The Fuzzy Logic for Machine Vision System Effectiveness Assessment

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Abstract

The effectiveness of the Machine Vision System is estimated by fuzzy logic model. It is designed as a hierarchical structure with two inputs “Performance” and “Reliability” and one output “Effectiveness». The way of estimation of the MVS performance is based on the results of the risk assessment for five optical laboratories. It is developed the reliability evaluation criteria by number of MVS corrections per day. It is developed the rules for definition effectiveness of the system according to the value of the performance and reliability. The necessity of using fuzzy logic is described. Three fuzzy sets “Performance”, “Reliability” and “Effectiveness” with five linguistic variables “Very low”, “Low”, “Moderate”, “High”, “Very high” are investigated. The features of fuzzy sets as normality, non-unimodality, and convexity are discussed. The method of building membership function and blurring the border is presented. Based on Mamdani algorithm and the center of gravity method the effectiveness of the MVS is calculated. The suggested solution can be applied for supporting the decision making system of MVS choosing for the stakeholders.

Keywords 1

Fuzzy Logic System, Machine Vision System, Effectiveness Assessment

1. Introduction

The Machine Vision System [1] is based on the capability of a computer to perceive the environment by video camera and sending the image data to a computer or robot controller [2]. The Machine Vision System with Artificial Intelligence (MVSAI) is used in science and technology innovation for acquisition, inspection, evaluation, and processing of optical images suggests the smart solution providing the iterated high accuracy of measurements and reliability of the data. The MVSAI is a fruitful tool to conduct optical research and to track the movement of microparticles, transport and space objects.

In our consideration MVSAI contains the source, optical elements, a CCD camera, a computer, software, a decision support system with AI (Figure 1). An iterative improvement of all elements of the system is assumed through the use of feedbackand methods for assessing a quality by means of fuzzy logic. The relative error of the image parameters definition is under influence of fluctuations, instabilities and aberrations of the system due to AI employing can be smaller than 10 %.

Problems of visual image recognition remain an urgent task, which increases the number of parameters for analysis and improves the ability to classify [3, 4]. Deter- mining the measurements quality and the risk assessment are the important parts of IT system audit. Most often, decisions are made in conditions of uncertainty, which at the present stage are proposed to be solved by the methods of fuzzy logic. Nowadays, fuzzy logic modeling is one of the most active and promising way in the field of management and decision making of any applied research [5,6].

COLINS-2021: 5th International Conference on Computational Linguistics and Intelligent Systems, April 22–23, 2021, Kharkiv, Ukraine
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Let’s consider the decisions which are made by operators and managers according to Figure.1. First of all based on the task requirement is chosen the setup type and its components: optical sources, elements and cameras, their arrangement and fixing. Then they have to choose hardware for elements movement and software for its managing. If this module is not accessible the operator aligned the setup himself. Next step is choosing the software for images and video analyzing. After the first experiment usually there are several iterations to improve the system. Making a choice by a person for all stages including the level of achieving the required image quality with a support of artificial intelligence, implemented through fuzzy logic methods, will ensure the creation of a high-quality system. To develop the method of MVS effectiveness assessment by fuzzy logic modelling for supporting the decision making system at different stages of MVS planning, construction, control and management.

