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Adaptive Image Enhancement Model for the Robot Vision System

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***Abstract*. Robotics is one of the important trends in the current development of science and technology. Most modern robots and drones have their own vision system, including a video camera, which they use to take digital photos and video streams. These data are used to analyze the situation in the robot's camera field of view, as well as to determine a real-time robot's behavior algorithm. In this regard, the novelty of the paper is special polynomial mathematical model and method for adaptive gradational correction of a digital image. The proposed model and method make it possible to independently adjust to brightness scales and image formats and optimally perform gradational image correction in various lighting conditions. Thus, ensuring the efficiency of the entire subsequent cycle of image analysis in the robot's vision system. In addition, the paper presents the results of numerous experiments of such gradational correction for images of various classes, as well as conditions of reduced and increased levels of illumination of the field of view objects. Conclusions and recommendations are given regarding the practical application of the proposed model and method.**

Keywords: Digital Image, robotics, robot vision system, image enhancement, gradational correction.

I. INTRODUCTION

The number of different robots and drones that we already see at the operational stage, as well as those still in development, is simply amazing [1, 2]. Most of these robots (and drones) are equipped with a video camera and their own vision system [3-5], so that the robot can independently monitor and analyze the situation according to specified algorithms in offline mode [6].

For example, in [7] a new method for improving the input image is presented, which is based on the use of Retinex. This solution is used for robotic capture of an underwater surveillance system.

The publication [8] presents an algorithm for controlling the operation of a robot with feedback, which is based on real-time segmentation and estimation of the width of the roadway.

The paper [9] presents the results of solving the localization problem for a mobile robot. The paper proposes a new localization system that combines the use of machine vision and lidar in its work, moreover, for conditions of significant occlusion.

The publication [10] presents the results of research and proposes a new algorithm for controlling the movement of a robot based on the use of machine vision to solve the problem of self-localization. The event and deadline-based algorithm largely avoids delays in the robot control loop.

The paper [11] presents the results of a study of a complex robotic system for gesture recognition.

The work [12] presents improved algorithms for implementing the capture function by a robot, based on the use of a machine vision system, which is relevant for intelligent robots that perform complex manipulations.

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A separate class of works is devoted to the development and improvement of UAV vision systems in terms of improving the efficiency of their work in offline mode [13-15].

In general, if we talk about mobile robots, the analysis of the current state of the issue shows that special attention is paid to the development and improvement of automatic image enhancement algorithms. Since the efficiency of the entire cycle of image analysis of autonomous robots depends on the efficiency of these algorithms [16-18].

In this regard, the aim of the paper is to present a mathematical model and an algorithm for adaptive gradational correction of a digital image, as well as the results of experiments for various classes of objects and conditions for obtaining images. The value of the model and the algorithm lies in the fact that they are automatically adjusted to the brightness scale and image format and carry out gradation correction of the image in automatic mode.

In addition to robotics, an effective solution to the problem of automatically improving the quality of a digital image is important for image search services that operate autonomously or as part of image storage management systems [19–21].

II. MODELS, METHODS AND MATERIALS

The key requirement for the model and method of gradation correction of the machine vision system of an autonomous robot is that such a model (and method) should automatically adjust to the initial data. First of all, on the image brightness scale, which can vary over a wide range.

In addition, the gradation correction model should be flexible enough to provide both linear and non-linear image brightness transformation depending on the requirements of the applied task.

Currently, the main models that are used for such purposes are linear, exponential and logarithmic models. The linear model is not flexible enough, while the exponential and logarithmic models are often too harsh.

Considering these aspects, a power-law model of gradation image correction is proposed, which allows to smooth out these shortcomings.

Such a power-law model in a unified form has the form

$$h_\gamma(x) = \frac{d-c}{(b-a)^\gamma} \cdot (x-a)^\gamma + c. \tag{1}$$

where:

- x - input brightness value.
- γ - degree exponent.
- h_γ - output brightness value.
- $[a, \dots, b]$ - the input brightness range.
- $[c, \dots, d]$ - the output brightness range.

