Methods for improving contrast of agricultural images

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Abstract. In recent years, there has been a sharp increase in interest in using satellite imagery in agriculture. These images are useful for monitoring crops, analyzing soil conditions, and identifying potential machine problems. However, the quality of these images can vary greatly depending on factors such as weather conditions, time of day, and the type of satellite used. One common problem with images, in general, is poor contrast or lack of contrast, which can make it difficult to identify objects such as crops or machinery. This work is devoted to methods of contrast enhancement and evaluation criteria used to improve the quality of agricultural images obtained from satellites and unmanned aerial vehicles, as well as the selection of the optimal pair of criteria and methods.

1 Introduction

Currently, monitoring technologies are widely used in almost all areas of agricultural activity. In particular, based on images obtained using space or unmanned vehicles, many tasks can be effectively solved, such as inverting agricultural land, monitoring the state of crops, determining the state of waste of land resources, and identifying threats to crops. Despite numerous advantages, the use of such technologies is not without drawbacks. For example, obtaining quality data depends on the weather, insufficient image contrast, etc. In addition, the low quality of satellite images compared to images obtained from unmanned aerial vehicles also causes various problems in image processing and recognition.

The results obtained in the test areas are recommended to be considered when processing images taken from a long distance. Typically, images obtained from such locations are compared with the field survey results. The results obtained allow us to improve the processing algorithms to further improve the measurement and prediction of quantitative indicators.

Drones usually have cameras that capture images based on the RGB model. Modern agricultural drones are equipped with temperature sensors. This type of image allows you to identify damaged or dead cultures. Special drones also work with thermal and RGB models,

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but they are more expensive.

Satellite images are of relatively poor quality but sufficient for monitoring crops. If accuracy and detail of data are required, then it is recommended to use high-quality satellite images. In some cases, satellite and drone images can complement each other. For example, a problem area can be identified by satellite and analyzed in detail based on drone images. We must not forget about the problems of storing, processing, and recognizing large images.

Satellite images are increasingly being used to optimize agricultural production [1]. Since the launch of the first Landsat satellite in 1972, agricultural monitoring has been introduced and improved worldwide [2]. Satellite imagery is becoming an increasingly important tool in today's agriculture, allowing farmers to quickly provide valuable information about crop health, soil conditions, and machine performance. However, the quality of satellite images can be affected by some factors, such as atmospheric conditions and time of day. This complicates the process of identifying important features of images. One of the main problems is low contrast, which can affect the visibility of crops and machinery. Some of these problems can be solved by using contrast enhancement techniques to improve the quality of agricultural satellite images. Many studies have proposed methods and algorithms for enhancing contrast [3]. This article discusses the most effective methods of contrast enhancement, including histogram smoothing, contrast stretching, and adaptive contrast-limited histogram smoothing, methods of morphological contrast enhancement algorithm. Farmers and agricultural researchers can use these methods to obtain more accurate and useful images for their research than satellite imagery. Usually, pre-processing steps are carried out before image recognition. Image pre-processing is used to deliver a quality image to the next step and is performed in the following steps:

1. Reading and downloading an image. In this case, the image is captured and sent to an image processing or recognition program.
2. Filtering [4-5]. This includes decluttering, smoothing, contrast enhancement, and color adjustments.
3. Image normalization [6]. This includes rotating the image to the right angle and resizing the image to the right size.
4. Segmentation [7-8]. This is where the objects in the images are highlighted.
5. Formation of features [9]. In this case, a set of features is formed that ensures the originality of the image, and a set of informative features is determined [10-21].
6. Recognition [22]. Recognition is carried out based on the formed informative features.

One of the main actions in pre-processing is to increase the contrast of an image, which is one of the main parameters that determine the quality of an image. Contrast is a property of gradation based on the difference in brightness between the brightest and darkest areas of a black-and-white or color image [23]. A high-contrast image will have a wide range of pixel brightness, while a low-contrast image will have a narrow range of pixel brightness. In agricultural mechanization, image contrast assessment is critical to ensure image analysis and interpretation accuracy and reliability. The following are some of the methods and algorithms that can be used to evaluate the contrast of agricultural images. Subjective and objective methods widely used in image contrast assessment are considered separately.

