Selection of the basic parameters of the lens for the optic-electronic target recognition system

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Abstract: This article deals with determination of lens parameters of the optic-electronic system for detection, recognition and identification of moving military targets in dependency on their distance. There are basic assumptions for determination of the most important parameters of the lenses suitable for systems of automatic target acquisition described in the article.

Key-Words: Lens, camera, image, military target, detection, recognition, identification

1 Introduction

Observation and automatic processing of the scene at the military applications differs from the industrial applications especially at the distance of observed moving objects – military targets.
The optical part of the intelligent system for observation of the combat scene must allow tracking of moving targets up to distance of 3000m. This big range of distances of the target creates very high demands on quality of the optical system, the optic-electronic system, and also the capability of the algorithm to recognize and identify the military target.
The "surveillance path" of the optic-electronic system for object recognition consists of surveillance camera with lens, electronic unit and display unit. The system surveillance path – computer-software algorithm allows detection, recognition, and identification of the target. By means of this system is a rangefinder guided on the target to localize him.

2 Problem - Detection, recognition and identification of the target

The most important parameter for evaluation of quality of optic-electronic system for target recognition, from user point of view, is his range for individual types of targets. The range of the surveillance path is the maximum distance of the target at which can be detected, recognised and identified. Detection, recognition and identification are three levels of reconnaissance task, see Table 1.

Table 1 Resolving criteria

criterion	description of image of the target
detection	patch, target will bee seen
recognition	target recognised, distinguished class (tank, armour fighting vehicle, etc.)
identification	target recognised, specified type (tank T-72, version M1)

3 Solution of the problem

The range of optic-electronic system for target recognition and quality of image of the target are always defined on the basis of the following conditions and parameters:

- emissive and reflective characteristics of the target, his effective surface area and orientation;
- distance of the target and his contrast towards background;
- transfer characteristics of atmosphere;
- focal length of scan lens and its focal ratio;
- quality of optical imaging;
- geometric characteristics of detector;
- sensitivity of detector;
- minimal illumination, exposure time.

On basis of many experiments, e.g. [4], [7] was concluded that the most suitable parameter for evaluation of accomplishment of given visual

reconnaissance task, i. e. detection, recognition or identification of the target, is the bar-chart resolution test. The measures and criteria of performance of resolution were originally developed by Johnson at 1958. Today is this method still improved and elaborated.
Spatial frequency (period), dimensions, mean magnitude of luminance and contrast of bar-chart resolution test depends on solved reconnaissance task, type of tracked target, and conditions of observation. Dimensions are the same as critical dimensions of the target (the smallest dimension of the target). Mean magnitude of luminance $L_{S,T}$ depends on both mean magnitude of luminance of target $L_{S,C}$ and background $L_{S,P}$:

$$L_{S,T} = \frac{L_{S,C} + L_{S,P}}{2}. \qquad (1)$$

Contrast of bar-chart resolution test is given by:

$$C_T = \left| \frac{\frac{L_{S,C} - L_{S,P}}{2}}{L_{S,T}} \right| = \frac{\Delta L_T}{L_{S,T}}. \qquad (2)$$

According to [4] holds true for determination of probability of detection, recognition and identification in dependency on number of periods at equivalent bar-chart resolution test across target of critical dimension following relations:

$$P_n = \frac{\left(\frac{n}{n_{50}}\right)^E}{1 + \left(\frac{n}{n_{50}}\right)^E}, \qquad (3)$$

$$E = 2.7 + 0.7 \cdot \left(\frac{n}{n_{50}}\right), \qquad (4)$$

where n is a number of periods at equivalent bar-chart resolution test and n_{50} is number of periods at equivalent bar-chart resolution test for 50% probability of detection, recognition and identification. Individual probabilities are shown at Figure 2.