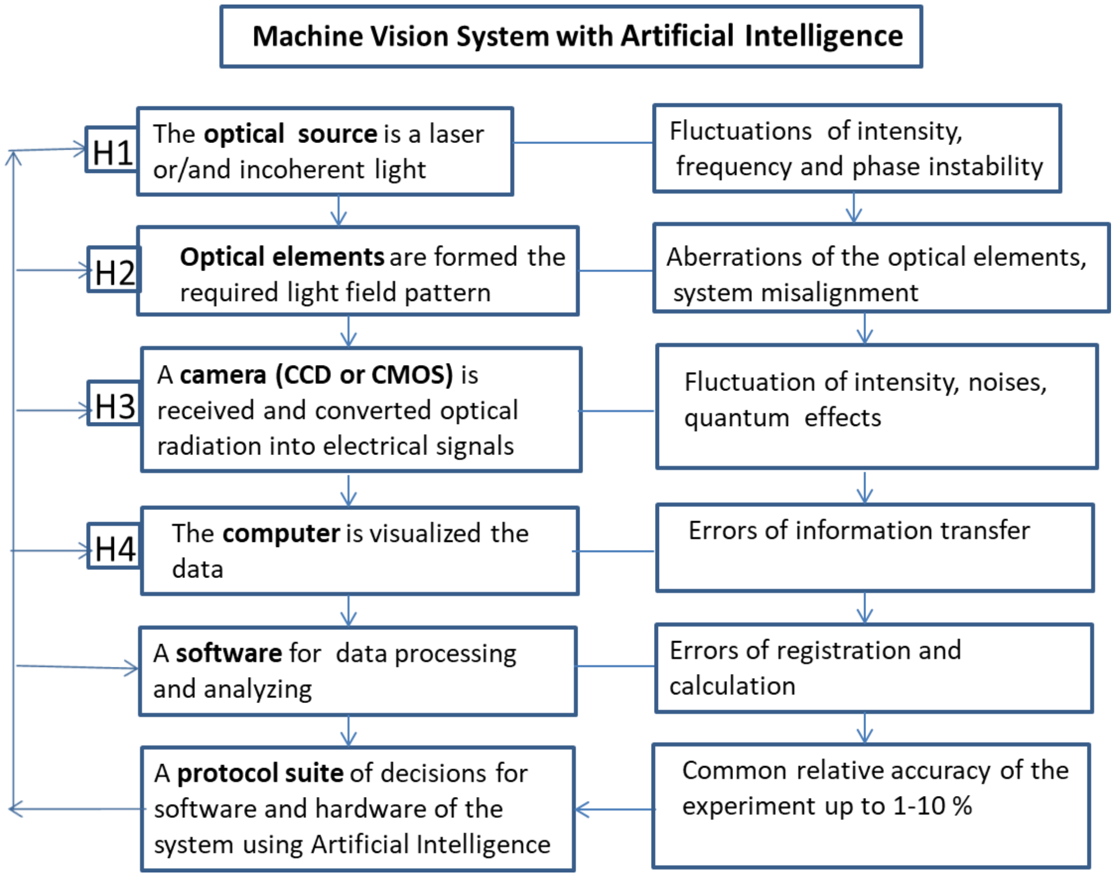

Figure 1: Common view of the machine vision system with an Artificial Intelligence for optical research realization

The work is focused on the transforming clear data to fuzzy data with keeping ex- pert assessment to explain the choice of border values for every linguistic variable. So,the task should be solved by the efficient way in the process of data preparation for theartificial intelligent system.

2. The Machine Vision System Effectiveness Concept.

System effectiveness is defined by many authors with a relation to the cost [7,8]. Considered MVSAI consists from mechanical devices, electrical devices and soft- ware. The mechanical devices are optical elements, their apertures, holders and fixing system. The electrical part is represented by PC, optical sources and cameras. The software is analyzed the results and is generated the decisions about actions to improve the MVS. The robot or/and the person aligns and repairs the system. The view of the registered image for the optical research with the diffracted field pattern is shown in Fig. 1a and microparticle observation by the visual-optical method with is represented in Fig.1b.

Traditionally, operational effectiveness [9] can be calculated as the product of the three characteristics: performance capability, Reliability and Availability.

$$\text{Effectiveness} = \text{Performance} \times \text{Reliability} \times \text{Availability} \quad (1)$$

First of all, it is necessary to achieve the understanding of every characteristic, and then justify the simplifications for the machine vision systems and to define their values for the real cases. The definitions of the terms in formula (1) are perceived or fathomed from the practical point of view in the post [10] that are adopted here for MVS.

So, the performance capability (P) is shown how well the system does its job when working properly. Such values were defined for the visual and optical systems in the paper [11] for five laboratories which perform the machine vision system. The next characteristic is the operational reliability (R) measures "how long" it is capable of working without failure. Availability (A) is a measure of the system readiness to start a mission at a random point in time. For existed MVS it is assumed that A=1 because they are ready to be used in any time. Here, it is suggested to keep the same scale for estimation every parameter without using formula (1).

