Fuzzy Model of Raster Transformation of Square Elements

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Abstract

Mamdani fuzzy model of the image raster transformation for square elements has been developed on the basis of a fuzzy set of rules that reproduce the input geometric size and its area, which is an information carrier, its fuzzification and inference have been carried out using the input and output membership function, which more fully and quantitatively describe the fuzzy ranges of light, gray and mid tones reproduction in the tone interval.

A simulator of a fuzzy model of raster transformation in Matlab: Simulink package has been developed with the help of Fuzzy Logic Toolbox, which has simplified its implementation. The simulator calculates three membership functions of fuzzy sets and visualizes them. The results of the simulation modelling in the form of graphs of membership functions of input and output variables are presented and their properties are analysed. Fuzzy models quantify and objectively evaluate fuzzy ranges of light, gray, and dark tones during the rasterization process, which is the advantage of fuzzy models over traditional ones.

Keywords

Raster transformation, fuzzy model, square, tone, fuzzification, inference, interval, simulation

1. Introduction

Rasterization is practically the most important basis for reproducing images in the printing industry, which allows one to control the tone transfer. The term "rasterization" means the decomposition of the image into small elements, which consist of printed and blank elements. Depending on the ratio of the areas of sub-elements covered with paint and white paper for the human eye, the impression of a gray tone is created [1, 2, 3]. This definition of the term rasterization is quite narrow and mainly characterizes its technological and physical essence. At the same time, rasterization is the main controlling, corrective and compensatory effect for other stages, namely the production of printing plates and printing. Physically raster element first appears on the printing plate as a printing element. The stage of making a printing plate and printing have limited control capabilities. In the process of printing, the printing elements are covered with ink, a color image is created, which is transmitted to the printed material through the offset cylinder. This is a physical increase in color dots, which causes distortion of the raster image, which is called compression [4, 5, 6, 7, 8]. The compression itself is due to the increase in the area of raster dots at the stages of manufacturing the printing plate and printing is the main reason for the deterioration of the quality of the raster image. These and other effects must be corrected and compensated at the stage of rasterization.

The latest CtP technologies provide high-quality production of raster printing plates, but do not significantly improve the quality of printed products. Today, most traditional classical rasterization methods are used in CtP systems, where you can select the desired form of the raster element and specify the desired literature. The developers of these systems develop and, at the request of customers, install alternative programs of frequency, hybrid, stochastic rasterization, which provide higher quality color publications [7, 9, 10].

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The main problem is the strict requirements for standardization and normalization of all processes, materials, machines and the availability of expensive multi-channel systems for zonal adjustment of the supply of paint to a given circulation, which significantly limits the introduction of alternative screening methods not only in Ukraine but also in other countries.

The theoretical foundations of raster transformation, which mathematically describe the transformation of a continuous image (illustrations) into a discrete raster, lag far behind the theory of digital processing and image conversion, which is widely developed, has different processing methods that can significantly improve visual quality are illuminated on the monitor screen. Note that the digital image is represented by arrays of numbers and corresponds to [0; 255] grayscale, which are used in digital image processing [1, 2, 11-14]. Instead, in printing with raster transformation, raster elements of different geometric sizes, different shapes and lines are used, and the main carrier of image information is the relative area of the raster element, which is within [0;1]. Therefore, existing digital image processing methods cannot be directly applied to bitmap conversion.

The physical processes that occur during rasterization, mold making and printing are diverse and complex, so little is studied. Experimental research is time consuming and expensive, requiring complex measuring equipment. In addition, the effects of various perturbations can significantly distort the results of research. On the basis of experimental researches and densitometric measurements build and analyze gradational characteristics of printing, carry out adjustment of rasterization. However, on based on experimental data, it is impossible to make optimal adjustments and compensation for different effects for different lines and shapes of the raster element.

Mathematical models of raster transformation, raster characteristics for elements of different shapes and lines and adjustments and properties characteristic of a given line and shape of raster elements are presented in available sources [3]. In the presented and other sources there is no general approach to the analysis and synthesis of raster transformation, in particular to the synthesis of parameters of the corrective link of different lines and shapes of raster elements. disadvantage. An even more difficult problem is the optimization of raster parameters and adjustment parameters. To solve these problems, it is necessary to develop models of raster transformation.

