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METHOD FOR DETERMINATION OF TARGET ACQUISITION AND RECOGNITION TIME WITH ENGAGEMENT OF LAND UNMANNED COMPLEX

Existing model of adversary engagement does not permit to assess the time behavior of adversary engagement process and it should be upgrade. Land-unmanned complexes equipped with both wide-angle TV-camera and TV-sight is considering as the first opposing force.

The main parameters of viewing process at acquisition and recognition: condition of image watch and target contrast are took into consideration. Time of target acquisition and recognition is assessed for different contrast and target image watch conditions: on remote display or head-mounted indicator.

Assessment results have shown following. Information should be present simultaneously on remote display and head-mounted indicator at target acquisition by wide-angle TV-camera and target recognition by TV-sight taking into account the relevant advantages of augmented reality systems.

Keywords: *land unmanned complex, adversary engagement, acquisition and recognition time.*

INTRODUCTION

Analysis of the trends on armament and military equipment development of the leading states has permitted to identify an important trend [1]. It is engagement of the battle robots for execution of the reconnaissance, engineering, battle and logistical tasks. It deals with prospects of the land-unmanned complexes (LUC) of heavyweight and middleweight classes [2]. Therein an assessment of LUC participation results in adversary engagement with the different kinds of enemy weapon is important.

As it is shown in paper [3], the most probability for target discomfiture in adversary engagement has a party X or Y, which early has acquired and recognized target and began to attack it:

$$P_{X>Y}(t, \Delta t) = [e^{-x\Delta t}\, e^{-x(t-\Delta t)}\,(1- e^{-y(t-\Delta t)})]/[1-(1- e^{-x(t-\Delta t)})\,(1- e^{-x(t-\Delta t)}\, e^{-y(t-\Delta t)})], \qquad (1)$$

where $P_{X>Y}$ – win probability of X party the Y party, t – shooting duration, Δt – advantage in time for shooting start of one from party, x and y – density of shot flows of opposite parties X and Y accordingly.

However, that model of adversary engagement does not permit to assess the time behavior of adversary engagement process and it should be upgrade.

The purpose of this research is to develop the method for determination of target acquisition and recognition time with engagement of LUC.

TARGET ACQUISITION TIME

Target acquisition is carrying out by wide-angle TV-camera, target recognition is carrying out by TV-sight and information is presenting on remote display, when LUC participates in adversary engagement from X party. Therefore, a time advantage in shot start is determining by formula

$$\Delta t = (t_{acqY} + t_{recY}) - (t_{acqX} + t_{recX}). \qquad (2)$$

In addition, it depends on operator experience [4] which interacts with remote display, where t_{acqY} is target acquisition time by *Y* party, t_{acqX} is target acquisition time by *X* party, t_{recY} is target recognition time by *Y* party and t_{recX} is target recognition time by *X* party.

Let we analyze the possibility of early target acquisition on screen of remote display on basis of random search theory [5]. Time $t_{acq,j}$ depends on coefficient α only when probability $P_{acq,j}$ of target acquisition is prescribed:

$$t_{acq,\,j} = -ln(1- P_{acq,j})/\,\alpha_j. \quad \ldots \qquad (3)$$

Whereas coefficient α (at other equal conditions) depends on object image area on display γ^2 (min^2) and its contrast *K*:

$$lg\alpha_j = -4{,}3 + 5{,}6K + 1{,}6lg\gamma_j^{\,2}. \qquad (4)$$

Let we consider a model of wide-angle TV-camera for determination of parameter γ_Y^2 (Fig. 1).

As it is shown in paper [5], observer begins to act on determined system in training process when target search within wide field. He divides that field mentally by zones, where he realizes an accidental target acquisition and transition between zones is realizing line-by-line of row-by-row. There is necessary to take into account the eye view field, where image quality is satisfactory, to prevent time losses during view transfer. According to [6] that field is 30° on elevation angle and 40° on azimuth.

Then, the display dimensions should not exceed 182 mm on horizon and 134 mm vertical (diagonal is 226 mm = 8,9") at information imaging on remote display 4, which is observed from distance of the best eyesight equal to 250 mm.

Electron magnification M_{el} in information imaging system is determining as ratio of the display and CCD-matrix and at application of CCD-matrix with average size (width 20,32 mm, height 15,24 mm, diagonal 0,5", pixel size a_{ccd} = 2 µm) M_{el} =8,9"/0,5" = 17,8^x.