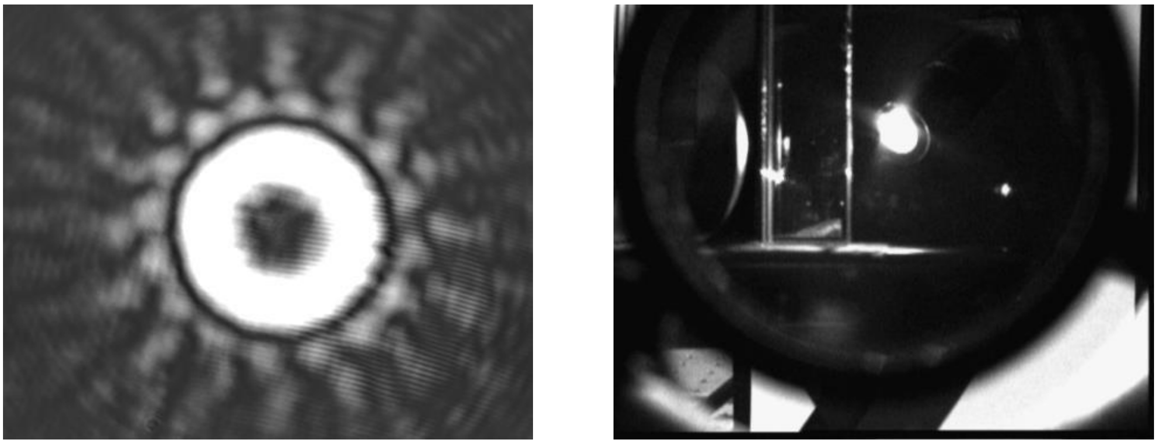

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Figure 2: A laser beam with diffraction pattern (a). One frame from the video file demonstrated a part from laser setup with chamber at different initial conditions ready for microparticles guiding recorded by CCD-camera (b)

One of the most important characteristic by opinion of many authors is reliability, because it directly influents on system effectiveness and indirectly on availability, andperformance capability [12, 13].

Let's estimate the reliability value according statistical data, which is equal to the number of operator interventions in the system to prevent or to correct the setup at thetime of MVS working.

3. Fuzzy Logic System for MVS Effectiveness Assessment

The fuzzy logic model for MVS system assessment is designed as a hierarchical structure with two inputs "Performance" and "Reliability" and one output "Effectiveness". The "Performance" capacity of machine vision system was estimated due to developing a methodology for decision - making to assess the compliance of the optical laboratory with technical requirements using Failure Mode and Effects Analysis (FMEA). The FMEA method has been adapted to the analysis of the quality of measurements in the optical laboratory [11]. The choice of the calibrated theoretical and experimental images on which the fitting of the results is carried out is discussed [14]. The algorithms of obtained images improvement are given. The relationship between the causes and consequences of physical phenomena causes the defects formation in the optical image by the scheme of Ishikawa is constructed. The quality and ways to improve gradually the experimental image are established using a Pareto diagram. Decision support methods are developed for the problems in applied optics in [11, 14] in which it is the estimation of the optical laboratory technical condition and optical image are developed. The information about five research laboratories from different countries is studied. It is determined the criteria of measurements quality based on the collected and processed data. The performance quality in five optical laboratories is presented in the Table 1.