This function was obtained in the course of transformations from the basic representation of a power function of the form

$$y(x) = k \cdot x^\gamma, \gamma > 0, \tag{2}$$

by substitution of coefficients a, b, c, d, where

- $[a, \dots, b]$ - the input brightness range.
- $[c, \dots, d]$ - the output brightness range.
- k - normalization coefficient.
- γ - degree exponent.

In doing so, the following conditions were met: coefficient k is determined from the condition $y(b) = d, y(a) = c$.

The proposed power-law model is shown in Fig. 1.

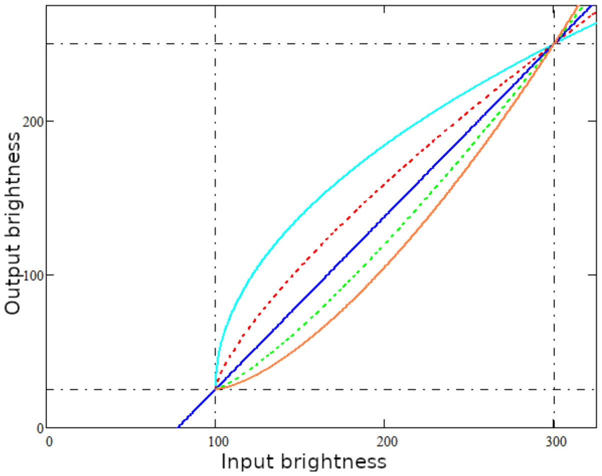


Fig. 1. A family of power-law gradation correction functions that are built with a step of 0.25 ($\gamma = 0.5, 0.75, 1, 1.25, 1.5$) for brightness values: $a = 100, b = 300, c = 25, d = 250$; the x-axis represents the brightness of the input image, and the y- axis represents the brightness of the output image.

With an increase in the exponent greater than one, model (1) becomes similar to an exponential. Such a model serves to significantly enhance the brighter part of the spectrum and suppress its darker part. When we decrease the exponent below one, model (1) becomes similar to a logarithm. Such a model serves to significantly enhance the darker part of the spectrum and suppress its lighter part. When the value of the $\gamma = 1$ we get the classical linear function of the proportional change in the brightness of the image. Thus, depending on the requirements of the task, one can very flexibly tune the model (1). The model automatically adjusts to the brightness level of images when used (due to parameters a, b, c, d).

Consider the method of applying the model (1).

At the first stage (when the model parameters are determined), for a given brightness range of the input and output images, we once, using model (1), construct a tabular function $f(x)$ (row matrix) for converting the input brightness to the output. In order not to perform these time-consuming repetitive calculations in the gradation image correction cycle.

Then, using the $f(x)$ table, we quickly change the brightness of the input image to the corresponding output values.

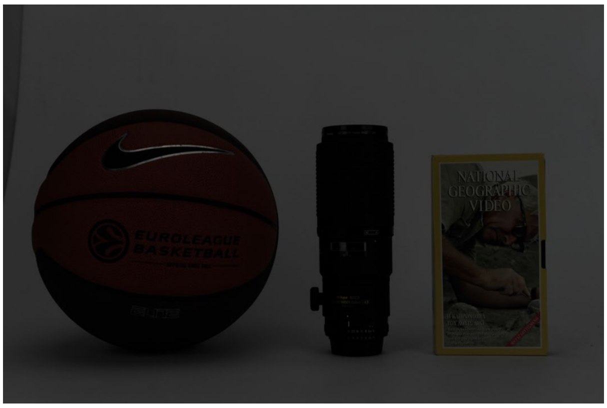
The complexity of the method is determined by the linear estimate $O(n)$, since in the body of the tonal correction cycle only one operation of changing the brightness of the form $x[i,j] = f(x[i,j])$ will be performed.

The efficiency of the gradation correction method can be increased many times over by pre-trimming the tails of the brightness histogram of the original image. If you build a brightness histogram of the original image, it has tails, represented by a series of low frequency values. If they are reset to zero and new extreme values a, b are found with a non-zero frequency, when performing gradation correction, the level of image contrast will increase significantly.