Thus, the urgent problem is to develop a normalized raster transformation, which would adequately describe the raster transformation regardless of the raster line, allow to build raster characteristics, synthesize the adjustment link, compensate and optimize the raster. Reproduction of the tonality of the image by printing means is carried out by changing the relative areas of printing and blank elements. To do this, printing originals (photographs, drawings, images, digital images) are sampled and converted into growth. ditch form, which has a regular raster lattice structure in which the raster elements are located. In general mathematical terms, the traditional raster image transformation is expressed by the gradation transformation function where the basic value is the geometric size of the raster element, which is placed in a raster cell (raster square), the dimensions of which are set by the raster line, maximum raster element size element obtained after conversion, which corresponds to the optical density of the image.

The shape of raster elements and raster lineage depend on the type of printed products (books, magazines, newspapers) and materials that significantly affect the quality of printed products. Traditionally, the raster transformation of a given lineage is analyzed, which can be set in a wide range (from 30 to 120) lines / cm. Raster conversion is indicated on a limited tone interval, which is set by the variables DM and XM for a given line. The results of analysis and synthesis and the parameters of the corrective link in the traditional raster transformation depends on the shape of the raster elements and the raster line, which is a disadvantage and is inconvenient for practical applications and adjustment of tone.

To generalize the analysis and synthesis of raster transformation, a mathematical model of normalized raster transformation in the form of a two-digit function with a domain - closed single raster square and many values of relative areas closed closed interval [0;1]. The square raster cell has constant unit dimensions. The raster element of a given shape is located in the center of the cell. In the process of raster transformation, its geometric dimensions change within [0;1].

Modern computer publishing systems allow one to choose the shape of the raster element and adjust the tone transfer. However, the gradational content of images can be varied. They can be light, gray, dark and differ in contrast, maximum and minimum values of optical density [3]. If the interval of optical densities of the original and reproduction is set during the tone transfer synthesis, depending on the technological capabilities of a particular offset printing method, the tone transfer synthesis can be performed using the Adobe package in its working window, adjust and form the desired gradation characteristics of the tone transfer depending on the experience and intuition of the operator, technologist or customer, for each specific image [1–4].

One should note that the operator does not have enough quantitative data on the information content of the image, and verbal tone estimates as "light tones" or "shadows" are insufficient to form an optical gradation characteristic, so the operator makes selection based on his own experience and skills. The complete procedure of preparing images for printing is quite complex, lengthy and is used in the case of increased requirements for imprint quality [3–7]. Therefore, the use of fuzzy sets and fuzzy logic in order to obtain additional and quantitative information about the image is an urgent task.

2. Literature Review

The choice of the form of raster elements depends on the type of printed products, as the raster image is related to the structure of raster elements and their shape [3–6]. The clearest image is provided by a regular raster structure with a square raster element. An image with a checkerboard structure and a square element is visually perceived as a solid gray surface than an image with linear dashed elements. Therefore, the square shape of the raster element is considered one of the best for reproducing raster images by printing means [1, 2]. Graphical representation of the geometry scheme of the normalized raster transformation for a square element located in the center of a single cell of the raster grid.

Nowadays, the experience has been gained in the use of fuzzy logic to solve many problems that are difficult to solve by traditional mathematics [1, 7, 8, 9, 10, 11]. The ability to properly evaluate the original makes it possible to draw conclusions about the interval and ranges of tone. To do this, the characteristics of tone reproduction are divided into seven bands, which helps during tonal image correction, and tones are given in the processes: light areas - 2-10%, quarter tones - from 18% to 35% with a center of 25%, ordinal tones - from 35 to 65% with a center of 5%, three-quarter tones - from 65 to 80% ofaverage value of 75%, shadows - dark areas, which for high-quality offset can be up to 97%, which corresponds to the range of optical densities of the print 0-1.4 B [1, 4].