Table 1
Performance evaluation criteria

Result number of the Lab	Risk quantity	Risk quality	Performance quantity	Performance quality
1	3	Low	8	High
2	5	Moderate	6	Moderate
3	2	Low	9	High
4	2	Low	9	High
5	7	High	4	Low

Here, it is developed the method of MVS reliability estimation which is based on the definition of the occurrence evaluation criteria by the FMEA method [11]. The reliability of the system depends on the level of qualifications and skills of the operator. Usually the temporary fixation of optical elements in MVS makes it flexible for changing setup at any moment, but the construction is misaligned with the time. The correction of the setup is needed at the noticeable signal distortion. So, the moderate level of the MVS reliability means no correction during one working day. Very high level of reliability corresponds to more than 5 working day in a week without corrections. The reliability evaluation criteria are estimated by the statistical data obtained from experimental researches and experts opinions. Full set of linguistic variables of reliability depends on corrections number for MVS in a day is presented in the Table 2. For the convenience of the human evaluation an inverse scale has been added to show the characteristic quality in such a way that the higher the better.

Table 2
Reliability evaluation criteria

Probability of needed corrections	**Reliability**	Number of MVS corrections per day	Occurrence	**Characteristic quantity**
Very high	**Very low**	>100	10	**1**
		50-100	9	**2**
High	**Low**	20-49	8	**3**
		10-19	7	**4**
Moderate	**Moderate**	5-9	6	**5**
		2-4	5	**6**
		1	4	**7**
Low	**High**	0,4	3	**8**
		0,25	2	**9**
Very low	**Very high**	< 0,2	1	**10**

Table 3
The main input characteristics for effectiveness estimation

Result Number of the Lab	Reliability quantity	Reliability quality	Performance quantity	Performance quality
1	6	Moderate	8	High
2	4	Low	6	Moderate
3	5	Moderate	9	High
4	8	High	9	High
5	3	Low	4	Low

The combination of information in the Table 1 devoted to the connection between risk and performance quality and the information in the Table 2 described the results of the performance and reliability for five different labs allow us to estimate the effectiveness of the system as in the Table 3.

The rules for estimation effectiveness assessment in the consideration that reliability is more valuable than performance are the next. It is proposed to calculate the efficiency by the average value of performance and reliability. The average is rounded according to the rules of rounding to the greater side if the reliability is higher and to the lesser if the performance is higher than the reliability. The maps of such a consideration are shown in Fig.3.

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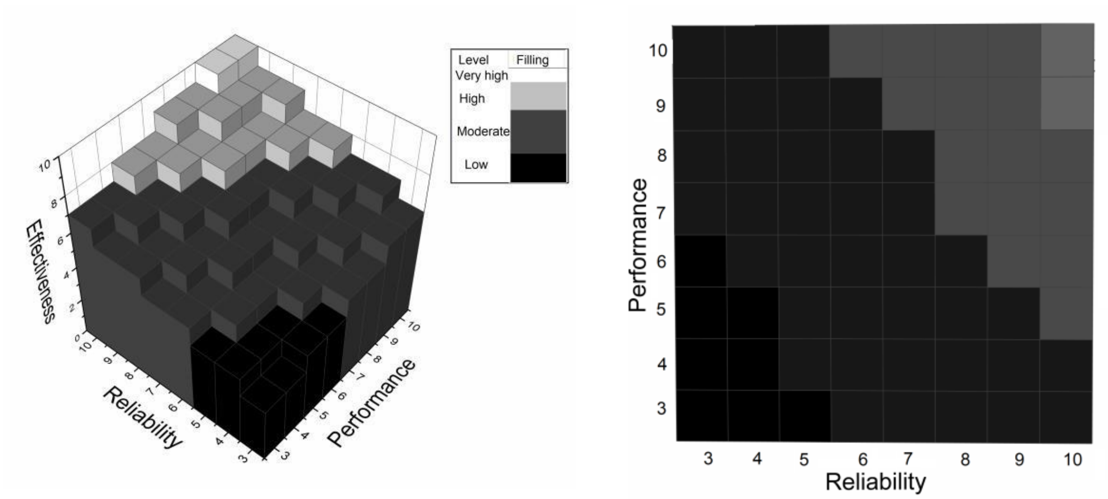

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Figure 3: The effectiveness of MVS depends on reliability and performance in 3D view (a) and 2D presentation (b)

4. Fuzzy logic for MVS effectiveness assessment

It is difficult to fix the result on the border of characteristic level such as 2 or 3, 4 and 5, 7 and 8, 9 and 10 in the cases when the estimator wants can't say exactly first number or second have to be chosen. Helpful think is to employ fuzzy logic [15-18] in such case and to blur the border. The fuzzy logic data processing consists of three stages. At the first one input numerical values are processed by the fuzzification method. Constructed form is moved to the fuzzy logic area where the application of the operators and rules are provided a fuzzy inference. The resulting number is defuzzed from fuzzy set by Mamdani, Sugeno, Larsen or Tsukamoto method.