1.1 Formulation of the problem

The quality of satellite images can vary greatly depending on factors such as weather conditions, time of day, and the type of satellite used. One common problem with such images is low contrast, making identifying features such as crops or machinery difficult.

Therefore, improving the quality of agricultural images received from satellites is necessary, including increasing their contrast.

2 Methods and algorithms

Visual evaluation. Visual evaluation is the visual perception of the difference between light and dark areas of an image [24]. This method is a subjective method that involves visually inspecting images and determining the level of contrast based on personal judgment. Visual evaluation is typically used when a quick evaluation of the contrast of an image is required. However, this method is subjective and more error-prone due to differences in individual perception.
Histogram analysis. Histogram analysis is an objective method used to evaluate the contrast of an image. It involves analyzing the intensity distribution of pixels in an image and determining the level of contrast based on the distribution. A high-contrast image will have a wide histogram distribution, while a low-contrast image will typically have a narrowly distributed histogram. Histogram analysis is used in image processing algorithms to automatically adjust image contrast.
Estimating image contrast in numerical terms is a widely used and objective method for evaluating image quality in the analysis and interpretation of agricultural images. Several methods are commonly used to estimate the contrast of an image in numerical terms.
Weber contrast. The Weber contrast is calculated by the following expression:

$$K_v = \frac{I - I_b}{I_b}$$

where I and I_b are, respectively, the contrast of the object and the background.
The Weber contrast is also called the Weber ratio, and it is useful when there is a small object against an equally large background, that is when the average brightness is approximately equal to the background brightness.
Michelson contrast. It is determined by dividing the difference between the maximum and minimum pixel brightness values by their sum, i.e.

$$K = \frac{m_{\max} - m_{\min}}{m_{\max} + m_{\min}},$$

where $m_{\max}$ and $m_{\min}$ are, respectively, the maximum and minimum brightness of the image; $K-$ image contrast [25].
RMS. It is a measure widely used in evaluating the contrast of any image and is defined as follows:

$$C = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(I_i - \bar{I}\right)^2},$$

where $\bar{I} = \frac{1}{n}\sum_{i=1}^{n} I_i$, I_i is brightness of i-pixel [26].

RMS is a widely used objective method for evaluating, analyzing, and interpreting image contrast in numerical terms. This method can obtain high-quality images suitable for analysis and interpretation. This leads to improved prediction of the condition of crops and improved management.

Image quality evaluation indicators. When evaluating image quality in numerical terms, three metrics are widely used, called Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE), and Structural Similarity Index (SSIM), which depend on the ratio between contrast and original image. To assess the effectiveness of improving image quality, the contrast-modified image and the original image are compared by these three indicators [27].

Peak signal-to-noise ratio (PSNR). PSNR is a measure of the quality of an image compared to the original, and the larger the value, the better the image quality. The PSNR value is calculated using the formula:

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) = 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right)$$

where MAX_I is the maximum pixel value of the image and MSE is the root mean square error between the contrast image and the original image.

Structure similarity (SSIM). SSIM is a measure of similarity between two images; the larger its value, the more similar these images are considered [28].

The above metrics are commonly used to evaluate image quality and quantify the performance of various algorithms.

Several methods can be used to enhance contrast, such as histogram smoothing, contrast stretching, and adaptive contrast-limiting histogram smoothing, and morphological contrast enhancement algorithm. Using these methods, it is possible to improve the accuracy and reliability of satellite images of the agricultural sector.

Histogram smoothing algorithm. This algorithm improves image quality by improving a distorted image [29] and redistributes pixel values in an image to evenly distribute the histogram. This method effectively increases or decreases contrast in low-contrast or high-contrast images. However, this method may result in an overly contrasting image. The histogram smoothing method is widely used to improve image quality [30].

