UDC: 004.8 (075) https://doi.org/10.15407/jai2022.02.098

PROBABILITY INCREASE OF TARGET RECOGNITION BY UNMANNED COMPLEX ARTIFICIAL INTELLIGENCE

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Abstract. The thermal imager, which helps operator to orient on area, detect and recognize target in the night conditions, is included as rule in structure of battle modules of unmanned complexes. Partially these tasks are placing on electronics at implementation of artificial intelligence into unmanned complex. But classical thermal imager optical system forms on digital photodetector the two-dimensional image of surrounding space. It hinders the target recognition by battle unmanned complex artificial intelligence at night conditions. It is well known from fundamental theory of phenomena of light reflection and refraction on border "medium-air", which is described by Fresnel's low for metals and dielectrics, the polarization rate of thermal objects depends on position of normal of object elementary small surface relatively to direction of its observation (relatively to optical axis of observation device). At the same time, polarization rate of surface own irradiation is increasing at rise of angle between irradiation direction and normal to irradiation surface. And that angle is changing within wide diapason, for example, during exploration from unmanned complex board. On that base there is possibility to determine the third coordinate of target elementary small surface and to image a 3D target on thermal imager display screen or to recognize a target by unmanned complex artificial intelligence. Authors show, including of infrared polarizer, rotating around the thermal imager optical system axis on fixed angles, into thermal imager structure permits to determine the third target coordinate and to increase a probability for its recognition by unmanned complex artificial intelligence in that case.

Keywords: unmanned complex, unmanned complex, thermal imager, infrared polarizer, recognition probability, heat target.

Introduction

The issues of artificial intelligence (AI) implementation into battle unmanned complex (UC) are considered in detail in [1]. There is emphasizing – UC AI has possibility to identify the images of obstacles and targets independently and to form a command for UC controls on maneuver for overcoming obstacles or for pointing guns at target on the results of self-study. Thermal imager is using for that purpose in night conditions.

Problem statement

Classical thermal imager optical system [2] forms on digital photodetector the two-dimensional image of surrounding space. It hinders the target recognition by UC artificial intelligence.

Analysis of the last researches and publications

The methods of object shape determination based on processing of the thermal image electrical signals by digital photodetector in process of infrared polarizer rotation are considering in technical literature [3-8]. But these methods are applying for scientific researches when object is situated on small distance, image is shown on display and system for object surface scanning and motors with reducers for scanning and infrared polarizer rotation are provided in thermal imager structure.

Research purpose

Target recognition in battle UC (like to unmanned aerial vehicle and land UC) is carrying out on big distance. Space analysis is carrying out in process of carrier movement and restrictions on the dimensions exclude using of scan mechanical system and motors with reducers. The thermal imagers for battle UC forms the two-dimensional image of surrounding space on digital photodetector [9]. This make it difficult to recognize a target in case of AI implementation.

Research purpose is development of thermal imager structural scheme for UC, which implements the well-known methods for target shape determination and upgrades a target recognition probability due to this.

Basic material description

From fundamental theory of reflection and refraction light phenomenon on border "medium-air", which is described by Fresnel's low for metals and dielectrics [10], it is well-known — the polarization rate of thermal objects P_ψ depends on position of normal of object elementary small surface relatively to direction of its observation ψ (relatively to optical axis of observation device):

$$P_\psi=[(n^2+k^2-1)\sin\psi]/[(n^2+k^2+1)(\cos^2\psi+1)+ 4n\cos\psi], \quad (1)$$

where n and k – the real and imaginary parts of complex refractive index of target elementary small surface material.

As it is seen from (1), the polarization rate P_ψ essentially depends on indexes n and k. For example, dielectrics have $k<<1$, and $1< n<2$ and polarization rate is less compared with metals, which have $(n^2+k^2)>>1$ [7]. We also note that P_ψ depends on state of irradiating surface. As shown in study [11], polarization rate of surface own irradiation of the metals, alloys and structural materials is stable enough, depends little on wave length in infrared diapason and keeps its significance even in roughly processed surfaces.

This implies an important conclusion: polarization rate of metal targets own heat irradiation and it angle indicatrix $P_\psi=f(\psi)$ are very informative unmask signs when targets detection on weak polarized natural background. It is a base for creation the polarization thermal imager for probability increase of the disguised targets.

