Change Detection Using Digital Panchromatic Aerial Photographs

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***Abstract*—The topic of change detection of different topographic features on the field using aerial images or satellite high-resolution imagery in digital format is very important for the military domain as well as for the civilian one (agriculture, forestry, natural disaster management, etc.). In this paper the authors treat some methods used for automated detection of changes on the terrain based on panchromatic aerial photographs (gray levels, 8 bits for color representation) acquired at different dates. One method is implemented in ERDAS Imagine software and the others were developed empirically by a third party. A new method for change detection is proposed by the authors, using Sobel edge detection operator, obtaining thus clearer contours of modified elements on the ground. The quality of the resulting modified elements depends very much on technical characteristics of compared images such as collection dates, atmospheric conditions during the capturing process, similarity of radiometry, spatial resolution and precise overlay, as well as the presence of clouds or shadows of topographic details on the images.**

***Index Terms*—high resolution imagery, image processing techniques, panchromatic, radiometry, Sobel operator.**

I. Introduction

Change detection presented a great interest for military and civilian users since the first aerial images were acquired, based on visual interpretation and analogue graphical presentation.

The automated detection of changed topographical features from aerial and satellite images has been an important direction of research in the field of digital photogrammetry in the last few decades, starting with the launch of Landsat-1 satellite in July 1972.

The development of hardware and software technology, data storage and processing technologies, as well as the continuously improvement of acquisition sensors technical performances influenced the evolution of digital change detection techniques.

Nowadays, comparing new with older digital images of the same area of interest is widely used in many fields of activity in order to detect and identify changes.

Thus, there are systems dedicated to military users which can automatically monitor changes on the ground which can show location of new elements like hidden explosive disposals, use of camouflage to cover possible suspicious activities, troop displacement or tracks of recent movement of vehicles.

If thermal images are used in combination with optical images, then recent human activity signatures could be detected.

Specific traces of chemical or organic materials can be identified based on their distinctive spectral reflections by using hyperspectral images, acquired by dedicated sensors.

Target identification from long distances, especially at night, is possible by using multi-spectral image fusing. Thus, to surpass the effect of visual reflection from a car windscreen in order to view persons inside a vehicle, one can combine Near IR with TV images.

According to specialized published documentation, image differencing and image ratio were the most utilized change detection techniques at the beginning of digital imagery era [1]. These methods are still very popular today, due to their simplicity and rapidity.

In the case of a series of images, rather than differencing adjacent frames in temporal image sequences, background images can be dynamically generated and these are differenced with each image instead [2,3].

Image differencing, implemented in commercial software like ERDAS Imagine and ENVI, is probably the most widely used change detection technique. Locations of change are indicated by large values of pixels in difference image, obtained by subtracting the values of corresponding pixels from each band of the two source images. The values of pixel from source images could represent radiometry or a feature index (vegetation, built-up areas, water, etc.) [4].

Another change detection method uses post-classification analysis, known as “Delta classification”. Source images are independently classified, unsupervised or supervised, and then compared. In this way, the impact of radiometric and geometric differences between source images is reduced. To reduce data dimensionality one can use a combined method based on principal component analysis (PCA) or Bayesian classifier [1].

Among linear transformation approaches, the most utilized is PCA, which reorganizes the variance in a multiband image into a new set of image bands, which are uncorrelated linear combinations of the input bands. Principal component transform finds a new set of orthogonal axes with their origin at the data mean, and it rotates them so the data variance is maximized. PCA is used in remote sensing to remove redundant spectral information from multiband datasets, to reveal complex relationships among spectral features and to identify spectral characteristics that are more prevalent in most of the bands, and those that are specific to only a few bands. Users can calculate and view statistics such as covariance, correlation, eigenvalues, and eigenvectors [5].

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Based on recent research, image differencing seems to perform better than other algorithms of change detection. For example, applications like object tracking, surveillance systems and interframe data compression use image differencing method. When comparing satellite images, this efficient technique is used to assess deforestation, land erosion, urban expansion, crop development, flooding, forest fires, etc.