In order to LUC operator had possibility to be oriented in space, view field of wide-angle TV-camera must correspond to observation angle of display (horizontal component of TV-camera view field $2\beta_h$ = 40°). Focal length f'_2 of lens 2 of wide-angle TV-camera is determining by formula $f'_2 = 20{,}32/2tg\beta_h$ and it equal to 28 mm at the mentioned type of CCD-matrix. Resolving power *R* of wide-angle TV-camera is determining by formula $R = a_{ccd}/f'_2$ and it is 0,07 µrad = 14".

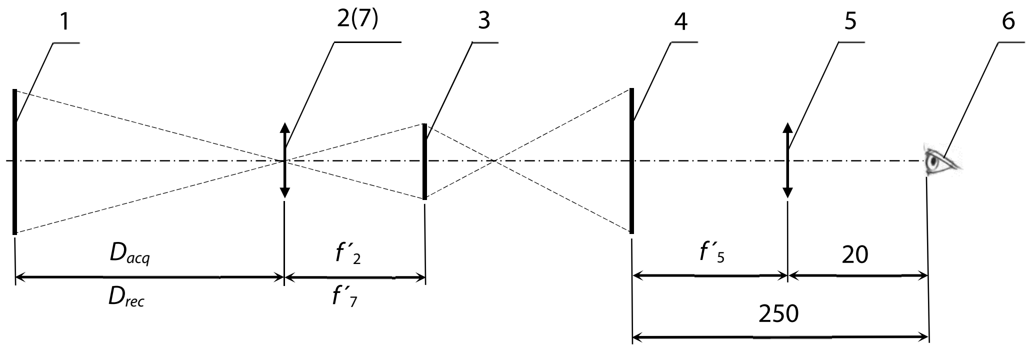

Fig. 1. Models of wide-angle TV-camera and TV-sight:
1 – target, 2 – lens of wide-angle TV-camera,
3 – CCD-matrix, 4 – remote display (micro-display when image presentation on helmet-mounted indicator),
5 – lens of helmet-mounted indicator, 6 – eye of LUC operator, 7-lens of TV-sight

Maximal distance D_{acq} for acquisition of man with average dimensions 1,67 x 0,41 m [7] in accordance with Johnson's criteria with probability 0,95 is determining by formula

$$D_{acq} = 0{,}41/M\,N\,R, \qquad (5)$$

where: N = 1 – quantity of test object equivalent periods for target acquisition with probability 0,5, M = 2 – factor for recalculation of probability perception [8] and 0,41 – man critical dimension.

We get D_{acq} = 2928 m, if to enter all known data into (5). In this case, parameter γ_Y^2 is determining by formula

$$\gamma_Y^2 = (1{,}67 \text{ x } 0{,}41)(3440\, f'_2\, M_{el} /250\, D_{acq})^2$$

and it is 3,7562 (min^2). Entering this value into (4) permit to get dependence of coefficient α_j on contrast K of target image on display:

$$\alpha_Y = 10^{-3{,}3804+5{,}6K}. \qquad (6)$$

Formula (3) takes a form:

$$t_{acq,X} = 3/10^{-3{,}3804+5{,}6K}, \qquad (7)$$

if to take into consideration the probability of target acquisition $P_{acq,j}$ = 0,95 for successful execution of battle task by party X with engagement of LUC.

As it has been shown on the last international exhibitions of armament and military equipment, the helmet-mounted indication system, which was applied at first in aviation engineering, find a wide application now in Land-forces. The advantage of that system before remote display is information correspondence to real observation direction into prescribed coordinates and information maintaining before operator eyes at free position of his head if there is integration with system for protect helmet positioning [9].

If information imaging on micro-display 4 of helmet-mounted indication, then linear aperture of lens 5 should be determined by formulas

$$\text{width} = d_{ex.pupil} + 2l tg\beta_h, \text{ height} = d_{ex.pupil} + 2l tg0{,}75\beta_h, \qquad (8)$$

where $d_{ex.pupil}$ = 8 mm on experience [10] – exit pupil diameter of helmet-mounted indicator, l =20 mm – eye relief (fig. 1).

Substitution of the known data into formulas (8) gives the valued of lens width 22,6 mm, height 18,7 mm and lens conditional diameter D_5 = 29,3 mm. Lens focus f'_5 would be determined from D.S. Volosov's quality criteria [11] for lens with diameter 29,3 mm and view field 50° (β = 25°):

$$f'_5 \geq (D_5\, tg\, \beta/C_Q)^2, \qquad (9)$$

where C_Q = 2,4 – lens quality criteria according to D.S. Volosov's researches.