The following operations should be carried out to get the third coordinate of target heat image [2]:

- to input target into thermal imager view field due to UC movement;
- to polarize an optical thermal imaging signal by means of linear infrared (IR) polarizer;
- to carry out an electron scanning of target surface by digital photodetector and to form a television frame;
- to convert an optical signal in electrical by means of digital photodetector;
- to form a series of polarizing thermal images with polarization azimuths in diapason 0…180° due to rotation of linear infrared polarizer on discrete angles;
- to calculate the third coordinate of target by the formulas on base of values of gotten video-signals for every element of television frame;
- to recognize a target by UC artificial intelligence on base of target 3D digital image.

Thermal imager block diagram for these operations implementation is shown in fig. 1.

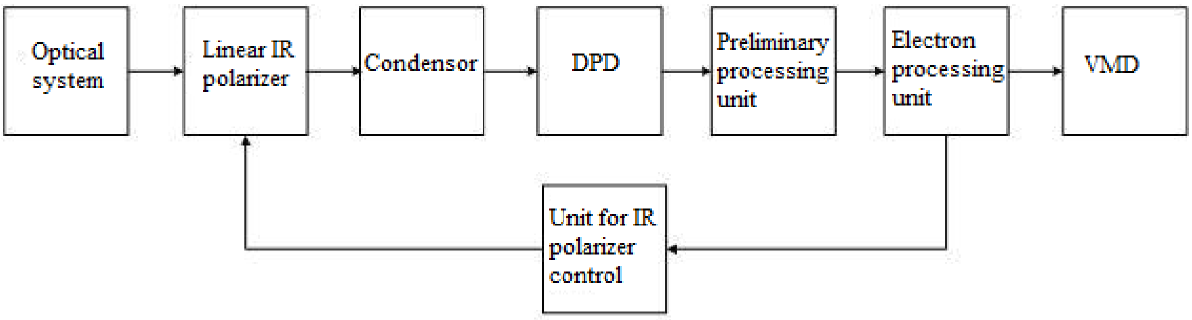

Fig. 1. Thermal imager block diagram

Theoretically, linear IR polarizer may be installed inside of thermal imager, in front of digital photodetector (DPD) [3]. In that case, optical system is IR telescopic system, because of linear IR polarizer should work in parallel beam of rays, and it demands a condenser installed in exit pupil of telescopic system in front of DPD. That all increases thermal imager length and restricts it usage in UC structure. From this point of view, it is better to install the IR polarizer on optical system input. In that case, optical system is ІЧ lens with DPD in it focal plane. In this case there is not necessity in condenser.

IR polarizer control may be carried out by stepper motor with reducer connected with electron processing unit [5]. If this is acceptable for scientific devices, then it will be problematic issue for thermal imagers intended for small-sized UC. Therefore, on our opinion, rotation of IR polarizer on discrete angles should be implemented by means of sequential turn on of electromagnets installed around of linear IR polarizer on the signals from electron processing unit.

DPD decomposes object image on separate elements in process of passage of heat irradiation from target in view field of thermal imager, installed on UC, through linear IR polarizer and optical system.

At the first, angle of inclination of every element of target surface relatively to observation direction ψ(N, K) (where *N* – number of line in frame, *K* – number of element in decomposition line) may be determined by four thermal images with polarization azimuths γ_n: 0°, 45°, 90° and 135° [12]. For that purpose, a linear IR polarizer is rotating by electromagnets system around optical system axis on angles 0°, 45°, 90° and 135°.

If IR polarizer azimuth $\gamma_п = 0°$, then on DPD exit within frame are formed NxK video signals $U_0(N, K)$. Similarly there are forming video signals $U_{45}(N, K)$ at $\gamma_п=45°$, $U_{90}(N,K)$ at $\gamma_п=90°$ and $U_{135}(N,K)$ at $\gamma_п=135°$ of all elements of television frame decomposition. All these four frames are memorizing in preliminary processing unit and information is processing in electron processing unit. In processing result of four polarization thermal images we can determine angle of inclination ψ(N, K) of every element of target surface relatively to observation direction by formula

$$\psi(N,K) = \arccos(1-M_1/M_2),$$

where

$M_1 =[U_0(N,K) — U_{90}(N,K)]/[U_0(N,K) + +U_{90}(N,K)]$,

$M_2 = g\cos\{\mathrm{arctg}[U_{45}(N,K) – U_{135}(N,K)]/ /[U_0(N,K) — U_{90}(N,K)]\}$,

g — constant, which depends on material and roughness of target surface.