Preparing a problem for solving by methods of fuzzy logic (fuzzification) allows to convert the real values of variables into fuzzy ones. Fuzzification consists in determining the degree of belonging of a variable to a fuzzy set. Two initial indicators MVS Performance capacity and MVS Reliability associated with the initial attribute Ai described by the i-th linguistic variable taking m (m =5) possible values (terms) Ai,1…, Ai,j,…, Ai,5. The output indicator MVS Effectiveness is associated with the resulting attribute described by linguistic variable B with the same number of terms B1,B2… B5 which are shown in the Table 4.

Table 4
Comparison of indicators and attributes associated with them, described bylinguistic variables

Indicator	Attribute	Attribute value
Type of the attribute is initial		
MVS performancecapacity	Performance (A1)	Very low (A1,1)Low (A1,2) Moderate (A1,3)High (A1,4) Very high (A1,5)
MVS Reliability	Reliability (A2)	Very low (A2,1)Low (A2,2) Moderate (A2,3)High (A2,4) Very high (A12,5)
Type of the attribute is resulting		
MVS Effectiveness	Effectiveness (B)	Very low (B1)Low (B2) Moderate (B3)High (B4) Very high (B5)

Fuzzy sets are characterized by the membership function M(x). The membership function can take any form. More often, piecewise linear functions are used to represent them, since they are characterized by simplicity and contain points that allow us to specify areas where the concept is true and where is false.

The sets A and B possess the following properties: normality, non-unimodality, and convexity. A fuzzy normal set is characterized by the membership function M(x): A → [0,1] with height or upper limit is 1. The set is nonunimodal, because the membership function, according to experts opinion, should be described by a trapezoidal function, for which there are several x values with M (x) = 1.

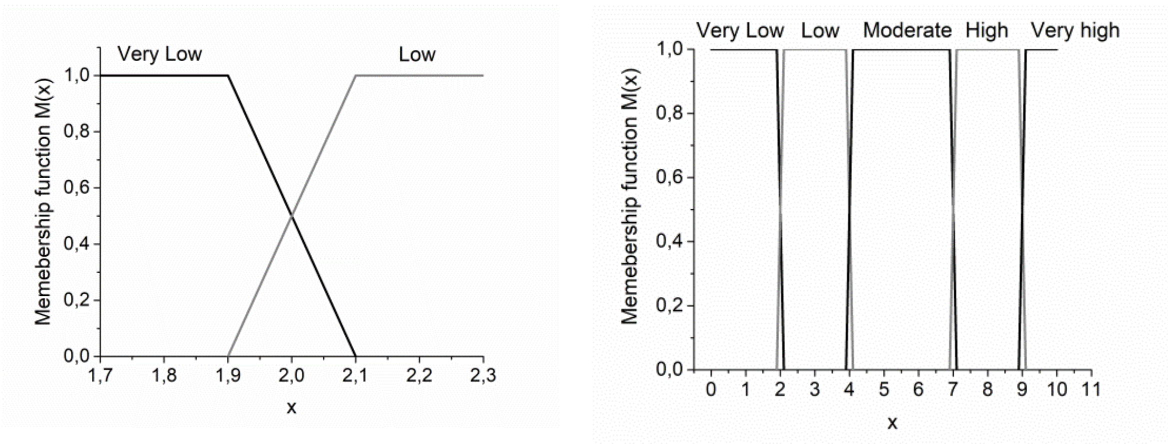

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Figure 4: The membership function M(x) for reliability and performance of one part of border blurring (a) and full view (b)

The membership function M(x) has the same view for reliability, performance and effectiveness. Their linguistic variables are: Very low, Low, Moderate, High, Very high, that is presented in fig. 4. The width of blurring is fixed by the expert decision. In our case 10% from one division or 0.1 blurring value in both sides from the border has been chosen.