In case of analyzing gray-level source images, in order to obtain a change/no-change classification, the difference image is usually transformed in binary format by using a threshold value. This value is very important and affects the quality of change detection process, since too low a value will overflow the difference image with false changes, while too high a value could eliminate relevant changes.

Due to the fact that atmospheric conditions, technical characteristics of the sensor, spatial resolution and collection season change over time, the proper value of the threshold should be calculated dynamically or user should empirically select a value. Often, in order to improve change detection, local thresholding could be used instead of global thresholding.

Change detection methods and workflows are implemented in different commercial software, like ERDAS Imagine Professional, ENVI, TerraImaging, or in dedicated software for military users.

In this article the authors propose a new method for change detection which uses Sobel edge detection operator and some image processing techniques applied to source images, like histogram matching, inversion, addition and threshold.

II. Methods Used for Change Detection

In mapping it is important to have up-to-date geospatial information, so a reliable method for automated change detection is needed. In the updating process, the most used images are obtained by using color or panchromatic optical images. For exemplification of different methods used for change detection, we will use two gray level rectified images, existing at the Defense Geospatial Information Agency of the Romanian Army (former Military Topographic Directorate). The area covered by these images is Valea Calugareasca, in Prahova County [6]. The images were acquired in May 1976 (Fig. 1) and August 2007 (Fig. 2).

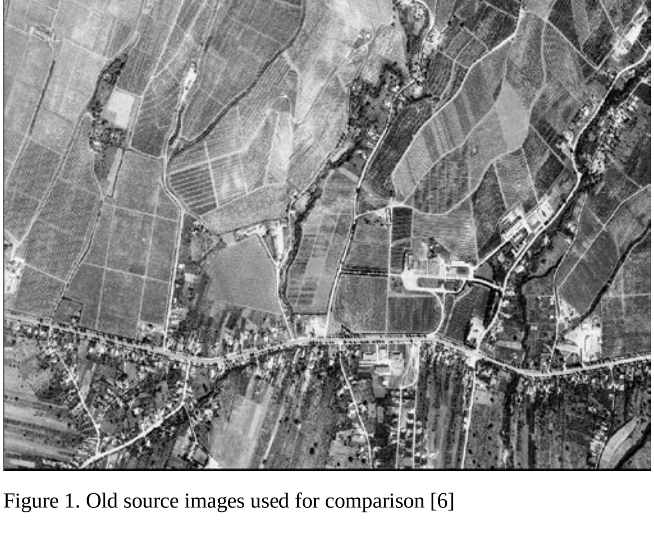

Figure 1. Old source images used for comparison [6]

The scanning resolution is 1270 dpi and these images are orthorectified at 1:30.000 scale based on ground control points and a digital elevation model in NATO standard DTED2 format [7]. The previous acronym stands for Digital Terrain Elevation Data - level 2 and the elevation model was produced by the Defense Geospatial Information Agency of the Romanian Army, for all Romanian territory in 2004.

The spatial resolution of pixels from rectified images is 0.6 m.

Figure 2. New source images used for comparison [6]

The method implemented in ERDAS Imagine software is based on images differencing [8], i.e. the older image is subtracted from the new one (Fig. 3).

Figure 3. Difference image resulted from applying change detection method implemented in ERDAS Imagine software

The difference image is then classified in five classes. The green zones are the highest values from the difference image and they usually represent changes which occurred on the ground or elements with a high reflectance. The red areas are the lowest values in the difference image and they usually represent unchanged areas or elements with a high reflectance which disappeared, as shown in the highlight image (Fig. 4).