With the advent of digital images, their interval is given by the number of discrete levels (grayscale 0–255), which are called eight-bit [2, 5]. Some applications of fuzzy sets for image contrast in general are presented in the monograph [2], there is also described the use of fuzzy sets for spatial filtering on a simple example of four neighbors and provides an illustration that confirms the effectiveness of spatial filtering based on fuzzy logic Some applications of fuzzy logic models to the image transformation are presented in the monograph [5, 13, 15], where red, yellow and green are used as linguistic values of the corresponding membership functions which are formalized by fuzzy rules IF-THEN and logic inference rules. Based on them, the problem of increasing the contrast of a halftone black and white image is solved, applying a fuzzy base of rules: if a pixel is dark, make it darker, if a pixel is light, then make it lighter. An example of the use of fuzzy sets is presented for raster filtering on the example of four neighbours as well as the illustration that confirms the effectiveness of spatial filtering to increase contrast.

In the work of the author [3, 19-22] Mamdani fuzzy model of the ranges of optical densities of the originals and reproductions associated with technological transformations in offset printing is constructed. A simulator has been developed that simultaneously calculates three membership functions of the optical density interval and performs their visualization. The properties of the model are considered, which quantitatively, and therefore objectively describes the fuzzy smooth ranges of tone transfer, which is the advantage of the fuzzy model over the traditional one [18, 19, 23].

There are various fuzzy models that describe different phenomena, processes, objects, and systems. The choice of model type depends on the object, the purpose of the study, the accuracy and the available information about the object.

Since the graphic characteristics of the tones of the originals, reproductions and raster prints are known or can be determined experimentally, we believe that the model of the object is known. In this case, the construction of a fuzzy model is called fusification (blurring) of the original model. To fusify the interval of optical densities, we use one of the most popular models - the Mamdani model [2, 7, 8], which should reproduce the input in output in the form of a set of rules, each of which defines one blurred point. Sets of blurred points create a blurred pattern in which the interpolation between points depends on the accepted apparatus of fuzzy logic, in particular the membership function, which can be segmental-linear or continuous [9, 11].

3. Models & Methods & Technology

3.1. Methodology of research

Rasterization There are various fuzzy models that describe different processes, objects, and systems based on their mathematical models or relevant data. In the process of raster transformation, the image (original) is transformed into discrete-continuous (raster) one, which is described by the area of the raster element, which is an information carrier about the image and is given by the analytical expression in general [2, 17]:

$$Sa(x) = F(x, a, L), IF\ 0 \le x \le a, \quad (1)$$

where *Sa(x)* - is the area of the raster element, *a* – is a raster constant, which is equal to the size of the raster grid, *L*- is the raster lineature, *x* - is the geometric size of the raster element (control effect), *F(·)*- is a nonlinear function.

When transferring from light to gray and dark tones, the size of a square raster element is gradually increased, and the area will be determined by the area of the square [2, 24]:

$$Sa = x^2, IF\ 0 \le x \le a, \quad (2)$$

If *L* line/cm is given, then the raster constant will be in μm and will be determined by the expression:

$$a = \frac{10000}{L}, \quad (3)$$

Then the relative area of the raster element will look like this:

$$S = \frac{Sa}{Sm} = x^2 L^2, \quad (4)$$

If in the expressions (2)-(4), the size of the raster element is linearly changed within the given limits $0 \le x \le a$, then they can be used to calculate and form the rasterization characteristic needed to construct a fuzzy raster transformation model. A simpler task can be solved by using object-oriented programming in the popular Matlab: Simulink package [8, 20-25]. In accordance with the modelling principles on the basis of the above formulas, a block diagram of the model of raster transformation has been developed in Simulink, which is presented in Figure 1.