III. EXPERIMENT

For the experiment several datasets were used. First [22] contains dark photos, taken outdoors. They vary in size, scene, and objects that are depicted on them. This dataset was chosen due to a big variety of scenes and light conditions, this helps a lot when testing of image enhancement algorithms is needed. A variety of depicted objects help for cases, when different recognition algorithms should use these images for object recognition, after enhancing by our algorithm. Also using of photos help, because these images are not perfect in terms of scene setup, so they are close to real life applications, then the laboratory images. Second dataset [23] contains indoor photos of different objects. Objects varying, as well as lighting conditions. This dataset is useful for research of how the different lighting conditions affect the perception of different objects. Also having the same objects in different lighting conditions helps to verify the work of enhancement algorithm. During the experiment we used power-law gradation correction to enhance images. The best correction was chosen by an expert.

Starting with the first image of the basketball ball, camera lens and the book Fig. 2. These objects contain valuable details, like text, which is readable only after image correction.



a)

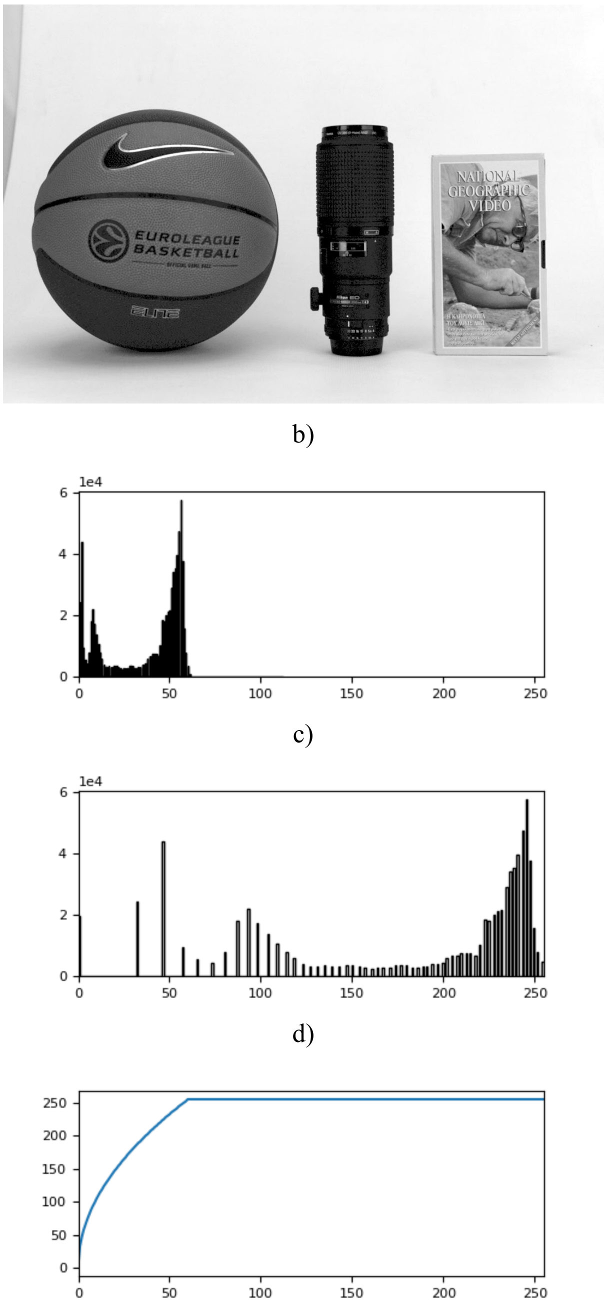
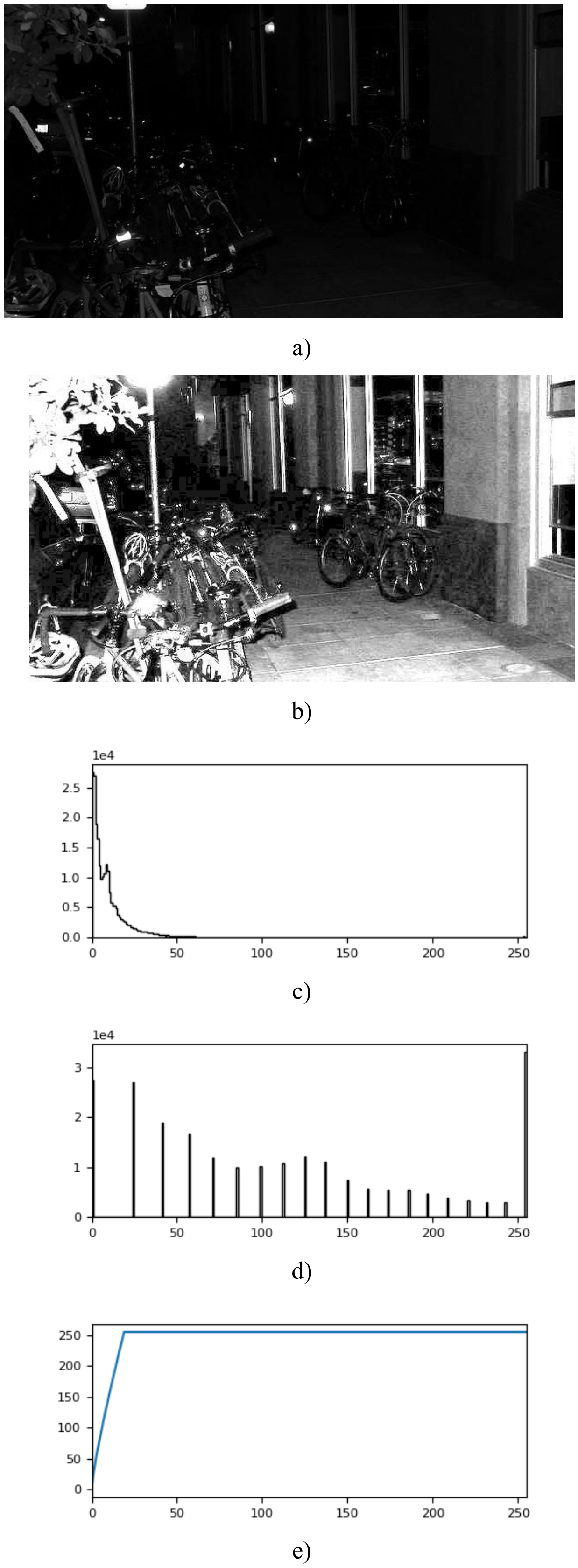