Contrast-limited adaptive histogram equalization (CLAHE) algorithm. To date, many methods for improving image quality based on image histogram replacement have been developed, among which the CLAHE algorithm is the most widely used and most effective. This algorithm is widely used in image processing such as underwater, X-ray, and over- or under-exposed images, and its implementation takes some time, which limits its application in real-time reporting areas. However, several modifications have been developed to meet the requirements of real-time mode. CLAHE is a more advanced method that can enhance the contrast of unevenly lit images. In the CLAHE algorithm, the input image is divided into several small blocks that do not overlap each other, and a histogram is formed in each small block. It redistributes the histograms to avoid over-amplification. In addition, bilinear interpolation is performed between adjacent subblock mapping functions to avoid block artifacts [31].

Contrast stretching algorithm. Contrast stretching is another technique that can increase the contrast of agricultural images. This method involves stretching the histogram of the image. In this case, the smallest pixel value will be converted to black and the largest value to white. This is useful for enhancing the contrast of images with a narrow range of pixel values.

Algorithm for enhancing morphological contrast. This algorithm is a technique used in image processing to improve the appearance of image details, and it uses morphological filters to change the shape and size of objects in an image while maintaining the overall structure [32].

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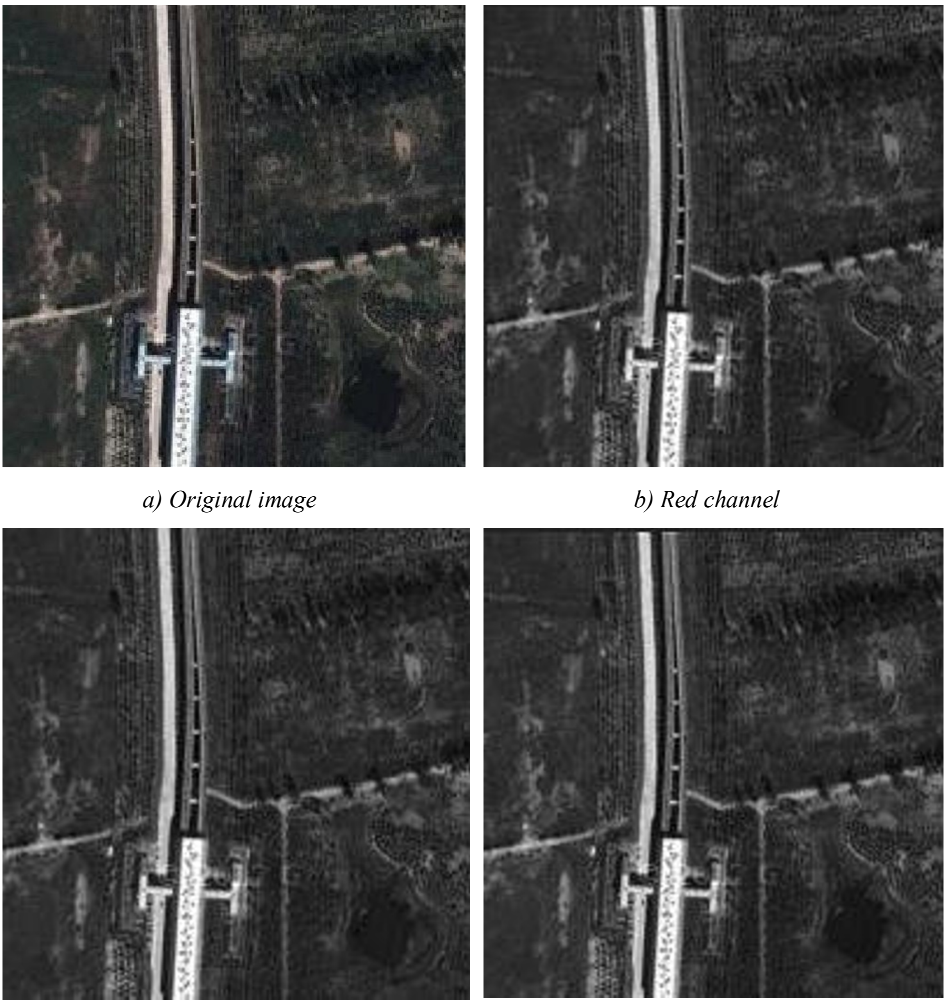
3 Results and discussions

Below is a computational experiment of various popular algorithms to evaluate image quality by increasing contrast. The experiment used a sample of 128 satellite images. Since the resulting images are in color, they were divided into color channels, i.e., red, green, and blue color channels, and contrast enhancement algorithms were applied to each color channel. By combining the resulting images, the final color image is created. An example of the result of dividing a color image into channels is shown in Figure 1.