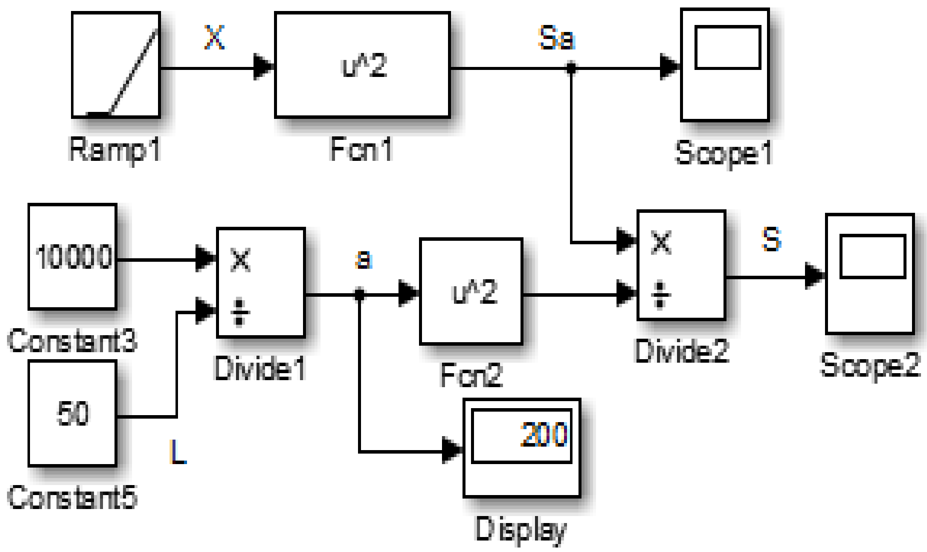

Figure 1 : The block diagram of the raster transformation model

The control effect generates the block *Ramp* and feeds it to the input of the block of mathematical functions *Fnc*, which calculates the absolute value of the area of the raster element. The relative area is determined by dividing the absolute value of the area in the block *Divide* by its maximum value, which is determined by the second block of mathematical functions *Fnc2* of the constant and the rasterization is determined on the basis of the expression (3). The results of the calculations are determined by the blocks *Scope* and *Display*.

For example, the lineature is $L = 50$ *lines/cm*. The model is adjusted to the specified lineature and parameters. The results of modelling in the form of a characteristic of the raster transformation in relative units of the elements area are presented in (Figure 2).

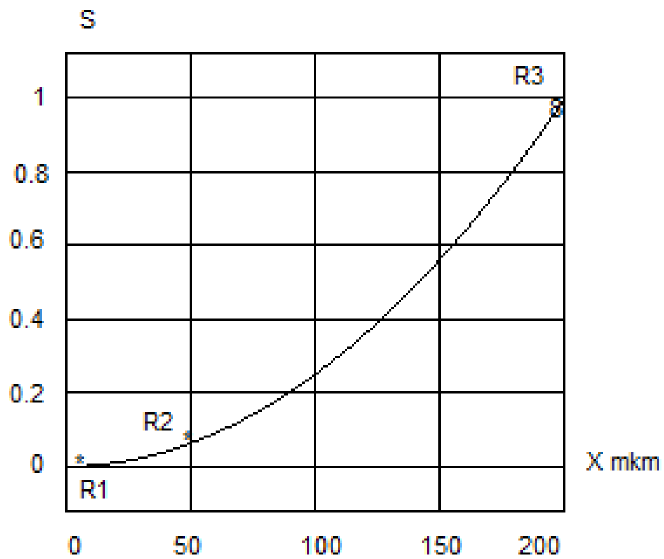

Figure 2 : The characteristic of the raster transformation in relative units

The characteristic of raster transformation is a concave quadratic curve, which corresponds to the optical density of reproduction of a linear raster scale [2]. Traditionally, to assess the tone of the originals and reproductions, the tone transfer interval is conventionally divided into three ranges: light $0 \le D \le 0.30$; gray $0.30 \le D \le 1$; dark $1.00 \le D \le 3.0$.

The sensitivity of the eye in different ranges varies.

The threshold of visual perception, i.e. the minimum change in optical density is in the light tones of the original, the largest one is in the dark [4].

Therefore, when preparing an image for printing, it is necessary to pay more attention to the transfer of light areas than to dark ones. Since the optical density corresponds to the relative area of the raster element, the selected ranges correspond to the following geometric dimensions of the raster elements: light $0 \le x \le 50$; gray $50 \le x \le 100$; dark $100 \le x \le 200\ \mu m$.

This approach to describing the division of tone transfer ranges is useful for analysing the distribution of tones and constructing a fuzzy model of raster transformation.

One should pay attention to features of division of the tone transfer ranges.

For example, the original having an optical density $D = 1.0$ is gray, and the original $D = 1.01$ is already dark. Therefore, the change in density by 0.01 which is less than the threshold of visual perception $\Delta D = 0.01$ is not possible to be noticed by the operator who performs the tone adjustment of the image, which is a disadvantage of using traditional tone transfer ranges.