Fig. 2. Image of a basketball ball, camera lens and a book (a)[23], its brightness histogram (c). Improved image (b) and its brightness histogram (d). The scale of the change in the brightness is: 1 division corresponds to the value 10^4. Image transformation function (e) x-axis represents the brightness of the input image, and the y- axis represents the brightness of the output image.

Next image on Fig. 3 is a photo of a night street, it is barely possible to see if there are any objects in this photo. After correction we can observe that there are a lot of objects on the way.



a)

b)

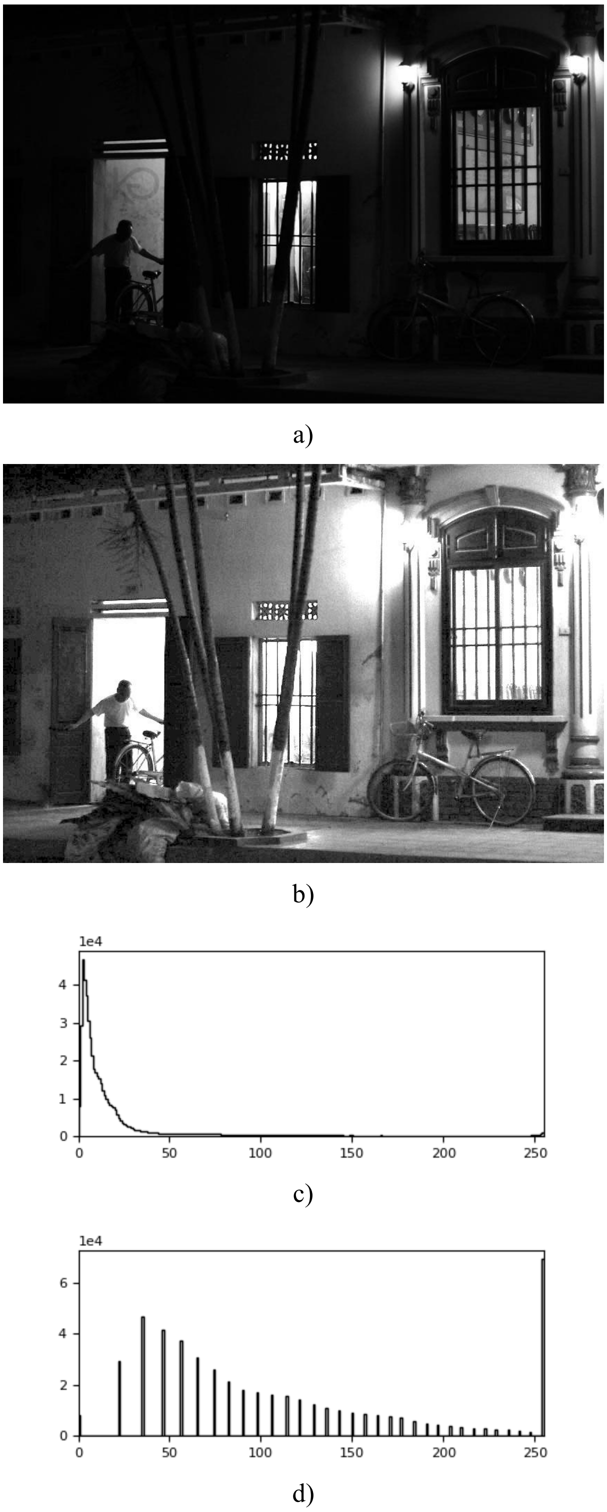
c)

d)

e)

Fig. 3. Photo of a night street (a)[22], its brightness histogram (c). Improved image (b) and its brightness histogram (d). The scale of the change in the brightness is: 1 division corresponds to the value 10^4. Image transformation function (e) x-axis represents the brightness of the input image, and the y- axis represents the brightness of the output image.

Very similar to Fig. 3 is Fig. 4. This is a photo of a house. As on previous image, in this photo it is not possible to see if there are any additional objects near the building. So, this is issue, in situation, when we need to be aware of any obstacles. Gradation correction easily fixes this issue, and it is possible to state that after correction bicycle under the window and trees are firmly visible.

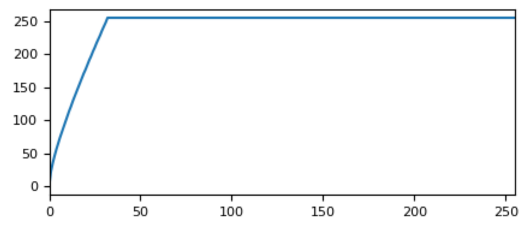


a)

b)

c)

d)

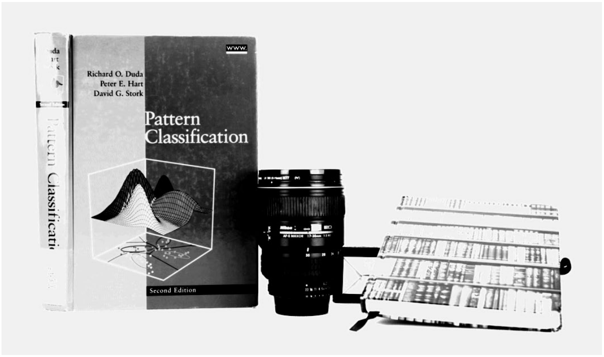


e)