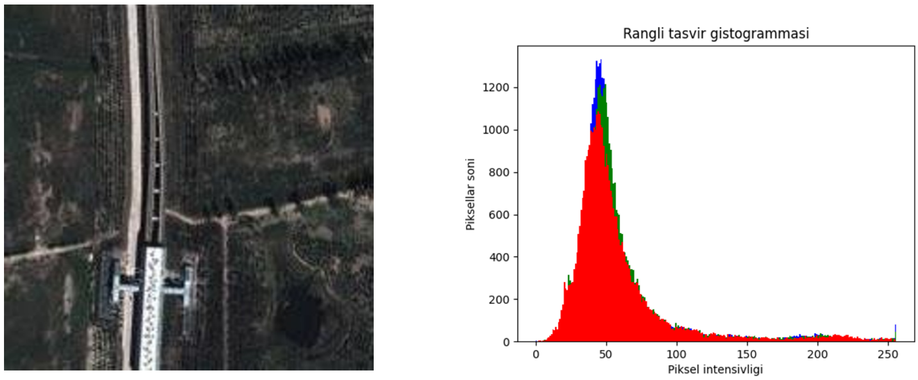


a) Original image *b) Red channel*

c) Green channel *d) Blue channel*

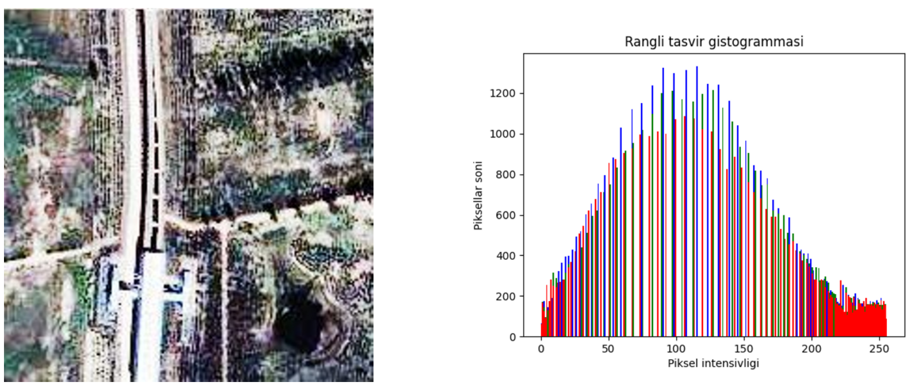
Fig. 1. Result of dividing color image into color channels

All sample images were created with a contrast-enhanced image using the image contrast enhancement algorithms described above. Images after applying contrast enhancement algorithms and their histogram are shown in Figures 2-6 (a-b).