Substitution of the known data into formulas (9) gives result $f'_5 \geq$ 32,4 mm. Let we accept f'_5 = 32,4 mm for minimization of the helmet-mounted indicator dimensions. Having such value of 5 lens focus the dimensions of micro-display 4 are determining by formulas

$$\text{width} = 2\, f'_5\, tg\beta_h, \text{ висота} = 2\, f'_5\, tg0{,}75\beta_h \qquad (10)$$

and it is 23,6 x 17,4 mm (diagonal 29,3 mm = 1,15"). The last achievements of micro-electronic engineering in area of production of the liquid-crystal micro-displays [12] (matrix 8K4K D-ILA has pixel dimension 4,8 micron) create preconditions for designing of the indicators with high resolution. Electron magnification M_{el} in information imaging system is 1,15"/0,5" = 2,3 ones when such micro-display.

In that case parameter γ_Y^2 is determining by formula

$$\gamma_Y^2 = (1{,}67 \text{ x } 0{,}41)(3440\, f'_2\, M_{el}/\, f'_5\, D_{acq})^2$$

and it is 3,7338 (min^2). Substitution of that value into (4) permits to get a dependence of coefficient α on contrast K of target image on display:

$$\alpha_Y = 10^{-3{,}3846+5{,}6K}. \qquad (11)$$

With accepted probability of target acquisition $P_{acq,j}$ = 0,95 an equation(3) gets a view

$$t_{acq,X} = 3/10^{-3{,}3846+5{,}6K}. \qquad (12)$$

Analyzing the dependences (7) and (12) we can do a following conclusion: time of target acquisition on screen of remote display is less to a certain extent then a time of target acquisition on helmet-mounted indicator. That time advantage $\Delta t_{acq,X}$ may be determined by dependence

$$\Delta t_{acq,X} = 70/10^{5{,}6K}.$$

We can see from that formula: if $K \to 0$ then $\Delta t_{acq,X} \to 70$ and if $K \to 1$ then $\Delta t_{acq,X} \to 0$. And it is meaning: if target contrast is high then both options of information visualization are equivalent. Option of information visualization on remote display has advantage if low target contrast.

Therefore there can be concluded – information should be presented simultaneously on remote display and on helmet-mounted indicator when target is acquisitioned with application of wide-angle TV-camera taking into account the relevant advantages of augmented reality systems. Operator will choose a need image personally estimating visually its quality.

TARGET RECOGNITION TIME

Let we consider possibility of early target recognition on screen of remote display on base of random search theory. As it was mentioned above, target recognition is carrying out by operator with application of TV-sight. Block diagram of TV-sight is similar to block diagram of wide-angle TV-camera presented in Fig. 1, where digit 7 indicates a lens of TV-sight. In choosing the view field of LUC TV-sight we should proceed from the following considerations.

In recognition of man with average dimensions 1,67 x 0,41 m on the Johnson's criteria with probability 0,95, the maximal distance for recognition D_{rec} is determining by formula (5), where $N = 8$ [8].

At CCD-matrix of chosen type, a focal length f'_7 of TV-sight lens 7 is determining by formula: $f'_7 = 20{,}32/2tg\omega_h$, where $2\omega_h$ – horizontal component of TV-sight view field.

The following condition should be carried out in order to LUC operator acquisitioned target on maximal distance D_{acq} = 2928 m and recognized it on a same distance:

$$f'_7 = 16\, D_{acq}.\, a_{ccd}\,/0{,}41. \quad (13)$$

Such approach is based on the fact that LUC has not always possibility to get near target for it recognition, therefore there is reasonably to accept $D_{acq} = D_{rec}$.

Substitution of the known data into formulas (13) gives result f'_7 = 228,5 mm. With these we get $2\omega_h$ = 5,1° and TV-sight resolution R is determining by dependence $R = a_{ccd}/f'_7$ and it is 0,009 mrad = 1,75".