 Digital Object Identifier 10.32754/JMT.2021.1.04

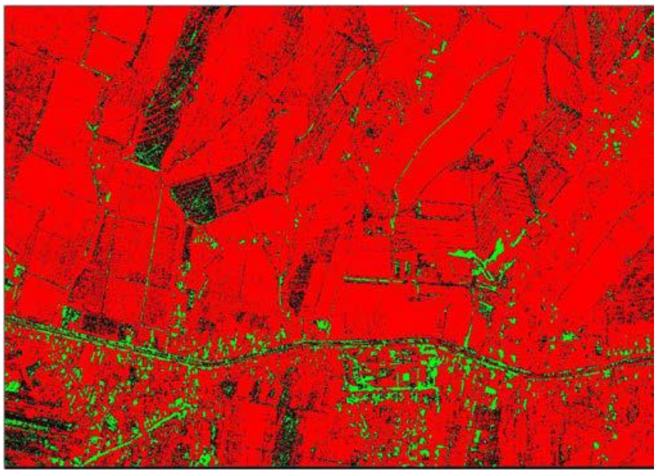

Figure 4. Highlight image resulted from applying change detection method implemented in ERDAS Imagine software image

This method offers a good indication of areas where changes occurred, but the result is not suited for data collection using automated or semi-automated procedures. In order to do this, it is necessary to have a better spatial resolution, a very precise localization for both images as well as similar periods for acquiring data (in the same season, preferable in the spring or in the autumn). Usually, there are performed some preprocessing operations in order to enhance the radiometric quality of images (histogram equalization, contrast and brightness adjustment, histogram matching).

The resulting highlighted image can be improved by using some morphological operators, like dilation, erosion, opening, closing.

Generally, common methods for change detection are based mainly on correlation of digital images, obtained at different dates, combined with other techniques for image processing.

Toderas presents two such methods which combine correlation of corresponding pixels representing the same area with radiometric operations or filtering [9]. He used these methods for detection of changes in urban areas using aerial photographs at scale 1:5000. The correlation coefficient r is described by the following relation:

$$r=\frac{\sum_{i=1}^{n} g_i q_i-\frac{1}{n}\left(\sum_{i=1}^{n} g_i\right)\left(\sum_{i=1}^{n} q_i\right)}{\sqrt{\left[\sum_{i=1}^{n} g_i^2-\frac{1}{n}\left(\sum_{i=1}^{n} g_i\right)^2\right]\left[\sum_{i=1}^{n} q_i^2-\frac{1}{n}\left(\sum_{i=1}^{n} q_i\right)^2\right]}} \tag{1}$$

where n is the number of pixels, variables g_i and q_i, $i=1,...,n$ represent the normalized grey scale values, with possible values in the range from $[-1,+1]$. When $r=0$, the variables g and q are independent or uncorrelated. A perfect or ideal correlation occurs for $r=\pm 1$ [10].

The correlation coefficient can have values close to 1 for corresponding pixels from both images and close to 0 for pixels which have no correspondent on the other image. Practically, the correlation is realized by calculating the correlation coefficient based on values of the corresponding pixels and their neighbors (for example, 3×3, 5×5 or 7×7 pixels windows). Depending on the scope of the processing, one can retain in correlated image both the correlated elements and the elements without correspondent or only one category. For example, applying a threshold of 0.7, the elements present in both images are saved in the final image. The details with a correlation value less the 0.7 have been changed.

After the identification of modified topographic elements, they must be enhanced in order to get their contours (using morphological operators like erosion, dilation, opening or closing) [11].

The first method consists of applying a correlation operation between the two images, followed by another correlation between the obsolete or the new image and the correlated image at the first step. Then a subtracting process is applied between the correlated image from the second step and the obsolete / new image. If one uses in the second and the third steps the obsolete image, one can obtain the elements which disappeared or, conversely, one can get the new elements if he or she uses the new image in the second step. Finally, one can obtain a binary image by applying a thresholding operation to the previous image. The execution flow is presented in Fig. 5.

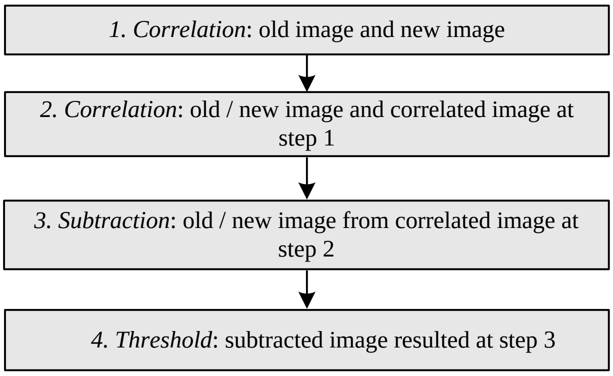

Figure 5. The flow of the first method for change detection

In order to visually compare the results obtained we extracted the same area from an older image (Fig. 6) and the new image (Fig. 7).