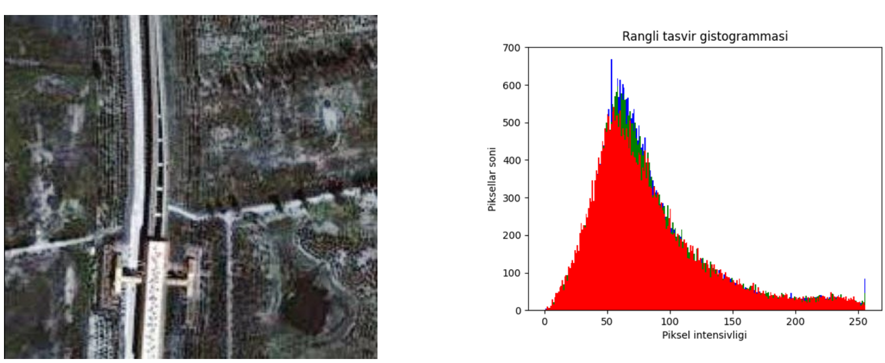
a) *b)*

Fig. 2. Original image and its histogram



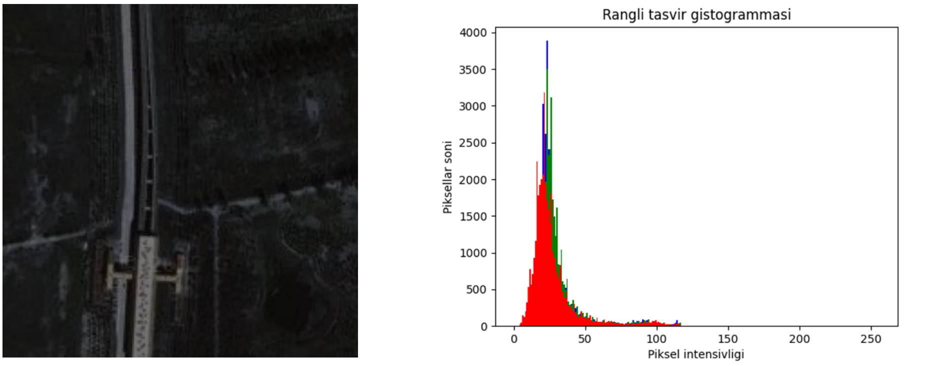
a) *b)*

Fig. 3. Image obtained as result of applying histogram smoothing algorithm and its histogram



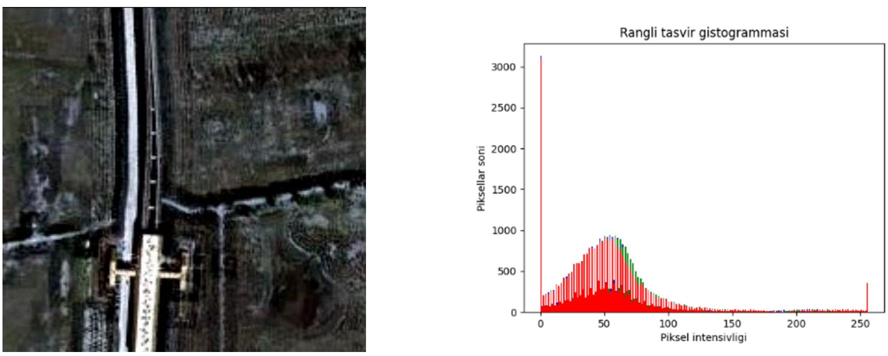
a) *b)*

Fig. 4. Image obtained using Contrast-limited adaptive histogram equalization (CLAHE) algorithm and its histogram



a) *b)*

Fig. 5. Image obtained using contrast stretching algorithm and its histogram



a) *b)*

Fig. 6. Image obtained as result of applying morphological contrast enhancement algorithm and its histogram

The results of image quality estimation according to the SSIM, PSNR, and MSE criteria using the contrast enhancement algorithms described above on the obtained sample set of images are presented in the following table.

Table 1. SSIM indicators of contrast enhancement algorithms

Histogram Smoothing Algorithm	Contrast-limited adaptive histogram equalization (CLAHE) algorithm	Contrast Stretch	Morphological Contrast Enhancement Algorithm	Algorithm number with highest SSIM value
0.3757	0.8391	0.6499	0.7452	2
0.3479	0.7950	0.7368	0.7200	2
0.5073	0.7670	0.7346	0.8456	4
0.3672	0.7655	0.6466	0.7841	4
0.3760	0.7714	0.6753	0.7247	2
0.3981	0.7639	0.7229	0.7765	4
0.4671	0.7913	0.6552	0.7905	2
0.4196	0.8171	0.8094	0.7629	2
0.3014	0.7900	0.7877	0.6790	2
0.2866	0.7821	0.7319	0.8108	4
…….	…….	…….	…….	

The SSIM scores were as follows: out of 128 images, none in Algorithm 1, 47 in Algorithm 2, 29 in Algorithm 3, and 52 in Algorithm 4 produced the highest SSIM values. Based on the results presented in Table 1, Algorithm 4 can be recognized as the best algorithm for this indicator.