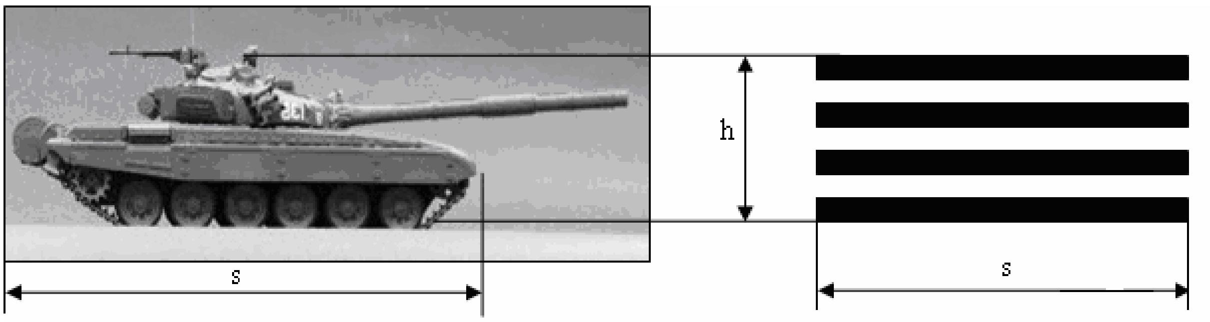

Fig. 1 Equivalent bar-chart resolution test for determination of 50% probability of detection, recognition and identification

Table 2 50% probability of solving reconnaissance task

target	number of periods of equivalent bar-chart resolution test on critical dimension of target		
	detection	**recognition**	**identification**
tank	0.75	3.5	6
AFV	1	4	5
car	1.2	4.5	5.5
person	1.5	3.8	8
howitzer	1	4.8	6

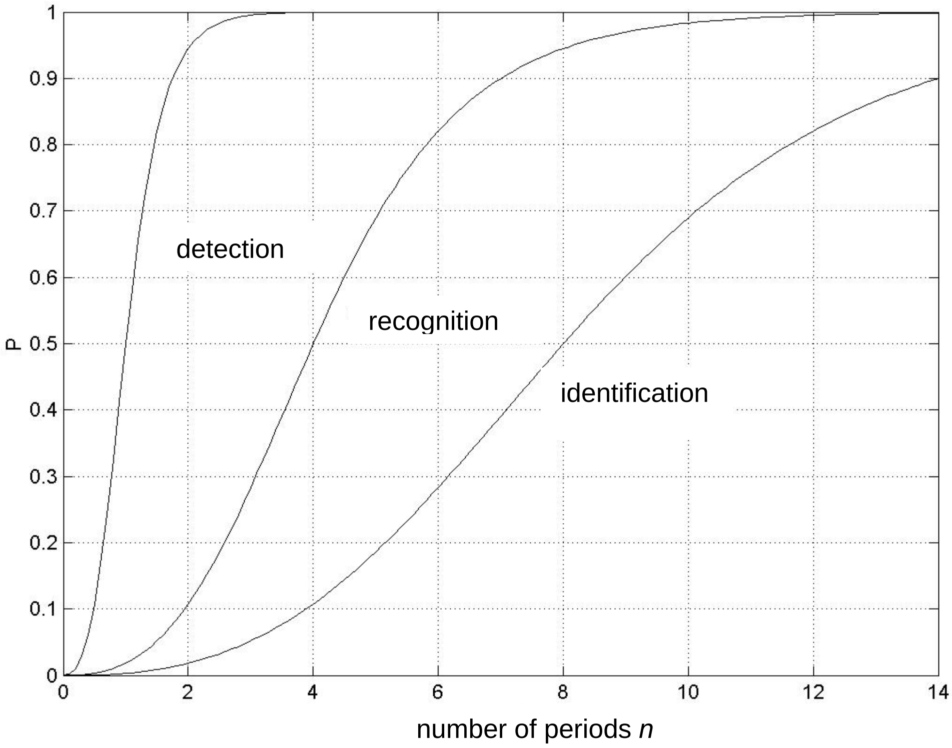

Fig. 2 Individual probabilities of detection, recognition and identification of the target in dependency on number of periods of equivalent bar-chart resolution test

Table 3 50% probability of solving reconnaissance task for target of height of 3m in dependency on focal length of scanning lens

f' [mm]	$2\omega_v$ [° ′]	$2\omega_s$ [° ′]	**detection** [m]	**recognition** [m]	**identification** [m]
15	15 12	23	2812	703	350
25	9	13 40	4687	1171	585
35	6 30	9 50	6562	1640	820
50	4 40	6 50	9375	2343	1171
75	3	4 40	14062	3515	1757
100	2 20	3 25	18750	4687	2343
150	1 30	2 20	28125	7031	3515

On the basis of calculation of the 50% probability solving of reconnaissance task for target of height of 3m in dependency on variable focus length of scanning lens were obtained the ranges for detection, recognition and identification for seven different lenses, see Table 3.
From Table 3 follows that for real observation can be used the lens with focal length $f' = 50$ mm.