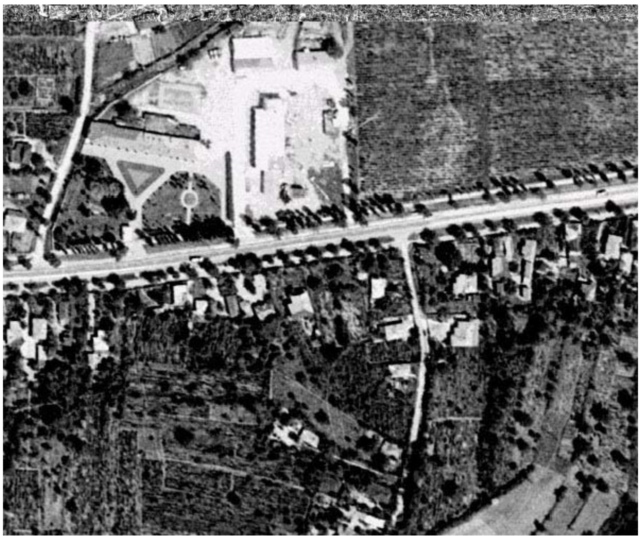

Figure 6. The extracted area from old image

The images resulted from applying the first method steps on the images from Fig. 6 and 7 are presented in Fig. 8 and Fig. 9. These images cannot be used for extracting vector data automatically because the elements are very fragmented and they have small dimensions.

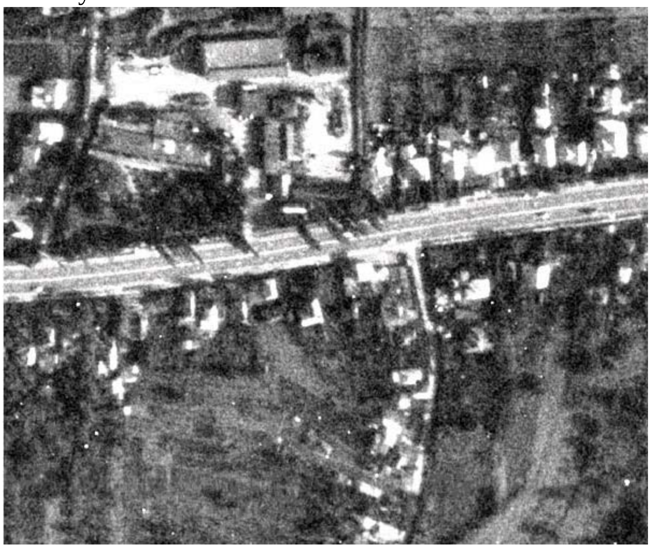

Figure 7. The extracted area new image

Visual check must be performed due to the presence of the shadow on both images. In the image from Fig. 8 the elements which have been modified (trees on the main road sides, orchards, grass lands, vineyards, buildings and, of course, shadows of different elements) are highlighted in white. In Fig. 9, there are shown in black the new elements which appeared in the same area after 31 years. We can distinguish new buildings, orchards, vineyards, the enlarged main road as well as shadows.