Since Figure 1 shows the characteristics of the raster transformation for square elements, one assumes that the model of the object is known. In this case, the structure of a typical fuzzy model is selected, which should contain a fuzzification unit that performs the operation of blurring of the input geometric size of the raster element.

One of the most popular Mamdani fuzzy models [1] is used for fuzzification, which corresponds to the characteristic of raster transformation in the form of a set of rules, each of which is determined by a blurred point.

According to the procedure, first the starting point *R1* of the zero geometric size of the raster element $x = 0.0$ and the end point *R3* for the size $x = 200$ *mkm* are selected.

The most important is the selection of the second blurred point *R2*, which should determine the most important properties of the raster transformation and corresponds to the geometric dimensions of the raster element $x = 50$ *mkm* and the optical density $D = 0.3$.

The selected characteristic points on the raster characteristic are represented by asterisks, which are closest to the reproduction of the raster transformation characteristic X → S represented by a fuzzy model.

The Mamdani model is a set of rules, each of which defines one blurred point. The set of blurred points creates a blurred drawing in which the interpolation between points depends on the accepted elements of fuzzy logic [1].

Fuzzy sets A_1 = *neighborhood of zero*, A_2 = *neighborhood of 50*, A_3 = *neighborhood of 200 mkm.* correspond to the selected dots. Then the constructed fuzzy Mamdani model for raster transformation is described by a set (base) of rules:

$$\begin{aligned} R1&: if\ (x \in A_1)\ Then\ (y \in B_1) \\ R2&: if\ (x \in A_2)\ Then\ (y \in B_2), \\ R3&: if\ (x \in A_3)\ Then\ (y \in B_3) \end{aligned} \tag{5}$$

where x – input variable of the model (geometric shape of a raster element) which is within [0, 200 mkm], y – model output (relative area S of a raster element) within [0, 1].

Each rule defines typical properties of a raster transformation that geometrically corresponds to a dot on the $X*Y$ plane. The results of fuzzy model reproduction (outputs) correspond to fuzzy sets:
B_1= *neighborhood of zero*, B_2= *neighborhood of 50*, B_3= *neighborhood of 200 mkm.*

The fuzzy set A of the area of geometric dimensions x of the raster element is a set of pairs:

$$A = [\mu_A(x), x], \tag{6}$$

where $\mu_A(x)$ – is a membership function of a fuzzy set A, which assigns to each dimension of the raster element $x \in X$ the degree of its membership $\mu_A(x)$ to the fuzzy set A where $\mu_A(x) \in [0,1]$. For three ranges of geometric dimensions of the elements we use a discrete notation of the fuzzy set A as a sum:

$$A = \frac{\mu_A(x_1)}{x_1} + \frac{\mu_A(x_2)}{x_2} + \frac{\mu_A(x_3)}{x_3}, \tag{7}$$

where the set A is a sum of sets, rather than an arithmetic pair $[\mu_A(x)/x]$

To build a model of raster transformation, we apply, respectively, the linear membership functions of a triangular shape of a fuzzy set to select three ranges of the variable x:

$$\begin{aligned} &\mu_{A1}(x), P_1[0, 0{,}50] \\ &\mu_{A2}(x), P_2[0, 50{,}200], \\ &\mu_{A3}(x), P_3[50, 200{,}200] \end{aligned} \tag{8}$$

where $P_i[\cdot]$ – parameters of the membership function of a triangular shape.

The membership function subordinates a certain value from the boundary [0, 1] to each value of the geometric dimension x of the raster element.

$$\mu_A(x): X \to [0{,}1], \forall x \in x, \tag{9}$$

Based on the research results, a method of using a fuzzy model and database of raster transformation and organization of defuzzification as well as fuzzy inference with the help of *MAX* operator to obtain the results of inference has been worked on.

To build a fuzzy model, the method of simulation in the package Matlab:

Simulink [1] was used. Operating blocks of fuzzy sets and membership functions, located in library of the Fuzzy Logic Toolbox from the Membership section, and the operation block

Triangular MF for generating the triangular membership function, and traditional visualization blocks were used for its building.

Based on the above, the block diagram of the fuzzy raster transformation simulator has been built, shown in Figure 3.

The main blocks are the operating *Triangular MF* ones which generate the membership functions of the triangular shape at the input of which is the geometric dimension of the raster element that forms the Ramp block.