The surveillance path can secure, in case of size one pixel of the surveillance CCD camera $\rho = 8$ μm, detection of above defined target at distance of 9375m, recognition at distance of 2343m and identification at distance of 1171m.

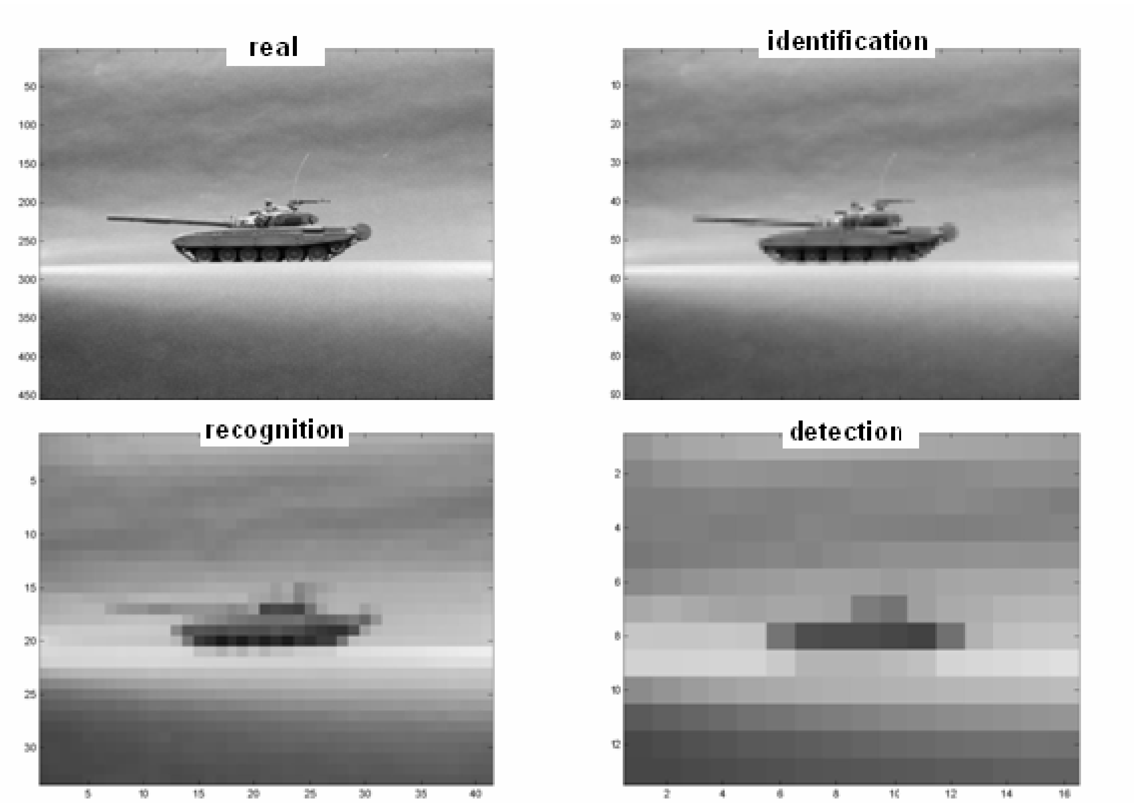

Fig. 3 Example of modelling of identification, recognition and detection of predefined target at different distances at imaging of surveillance path

The Figure 3 shows images, as they appear at surveillance path, from modelling of identification, recognition and detection of the defined target at different distances.

The distances presented at Table 4 are valid for individual levels of reconnaissance task only under assumption ideal visibility and introduce "geometrical" criteria of maximum range. Contrast between target and background is $c = 0.84$.