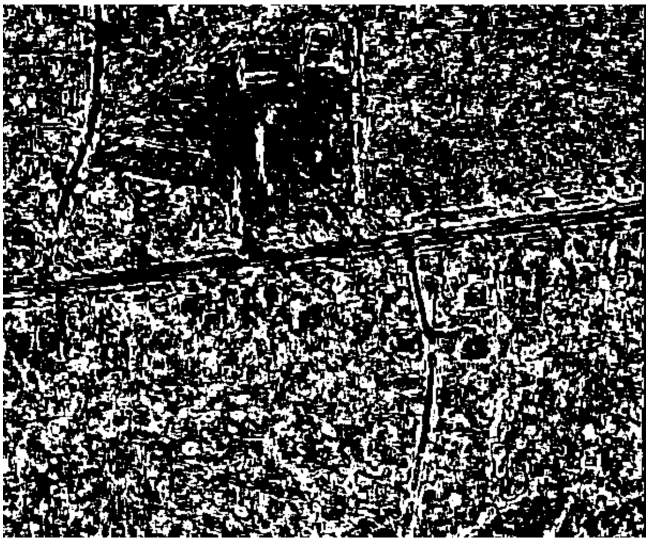

Figure 8. The resulted images depicting disappeared features in white

This method offers good results when the obsolete and new image have a good spatial resolution (better than 0.4 meters) and they overlay very precisely. It performs better for bigger scales of the aerial photographs where the topographic details are clear and have large dimensions. One way to improve this method is to mediate the values from both images before correlation, to adjust the contrast before thresholding and to use some morphological operators. However, when the shadows of the topographic elements are significant, they are detected as new or disappeared elements and the human operator must perform the photointerpretation.

Figure 9. The resulted images depicting new topographic elements (black)

The second method used by Toderas [9] involves the Roberts filtering for both images. In the second step, previously filtered images are subtracted. Next, the contrast of the resulted image is adjusted empirically, then the resulted image is inverted and, eventually, a logarithmic transformation is applied (Fig. 10).

1. Roberts filtering: old and new image

↓

2. Subtraction: filtered old image from new filtered image

↓

3. Contrast adjustement and inversion

↓

4. Logarithmic transformation

Figure 10. The flow of the second method for change detection

The relations used for Roberts operator are described by the next expressions:

$$\begin{cases} |W_1| = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}; \quad |W_2| = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \\ W = k\sqrt{W_1^2 + W_2^2},\ k > 0 \end{cases} \tag{2}$$

The difference image, resulted after the execution of the second step of this method on source images from Fig. 6 and 7, is presented in Fig. 11.

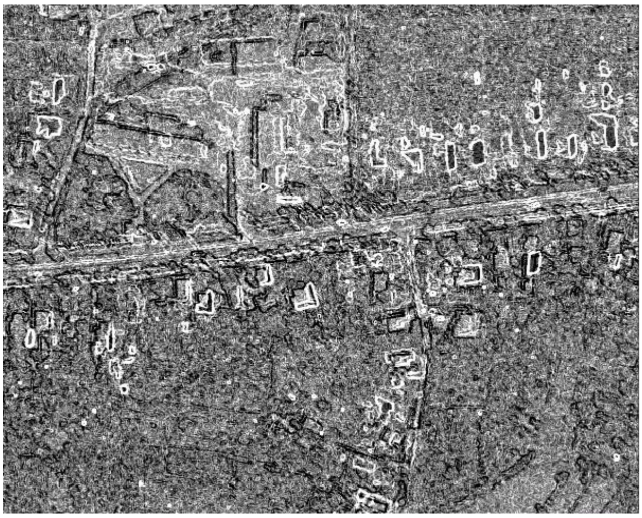

Figure 11. The difference image

 Digital Object Identifier 10.32754/JMT.2021.1.04

New elements are shown in white and they are similar to those detected using the first method, but this time they are clearer due to the fact that Roberts operator is a very powerful tool for edge detection. The features whose perimeter are black are those which disappeared. Both categories are highlighted in the Fig. 12, with the new elements (green) and the disappeared features (red).