The Scope and Display blocks visualize the membership functions after the inputs are blurred.

The simulator calculates three membership functions simultaneously and blurs the input signal.

The *MAX* operator is used to obtain a logical inference.

Parameters of the *Triangular MF* blocks were adjusted to the specified parameters of the model: $P_1[0, 0, 50]$, $P_2[0, 50, 200]$, $P_2[50, 200, 200]$, which were set in the dialogue boxes of the blocks.

The results of simulation of fuzzy raster transformation model in the form of membership function are presented in Figure 4.

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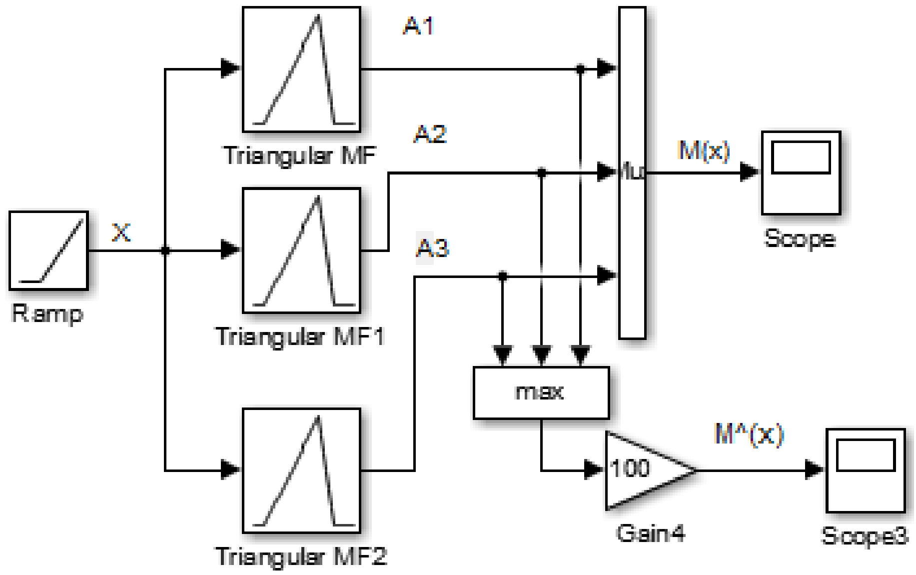

Figure 3 : The block diagram of the fuzzy raster transformation simulator

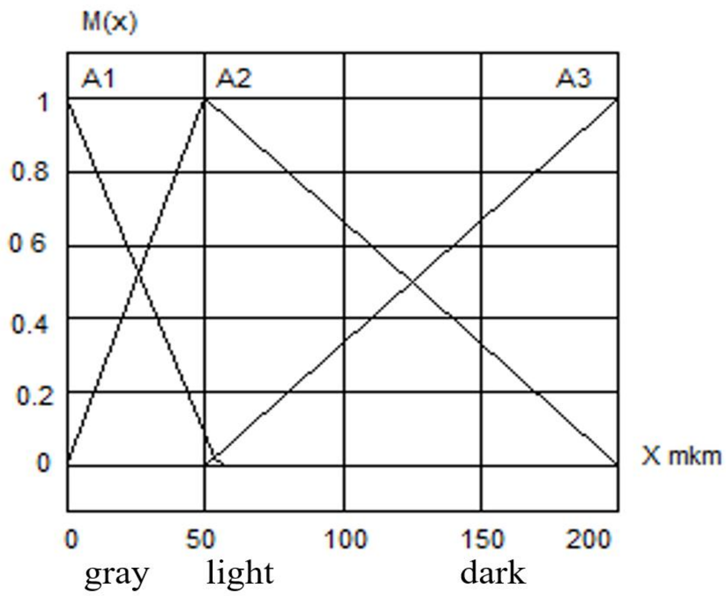

Figure 4: Graphs of the membership function for raster transformation

3.2. Experiments & Results & Discussion

Graphs of the membership function after blurring are asymmetric, shifted to the left and intersect. Different values of two membership functions correspond to the input variable x simultaneously. For example, specific numerical values of the compatible membership functions $\mu = 0.6$; $\mu = 0.4$ will correspond to the input variable $x = 20$

Let us assign linguistic (verbal) meanings of variables (light, gray, dark) to the graphs of membership functions and divide the interval of tone transmission into three ranges: light tones, gray, and dark.