During determination of basic parameters of the lens it is necessary to set the minimal focal ratio *c*. The selection of parameters of lenses is governed mainly by required quality of image of the target and must respect following physical limits. In case when one pixel of the detector is a square of side *d*, then focal ratio c_a of lens which Airy disc just fits into this pixel holds true following relation:

$$c_a = \frac{d_a}{2.44 \cdot \lambda}. \qquad (5)$$

Taking into account size of the pixel 8 μm x 8 μm, wave length λ = 600nm, the minimal focal ratio of the lens will be about 5.6.

Another important characteristic of the lens is its optical transfer function of contrast. In case of non-coherent radiation, all cases of scanning of military armament and vehicles, is the transfer function given by following relation:

$$D_{(s)} = \frac{2}{\pi} \cdot \left(\arccos s - s \cdot \sqrt{1 - s^2} \right), \qquad (6)$$

where $s = \lambda \cdot c \cdot R$ and R is real spatial frequency at image plane.

This characteristic is very important for determination of quality of imaging on the detector. For example when the tank of height of 2.5m is at the distance of 3000m from the camera its spatial frequency is 1200lines/rad and is imaged by lens with foal ratio $f = 5.6$ for wave length $\lambda = 600\text{nm}$, contrast $k = 0.88$, see point *d* at Figure 4. In case of recognition task when it is required to resolve 7 periods is the spatial frequency 8400lines/rad and they are imaged with contrast $c = 0.27$, see point *r* at Figure 4. When contrast of the tank with regard to the background is $c = 0.6$ and contrast of Johnson criteria is $c = 0.7$ then during detection the tank will appear with contrast $c = 0.528$ and contrast between periods of bar-chart resolution test will be $c = 0.189$ which is on boundary of recognition.

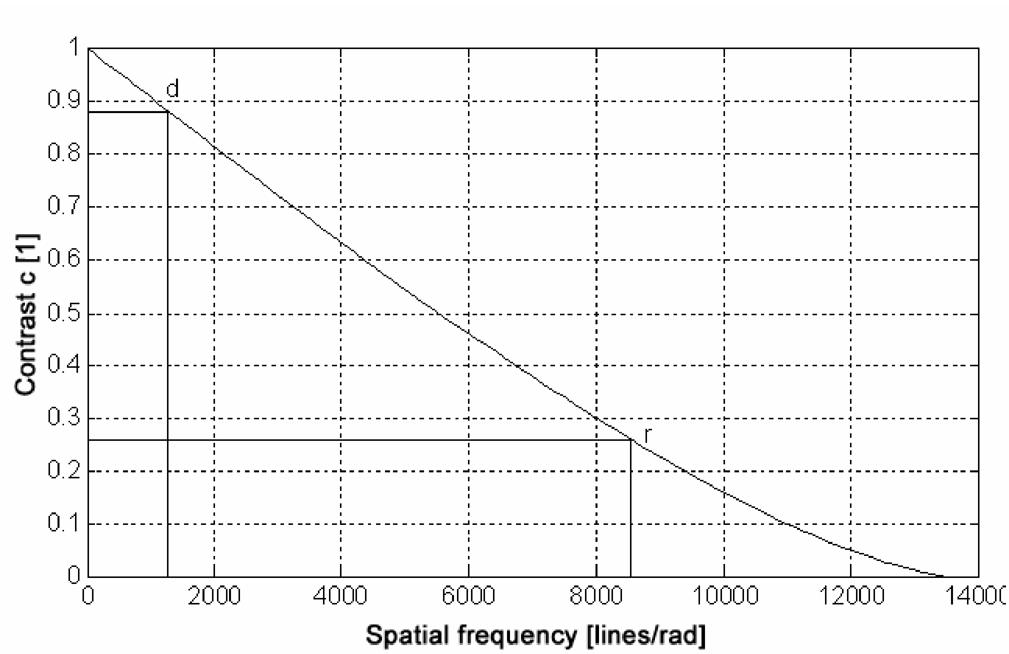

Fig. 4 Optical transfer function of lens contrast $c = 5{,}6$ for wave length $\lambda = 600\text{nm}$

4 Conclusion

There is shown way of determination of basic parameters of lens. The determination of these parameters belongs to the first step at synthesis of optic-electronic system for target tracking. These parameters allow, at least approximately, determine quality of image of the target at detector plane and consequently determine probability of detection, recognition and identification.

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