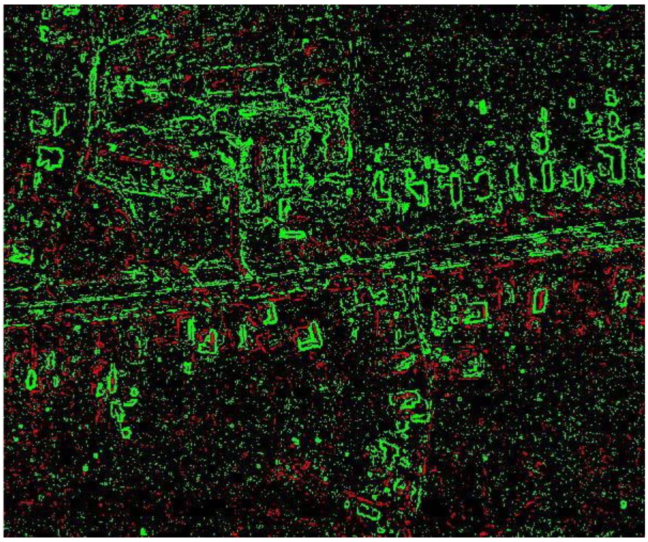

Figure 12. New features (green) and disappeared features (red)

The image on the right side can be used for semi-automated extraction of features but visual check is required due to shadows detected as new or erased topographic details.

The radiometric quality of the final image can be enhanced by using some morphological operations like erosion, dilation, opening, closing, thinning or thickening. The result is better than that obtained using the first method, mainly due to the Roberts filter which is a strong operator used for edge detection. There are other edge detection operators that can be used in this method instead of the Roberts operator, like Kirsch, Frei-Chen, Sobel, Gabor, etc.

III. METHOD PROPOSED BY AUTHORS, USING SOBEL OPERATOR

The method proposed by the authors consists of applying the following steps: histogram matching of the old image with the histogram of the new image, inversion of the old image, addition between the new image and the inverted old image followed by Sobel filtering and thresholding, as illustrated in Fig. 13.

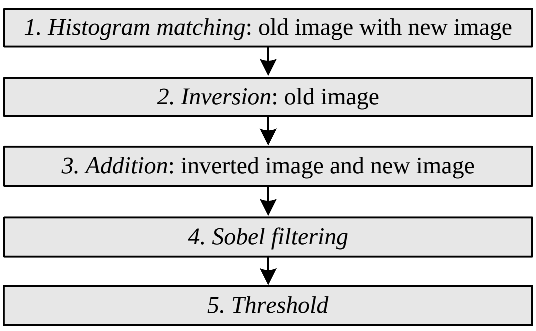

Figure 13. The flow of the method proposed by authors for change detection

Histogram matching is performed to ensure a better radiometric similarity of the two images. Some other operations, like contrast and brightness adjustment, could be used for radiometric enhancement of images. Addition of inverted image and the other original image will produce an image where the details which exist in both images will be brighter (higher values of intensities) and the details which are present just in one image will be darker (lower values of intensities). Sobel operator is used to get the contours of the features from the image obtained in the third phase of the method. Finally, a threshold value separates the necessary pixels from the filtered image.

The images obtained in the last two steps of the method presented before are represented in Fig. 14 and Fig. 15.

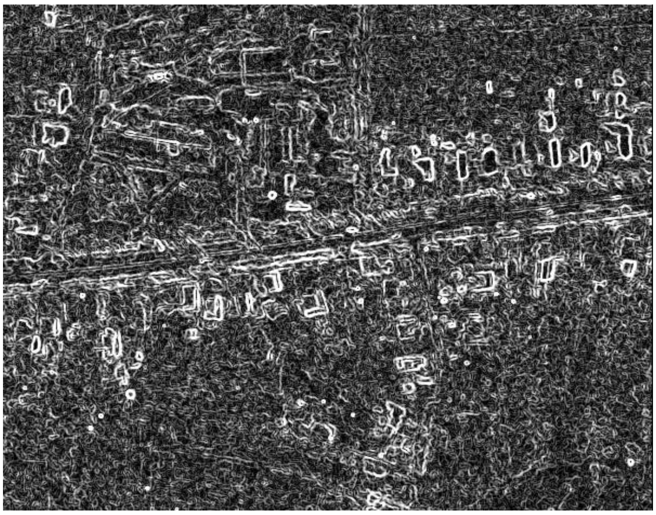

Figure 14. The image resulted after Sobel filtering

The perimeters of topographic details are very clear. The relations used for Sobel filtering are described by the following expressions:

$$\begin{cases} |W_1| = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}, \quad |W_2| = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix} \\ W = \sqrt{W_1^2 + W_2^2} \end{cases} \tag{3}$$

The idea behind using a weight value of **2** is to achieve some smoothing by giving more importance to the center point [11]. Note that the sum of coefficients in all the masks shown in relation (3) is **0**, indicating that they would give a response of **0** in an area of constant gray level, as expected of a derivative operator.