The membership function M(x) = 0, at the transition points x = Xb. We place thefuzzy data in the interval (Xb-0.1, Xb + 0.1) with a step of 0.02. For example, for the first border (number 2), the real number x*= 2-0.08 corresponds to the value of thelinguistic variable Very low with confidence 0.9 and value Low with confidence 0.1.The data in neighbor sets are specified by the Table 5:

Table 5
The data presentation on the blurring border

	Xb-0.08	Xb-0.06	Xb-0.04	Xb-0.02	Xb	Xb+0.02	Xb+0.04	Xb+0.06	Xb+0.08
$A_{i,j}$	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
$A_{i,j+1}$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

The basis for the operation of fuzzy inference is the rule base containing fuzzy statements in the form "if then" and the membership function for the corresponding linguistic terms. In this case, the following conditions must be met: 1) There is at least one rule for every linguistic output variable. 2) For any term of the output variable, there is at least one rule in which this term is used as the target part of the rule. Otherwise, there is a fuzzy rule base. Fuzzy inference is called obtaining a conclusion in the form of a fuzzy set corresponding to the current values of the inputs, using a fuzzy knowledge base and fuzzy operations. The standard logical operators AND, OR, NOT are used to write combinations of logical concepts of fuzzy logic and calculate the degree of truth. The fuzzy logical inference is based on Zadeh's compositional rule. Zadeh's compositional inference rule is formulated as follows: if a fuzzy relation between the input (x) and output (y) variables connected by the rule R, then with a fuzzy value of the input variable $x = \tilde{A}$, the fuzzy value of the output variable is defined as follows: $y = \tilde{A} \circ R$, where $\circ$ is the maxmin composition is provided by operator AND which returns the minimum value of degrees of truth and the operator OR their maximum value.

IF-THEN rules presented at the map (Fig.3b) are not ready for the use, because one linguistic term for first indicator Performance has different linguistic variables for Reliability in areas boarded by grey lines as shown in Fig. 5a. Correction of the situation is possible due to addition analysis of the input parameters and providing the new rules as presented in Fig. 5b.

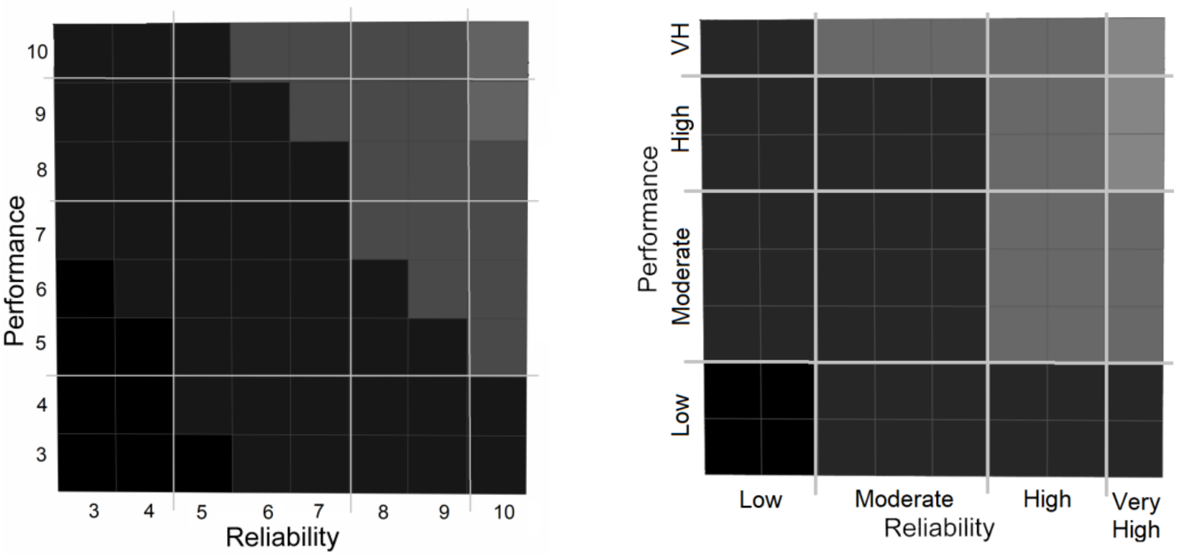

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Figure 5: Initial rules for the effectiveness estimation (a). The map of corrected rules is ready for working with fuzzy sets (b)