The fuzzy range of light tones of A1 image is quite narrow, while the range of dark is wide and shifted to the right.

Thus, black tones dominate in the raster transformation. In other words, raster transformation darkens the image. Instead, it distorts light images.

For example, at the output variables $x = 20$, the meaning 0,6 corresponds to the membership to the "light" tone, and 0.4 to the gray one.

Thus, fuzzy models assess raster transformation more fully, quantitatively, and, therefore, objectively.

A logical inference is organized with the help of MAX operator of the membership functions given in percentage, which is quite often used in printing, shown in Figure 5.

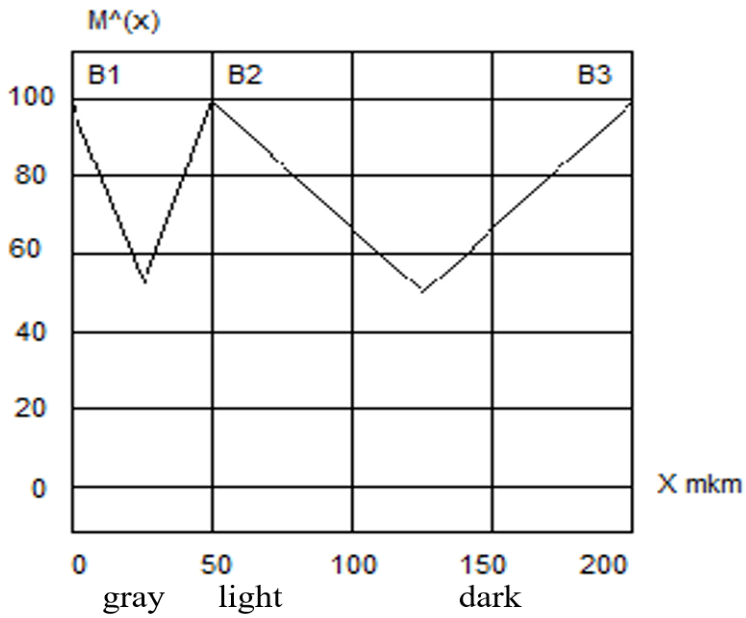

Figure 5: The results of logical inference of the membership functions with the help of MAX operator

The results of the logical inference are asymmetric segments of the maximum values of the membership function shifted to the left in light tones, and their obtained maximum values are 100% for each fuzzy range.

The lowest value of the tone indicator is on light tones and is 50%, and for dark is 55%. Thus, light tones have a smaller transmission range comparing to dark ones, so raster transformation reproduces dark images better than light ones.

Thus, the conclusion is that fuzzy models assess the tone transfer of the raster transformation for square elements more fully, quantitatively, and, therefore, objectively, which is the advantage of such models over traditional ones.

4. Conclusions.

A fuzzy model of the image raster transformation for square elements has been developed on the basis of characteristics of raster transformation in relative area units that correspond to optical density of reproduction of the linear raster scale with the three characteristic dots that correspond to neighborhood of three fuzzy sets. Parameters of membership function that describe fuzzy tone transfer ranges were discovered.

A simulator of a fuzzy model of raster transformation in Matlab:simulink package has been developed on the basis of Triangular MF operating blocks of fuzzy sets to generate membership function of triangular shape that has simplified its implementation. The simulator calculates three membership functions of fuzzy sets and visualizes them.

The results of the simulation modelling in the form of graphs of membership functions of input and output variables on the tone transfer interval and the results of logical inference are presented. It was found out that the graphs of membership function for raster transformation are asymmetrical, intersect and shifted to the light range.

The results of fuzzy tone transfer are two dimensional and define the degree of membership to two tones, e.g. 0,6 to the light tone, and 0,4 to the gray one.

Fuzzy models assess fuzzy ranges of light, gray, and dark tones reproduction during the process of raster transformation qualitatively, and, thus, objectively, which is the advantage of fuzzy models over traditional ones and will help to improve tone transfer adjustment.

For the printing industry, the introduction of this type of regulators will speed up the production of printed products and reduce shortage costs. Which in today's market conditions is a sufficient advantage over competitors in the financial sector.

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