JBIG2 [AKF01]. The size of multi-layer context template was chosen to be 10 as in standard JBIG to maintain computational complexity of compression algorithm.

Table 1 represents the average compressed sizes of restored *Water* and *Fields* semantic, corrupted and reconstructed layers and the compression improvement presented by the restoration algorithm. Morphological structure of these layers allows to perform efficient restoration obtaining significant compression improvement (up to 30-50% depending on the compression technique). On the other hand *Elevation* layer is of completely different structure and morphological reconstruction affects mostly its visual appearance. Improvement of its compression requires more sophisticated heuristics than mathematical morphology. Figure 9 illustrates compression improvements presented in a Table 1.

Table 2 represents the results which are the average compressed file sizes (the sum of all compressed layers: *Basic*, *Elevation*, *Water* and *Fields*) and compression rates for semantic, corrupted and reconstructed layers. Also alleviation of compression deficiency (in percents) for reconstructed layers is calculated (0% alleviation means that reconstruction does not affect the compression rate; 100% means that reconstruction increased the compression rate back to the level presented by semantic layer). Relatively low compression improvement is caused by the dominant size of non- (such as top-level *Basic* layer) or hardly- (such as *Elevation*) restorable layers. Figure 10 illustrates alleviations of compression deficiency presented in a Table 2.

Table 1. Restoration of Water and Fields layers

Compression algorithm	Semantic layers	Corrupted layers	Reconstructed layers	
			Size	Improvement
PNG	459 036	540 039	464 971	13.90 %
TIFF	192 267	406 278	194 977	52.01 %
JBIG	93 686	165 752	105 964	36.07 %
AKF2	55 148	89 218	64 427	27.79 %

Table 2. Total compression results

Compression algorithm	Semantic layers		Corrupted layers		Reconstructed layers		
	Size	Rate	Size	Rate	Size	Rate	Alleviation
PNG	2 085 871	47.94	2 149 490	46.52	2 078 254	48.11	111.97%
TIFF	1 473 824	67.85	1 708 362	58.53	1 480 657	67.53	97.09%
JBIG	684 978	145.99	790 257	126.54	720 185	138.85	66.56%
AKF2	624 117	160.22	696 017	143.67	660 661	151.36	49.17%

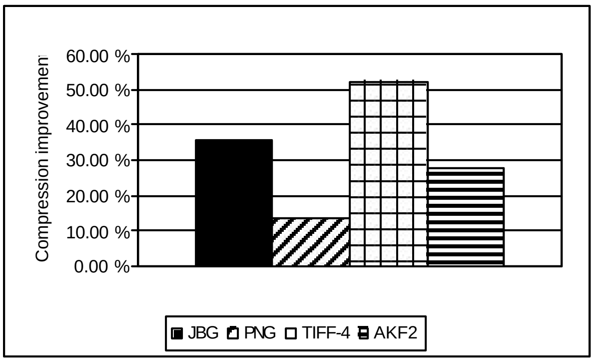


Figure 9. Compression improvement obtained by the restoration of Water and Fields layers

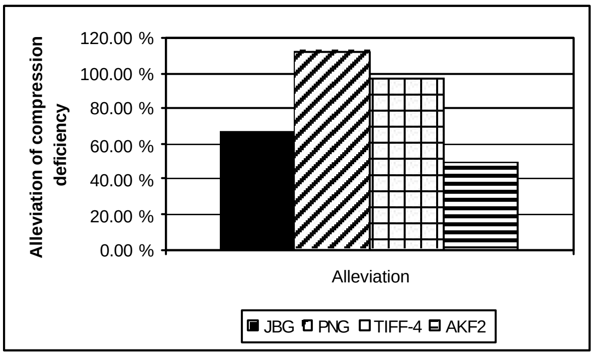


Figure 10. Compared alleviations of compression deficiency presented by restoration algorithm

5 Conclusion

We proposed a technique for restoration binary semantic layers of the map images from the corruption caused by the decomposition of the image using color separation process. The technique alleviates the deficiency of compression up to 90–100% (for PNG and TIFF) or up to 40–60% for JBG and *AKF2* compression technique. It allows obtaining up to 30-50% compression improvement for standalone layers and improves the total compression rate (calculated for the sum of the layers) up to 5–10% depending on the compression method. Low total improvement rates are caused by the presence of non- or hardly restorable layers, such as *Basics* and *Elevation*. The color map image resulting from the combination of the reconstructed layers remains identical to the original because all changes to the layer content are performed only within those areas that will be certainly overlapped during the composition.

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