The purpose of the basic rules of fuzzy logic is formalization and application of human inferences. So, fuzzy logic is a part of artificial intelligence. Rule bases fuzzy logic are the most commonly used tools in applications with fuzzy logic. Base fuzzy logic rules are a set rules that are usually used in parallel, but in some applications can be combined consequently.

Let’s consider the input data for second laboratory MVS in a view: reliability – 4,06 and performance – 6,88. These values are corresponded to Moderate linguistic variable. Membership functions are built twice for input reliability, performance and three times for output effectiveness are shown in Fig. 6. Every row of graphs is demonstrated how to use fuzzy logic to obtain the result. The linguistic term has chosen according to the rules are shown in Fig. 5b. The trapezoids are shaded till upper border defined by the point in which input points cross the membership function. Operator AND represents the necessity to choose the minimal value from 0.6 and 0.8 that is defined the upper value 0.6 of the system effectiveness. The position of the trapezoid is determined by the rules in the map (Fig. 5b) as the Moderate. In the second row, it is considered another intersection of the input points with the membership functions. The linguistic variables Low and High are marked. The minimum value is 0.2 helps us to determine the effectiveness. After that the operator OR should applied to the two upper graphs for effectiveness. The meaning of the operator allows us to choose the maximum value of our previous results. The aggregated membership function is a figure for effectiveness in a view of two trapezoids combined into one shape. In our case both resulting figures in the right column are located in the term “Moderate” so the result is one larger trapezoid is shown