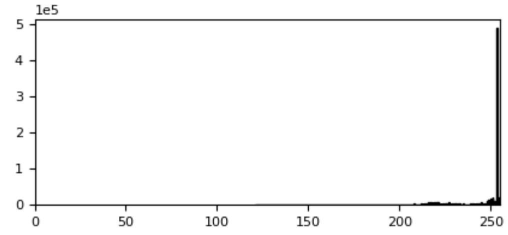
Fig. 4. Photo of night house (a)[22], its brightness histogram (c). Improved image (b) and its brightness histogram (d). The scale of the change in the brightness is: 1 division corresponds to the value 10^4. Image transformation function (e) x-axis represents the brightness of the input image, and the y- axis represents the brightness of the output image.

The final example is an overexposed photo Fig. 5. Too much light is also not a good lighting condition. In this photo text is not readable, and pattern and size of the notebook is not visible. Our algorithm can handle this situation too. Please note how the transformation function for the overexposed image on Fig. 5(e) changed. Input range is shifted to the right of the x-axis.

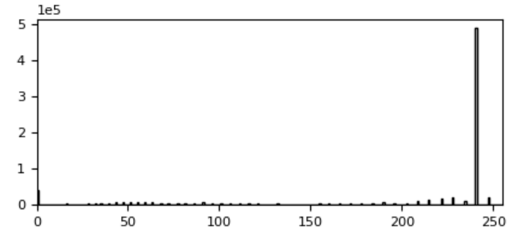
a)



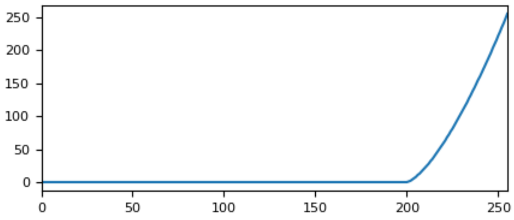
b)



c)



d)



e)

Fig. 5. Image of a book, camera lens and notebook (a)[23], its brightness histogram (c). Improved image (b) and its brightness histogram (d). The scale of the change in the brightness is: 1 division corresponds to the value 10^4. Image transformation function (e) x-axis represents the brightness of the input image, and the y- axis represents the brightness of the output image.

In the course of work on the article, a large series of 200 experiments was carried out. Half of the images for the experiments were selected from the considered dataset by experts. These are the 100 most distorted images according to experts. The second half was chosen at random. This image selection refer to first dataset [22], because there are more images. And all images from the second dataset [23] where used for conducting experiments.

Test software is written using Python 3. Test hardware uses standard consumer grade PC with i5-10300H processor. Test code is not optimized for parallel execution.

To demonstrate the capabilities of the proposed model, the paper presents the results of four experiments on images chosen by experts. Analyzing the results of the experiments, the experts gave the best recommendation for the model and the method of its implementation.

Since the proposed method of gradation correction works in real time, automatically increasing the contrast of bad images up to 5-7 times, making even the worst images clearly visible (this can be seen from the above experimental results).

The even not optimized experimental code, used for proving of concept gives very good results is terms of performance.

IV. CONCLUSION

Based on publication analysis we can conclude that video input is one of the most important inputs for robot systems, as it helps to navigate, detect needed objects, and give much useful information. That means that the quality of the input image data is crucial for successful operation, because if input data is not good enough, even the best algorithms cannot do much. This is very well-known concept in computer science garbage in, garbage out.

The novelty of the paper is special polynomial mathematical model and method for adaptive gradational correction of a digital image. This method helps to enhance images in a very fast and efficient way. This allows using such methods even in real time applications. Which could be very handy in robot navigation applications, or video streams enhancement, even in bulk enhancement of big storages of images.

Experiment was conducted, which proved that this method works and gives good results on a wide variety of image classes which has different lighting conditions including underexposing and overexposing, different scenes, even different approaches in photograph (casual photos, and professionally made photos). But, as always, there is a space for improvement in future research, for using different functions for image processing, depending on the scene and lighting conditions.

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