In that case parameter γ_Y^2 is 250,15 (min^2) when displaying on remote display. With the accepted target recognition probability $P_{rec,j}$ = 0,95 formula (3) get a view

$$t_{rec,X} = 3/10^{-0.4629+5,6K}. \quad (14)$$

When information is displaying on helmet-mounted indicator micro-display 4 (Fig.1) then parameter γ_Y^2 is 248,66 (min^2). With the accepted target recognition probability $P_{rec,j}$ = 0,95 formula (3) get a view

$$t_{rec,X} = 3/10^{-0,467+5,6K}. \quad (15)$$

Analyzing the dependences (14) and (15) we can do a following conclusion: time of target recognition on screen of remote display is less to a certain extent then a time of target recognition on helmet-mounted indicator. That time advantage $\Delta t_{rec,X}$ may be determined by dependence

$$\Delta t_{rec,X} = 0{,}0826/10^{5,6K}.$$

We can see from that formula: if $K \to 0$ then $\Delta t_{rec,X} \to 0{,}0826$ and if $K \to 1$ then $\Delta t_{rec,X} \to 0$. And it is meaning: both options of information visualization are equivalent.

Therefore there can be concluded – information may be presented on remote display or on helmet-mounted indicator when target is recognized with application of TV-sight.

Substituting the expressions (7) and (14) or (12) and (15) into (2) we can find the expressions for calculation of man acquisition and recognition time on distance 2928 m by party X with application of remote display and helmet-mounted indicator depends on target contrast:

$$(t_{acqX} + t_{recX}) = 7212 \times 10^{-5,6K}; \qquad (t_{acqX} + t_{recX}) = 7282 \times 10^{-5,6K}.$$

Obviously, a same approach may be applied for acquisition and recognition time assessment for any other target if it critical dimension is known.

There is necessary to know a target type and its search and sighting system for assessment of component $(t_{acqY} + t_{recY})$ in formula (2). It is reasonable to consider in the further researches.

CONCLUSION

The proposed method for determination of target acquisition and recognition time with engagement of LUC has permitted to identify some peculiarities. For example, time for target acquisition on screen of remote display is some less then a time of target acquisition on helmet-mounted indicator. Information may be displayed on remote display or on helmet-mounted indicator at target recognition by means of TV-sight because of both options are equivalent to recognition time.

General conclusion may be done on the results of the carried out comparison of man acquisition and recognition time at application of remote display and helmet-mounted indicator.

The images formed by wide-angle TV-camera and TV-sight of land-unmanned complexes should be displayed simultaneously on remote display and helmet-mounted indicator with purpose to present possibility for operator to choose image estimating visually its quality.

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МЕТОДИКА ВИЗНАЧЕННЯ ЧАСУ ВИЯВЛЕННЯ ТА РОЗПІЗНАВАННЯ ЦІЛІ НАЗЕМНИМ РОБОТИЗОВАНИМ КОМПЛЕКСОМ

Проведений аналіз розвитку озброєння та військової техніки провідних країн дозволив виділити важливу тенденцію: застосування бойових роботів при виконанні розвідувальних, інженерних, бойових і тилових задач. В Сухопутних військах це стосується перспектив створення наземних роботизованих комплексів важкого і середнього класу.

Тому оцінка результатів участі наземних роботизованих комплексів у протиборстві з різними типами ворожого озброєння є важливою. Для такої оцінки застосовується ймовірнісна модель, приймаючи до уваги щільність та тривалість обстрілів протиборчих сторін. Однак ця модель протиборства не дозволяє дослідити часові характеристики процесу протиборства і потребує вдосконалення.

Мета статті – розробити методику визначення часу виявлення і розпізнавання цілі протиборчою стороною, яка використовує наземний роботизований комплекс, обладнаний телевізійною камерою широкого поля зору і телевізійним прицілом, який розглядається як перша протиборча сторона.

Час виявлення і розпізнавання цілі оцінено, виходячи з теорії випадкового пошуку для різного контрасту і умов спостереження зображення цілі – на віддаленому дисплеї або на нашоломному індикаторі.

Запропонована методика визначення часу виявлення і розпізнавання цілі дозволила виявити деякі особливості. Наприклад, час розпізнавання на екрані віддаленого дисплею дещо менше часу розпізнавання цілі на нашоломному індикаторі. Інформація може відображатись на віддаленому дисплеї або на нашоломному індикаторі при розпізнаванні цілі телевізійним прицілом, оскільки обидва варіанти рівнозначні щодо часу розпізнавання.

Загальний висновок можна зробити за результатами порівняння часу виявлення та розпізнавання людини на віддаленому дисплеї і на нашоломному індикаторі.

Зображення, сформовані телевізійною камерою широкого поля зору і телевізійним прицілом наземного роботизованого комплексу, доцільно відображати одночасно на віддаленому дисплеї і на нашоломному індикаторі з метою надання оператору вибору зображення, оцінюючи візуально його якість.

Ключові слова: *наземний роботизований комплекс, протиборство, час виявлення і розпізнавання.*

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