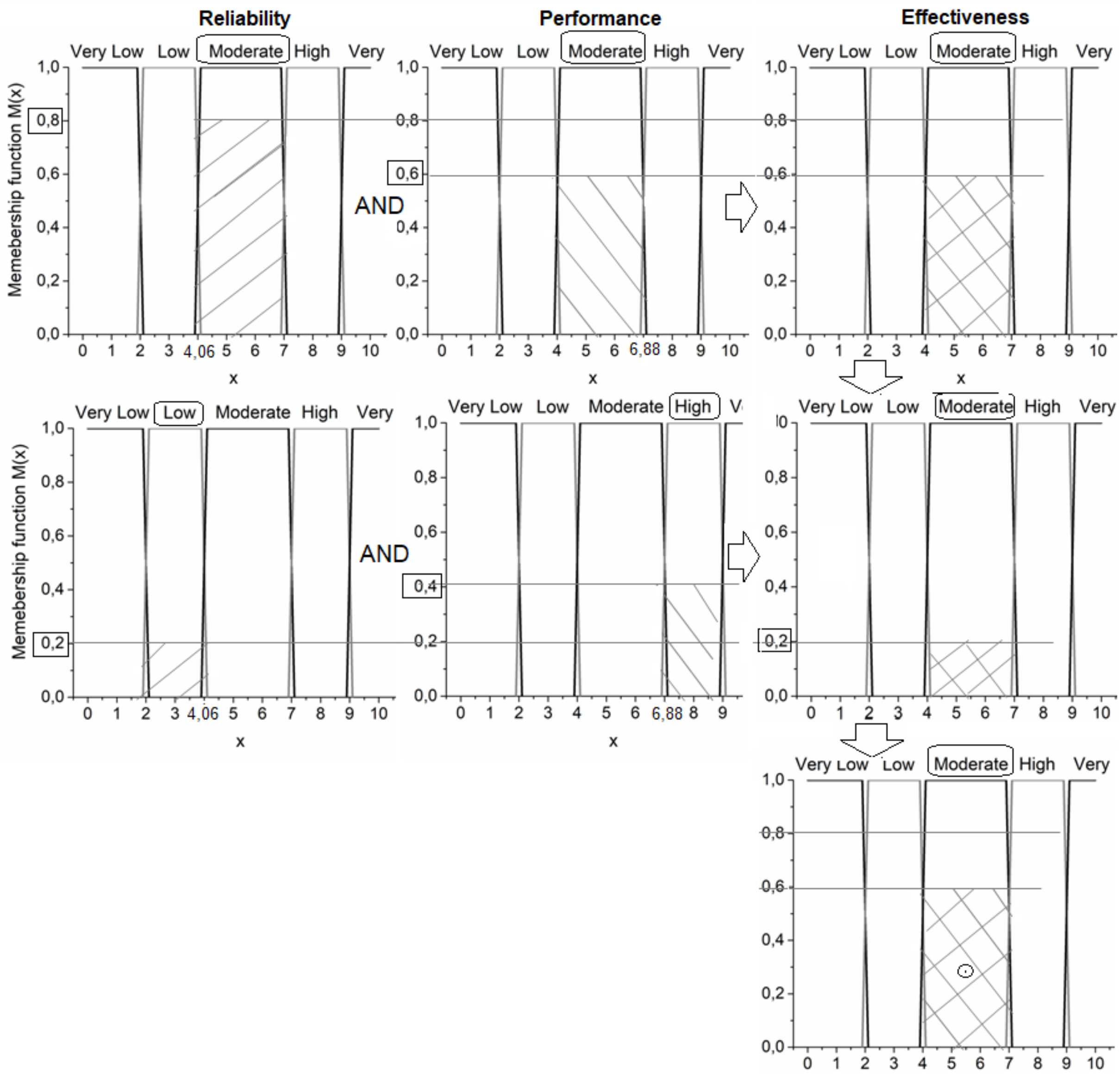

Figure 6: The system of a fuzzy inherence for the assessment of the system effectiveness based on input values of reliability and performance. The center of gravity of the trapezoid on the bottom graph is shown by point with a circle

by shaded figure on the bottom graph in Fig. 6. The crisp output value of the MVS efficiency in second laboratory is defined by defuzzification with the use of the center of gravity method [19]. In our case the answer is very simple. The gravity center is on a straight line that connects the midpoints between the bases of the trapezoid. It is calculated and shown by circle with point on the bottom graph in Fig.6. So, the output value of the MVS effectiveness is 5.5.

5. Conclusions

In this paper the structural scheme of the Machine Vision System is presented. The ways of using artificial intelligence system as helpful tool for the process of decision making for operators and managers are discussed. The Machine Vision System with Artificial Intelligence (MVSAI) is useful technique in science and technology innovation for acquisition, inspection, evaluation, and processing of optical images suggests the smart solution providing the iterated high accuracy of measurements and reliability of the data. The MVSAI is a fruitful tool in the perturbed optical field investigations and visual observations for tracking of microparticles, transport and space objects movement.
The quality of the Machine Vision System is estimated. The basic parameters "Performance", "Reliability" and "Effectiveness" is described the MVS completely. The way of estimation of the MVS performance is based on the results ofthe risk assessment for five optical laboratories situated in different countries and equipped by different manufacturer's devices. The "Performance" capacity of machine vision system was estimated due to developing a methodology for decision - making to assess the compliance of the optical laboratory with technical requirements using Failure Mode and Effects Analysis. The FMEA method has been adapted to the analysis of the quality of measurements in the optical laboratory. The relationship between the causes and consequences of physical phenomena causes the defects formation in the optical image by the scheme of Ishikawa is constructed. The quality and ways to improve gradually the experimental image are established using a Pareto diagram.

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The effectiveness assessment results contribute for increasing the risk managementefficiency in the optical laboratory which is used MVS. Presented method with fuzzy logic approach is the useful tool for supporting the decision making system of MVS choosing for the stakeholders.

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