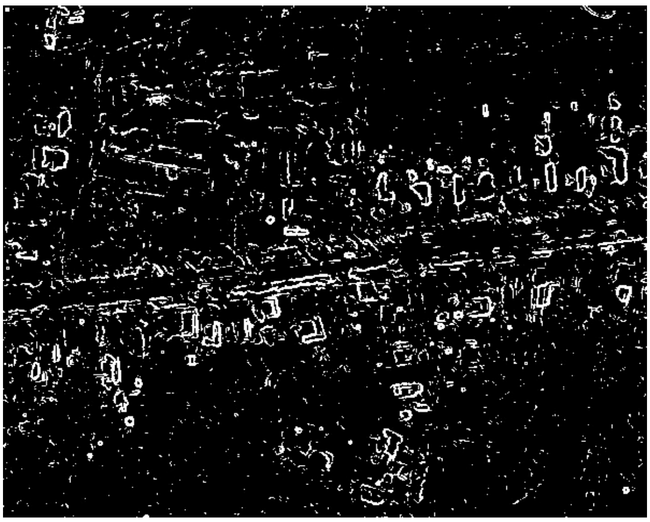

Figure 15. The image resulted after after threshold value is applied

IV. CONCLUSIONS

One application of growing importance of change detection is the ability to rapidly and efficiently map and detect changes in a given area of interest. Up-to-date and frequently revised baseline data is needed if change detection systems are to be effective. Traditionally, maintaining base maps has been highly time-consuming, costly and sometimes difficult work, especially in urban and high-density areas. Change detection can be critical in a variety of management capacities, from urban planning to forestry, but it is only effective if the data is timely and can easily be imported directly into administrative databases, existing digital maps, GIS or response models.

In order to use automated change detection in mapping process it is important to rely on very high-resolution data, taken in similar seasons. But, the most restrictive factor in automation of change detection process is the presence of shadows. Practically, shadows will exist on all aerial photographs, so the researchers are focused on the reconstruction of scene from Earth using a high-accuracy digital surface model and taking into consideration the physical factors (illumination, Sun's altitude, etc.) from the moment when photographs are taken. In this way shadows for both aerial photographs to be compared can be obtained by using specialized software and can be extracted from images. Furthermore, it is also necessary to execute histogram matching and some operations for radiometric enhancement. Finally, different methods for change detection can be implemented and used in order to detect the changes. The final image is used to extract vector data in a semi-automatic or automatic way. However, the human factor is always required for a visual checking of the results.

The result obtained using the first method proposed by Toderas is not satisfactory for rectified images at 1:30.000 scale and the 0.6 meters spatial resolution. This method works better for bigger scales [9]. Another reason is the correlation process. At this scale, the elements are fragmented and the correlation coefficient is not robust.

The second method proposed by Toderas performs better at this scale, mainly due to the strong edge detection Roberts operator. In the right image from Fig. 12 we can distinguish clearly the changed elements on the field. Morphological operations are needed for smoothing and / or sharpening the final image.

Due to the fact that the third method uses the Sobel operator, another strong edge detection operator, the contours of modified details are clearer, as shown in output image (Fig. 15). One minor disadvantage of this method is that after obtaining the modified elements, we have to visually check which are new and which have disappeared.

The method proposed by the authors could be implemented in software tools and used for automated detection of modified elements. Then, the output image could be used for semi-automatic or automatic extraction of elements from high resolution aerial or satellite images, with some limitations, mainly due to shadows of natural or artificial big objects.

Future work in the field would have to take into consideration the development of the method proposed by the authors, by combining edge operators with correlation technique or principal component analysis, in order to use multispectral images as input image sources.

ACKNOWLEDGMENT

The authors gratefully thank to the reviewers for their support and valuable comments, which helped to improve this article.

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