Table 2. PSNR indicators of contrast enhancement algorithms

Histogram Smoothing Algorithm	Contrast-limited adaptive histogram equalization (CLAHE) algorithm	Contrast Stretch	Morphological Contrast Enhancement Algorithm	Algorithm number with highest SSIM value
28.0464	28.8566	27.9235	28.0729	2
27.4229	27.4167	26.9142	27.2424	1
27.3537	27.9187	28.6059	27.6260	3
28.0345	28.0653	27.4350	28.6973	4
28.5141	28.1791	27.7832	28.5761	4
26.7712	27.0146	28.6491	26.6175	3
27.3768	28.2950	29.3693	28.1151	3
27.5060	28.6863	27.2967	27.6611	2
25.0170	25.0472	25.8753	25.0695	3
27.8533	28.3406	27.6394	28.2189	2
27.8451	29.0914	27.2321	27.9727	2
26.8839	27.7973	25.6032	25.7233	2
24.6711	25.5463	25.6560	24.9915	3
27.9974	28.3978	27.5691	27.6888	2
……	……..	…….	…….	……..

Table 2 shows the values of the PSNR index of image quality assessment obtained using histogram smoothing, adaptive contrast-limited histogram smoothing, contrast stretching algorithm, and morphological contrast enhancement for basic images presented in [30]. In terms of PSNR, the following results were obtained: out of 128 images, the highest values were obtained by the PSNR index of 9 images in Algorithm 1, 36 in Algorithm 2, 74 in Algorithm 3, and 9 in Algorithm 4. Based on the results presented in Table 2, Algorithm 3 can be recognized as the best algorithm in this indicator.

Table 3. MSE indicators of contrast enhancement algorithms

Histogram Smoothing Algorithm	Contrast-limited adaptive histogram equalization (CLAHE) algorithm	Contrast Stretch	Morphological Contrast Enhancement Algorithm	Algorithm number with highest SSIM value
28.0464	28.8566	27.9235	28.0729	3
27.4229	27.4167	26.9142	27.2424	3
27.3537	27.9187	28.6059	27.6260	1
28.0345	28.0653	27.4350	28.6973	3
28.5141	28.1791	27.7832	28.5761	3
26.7712	27.0146	28.6491	26.6175	4
27.3768	28.2950	29.3693	28.1151	1
27.5060	28.6863	27.2967	27.6611	3
25.0170	25.0472	25.8753	25.0695	1
27.8533	28.3406	27.6394	28.2189	3
27.8451	29.0914	27.2321	27.9727	3
26.8839	27.7973	25.6032	25.7233	3
24.6711	25.5463	25.6560	24.9915	1
27.9974	28.3978	27.5691	27.6888	3
…….	…….	…….	…….	

Table 3 shows the MSE values of the image quality assessment obtained using histogram smoothing, contrast-limited adaptive histogram smoothing, contrast stretching algorithm, and morphological contrast enhancement for basic images presented in [30]. The lower the MSE value, the better the image quality. For the MSE index, the following results were obtained: out of 128 images, the MSE index of 40 images in Algorithm 1, 21 in Algorithm 2, 22 in Algorithm 3 and 45 in Algorithm 4 gave the highest values. Based on the results presented in Table 3, Algorithm 4 can be recognized as the best algorithm in this indicator.

4 Conclusions

It has been determined that the quality of agricultural images obtained from satellites can be significantly improved using contrast enhancement algorithms. Using techniques such as histogram smoothing, contrast stretching, and adaptive contrast-limiting histogram smoothing provides a better representation of valuable information about crops, soil health, and crop health. Using contrast enhancement techniques, farmers and agricultural researchers can obtain sharper and more useful satellite images that help optimize agricultural operations, increase yields and increase overall productivity.

In the work using the SIRI_WHU satellite imagery database in tif format, the quality of images obtained by changing the image contrast by four algorithms was evaluated using three indicators SSIM, PSNR, and MSE. Based on the results of the calculation experiment obtained above, the following conclusion can be drawn:

- that the morphological contrast enhancement algorithm is the most optimal for the used set of images in terms of improving the quality of images in it;
- from the general image quality evaluation scores, it was found that the MSE and morphological contrast enhancement algorithm pair, the SSIM score, and the morphological contrast enhancement algorithm pair gave good results in image quality evaluation.

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