Then for random line of electron scanning of target surface the desired equations for it surface shape may be written as:

$$x(N,K)|_{y=const} = z(N,K)\mathrm{tg}\psi(N,K), \qquad (2)$$

$$x(N,K)|_{z=const} = y(N,K)\mathrm{tg}\psi(N,K), \qquad (3)$$

where *x* (depth), *y*, *z* – *C*artesian coordinates of the dots on target surface.

Presence of the third coordinate of object shape will help UC artificial intelligence to identify a target (obstacle) and to display it on screen pf video monitoring device (VMD) together with additional information of data base, which is stored in electron processing unit. UC operator is using this information for UC permission/ban on maneuver at overcoming obstacles and on defeat of the target.

Angle of inclination of every element of target surface relatively to observation direction ψ(N, K) may be determined by three thermal images with polarization azimuths $\gamma_п$: 0°, 60° and 120° with purpose to simplify a thermal imager structure and to reduce the time on information processing in electron processing unit. For that purpose, a linear IR polarizer is installing for rotation around optical system axis on angles 0°, 60° and 120° [7].

In this case the 3D shape of target within heat contour is determining by formulas (2) and (3) at

$$\psi(N,K) = \arccos(1-M_3/M_4),$$

where

$M_3=3[U_{60}(N,K) – U_{120}(N,K)]/g[U_0(N,K) + +U_{60}(N,K)]$,

$M_4 =1/\sin\{\mathrm{arctg}[3(U_{60}(N,K) –U_{120}(N,K))]/ U_{120}(N,K))]/[2U_0(N,K) + U_{60}(N,K)+ +U_{120}(N,K)]\}$.

Angle of inclination of every element of target surface relatively to observation direction ψ(N, K) may be determined by two thermal images with polarization azimuths $\gamma_п$: 45° and 90° with purpose to further reduce the time on information processing. For that purpose, an IR polarizer in block diagram on fig. is carried out as consecutively installed quarter wave plate with orientation angle of fast axis 45° and linear IR polarizer [13].

In this case the 3D shape of target within heat contour is determining by formulas (2) and (3) [6] at

$\psi(N,K) = \arccos[1-(M_5/M_6)^{1/2}/g]$,

where $M_5=U_{45}(N,K) – 1$,
$M_6=2\sin\{arctg[(U_{45}(N,K) –1)/(1-U_{90}(N,K)]-(U_{45}(N,K) – 1)\}$,
$U_{45}(N,K)$ and $U_{90}(N,K)$ – values of video signals of polarization images with polarization azimuths 45° and 90°.

Also, to determine a target shape in real time we can on base of one polarization image. For that purpose, an IR polarizer in block diagram on fig. Is carried out also as consecutively installed quarter wave plate with orientation angle of fast axis 45° and linear IR polarizer with azimuth γ_n: 0° [14]. As it is known, its transmission matrixes have a view:

$$\tau_{i,j}= \tau_{\lambda/4} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix};$$

and

$$\tau_{i,k}= \tau_n \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

where $\tau_{\lambda/4}$ and τ_n – transmission coefficients of quarter wave plate and linear polarizer accordingly. In this case a polarization image has not properties of classic thermos-gram and Stokes vector-parameter Φ_k for flow of irradiation of combined polarizer has view [14].

$$\Phi_k = \sum_{i=1}^{4}\tau_{i,k}^{(2)}\sum_{j=1}^{4}\tau_{i,j}^{(1)}\Phi_i, \quad k = 1, 2. 3, 4,$$

where Φ_i — flow of target own irradiation. Because of the first element of Stokes vector-parameter of heat irradiation Φ_k, which passed through combined polarizer, is characterizing the energetic flow of target heat irradiation, then DPD output signal may be presented as

$U_0(N,K) = \Phi_{k=1}S = S\tau_o\Phi\, \tau_{\lambda/4}\, \tau_п[1- P_\psi(N,K) \sin2\xi]$,

where S – DPD sensitivity, τ_o – optical system transmission index and ξ – index of heat irradiation ellipticity [10].

In this case the 3D geometry of target shape within heat contour is determining by formulas [6].

$x(N,K)|_{z=const} = x(N-1,K)+y(N,K)tg\psi(N,K)$,

$x(N,K)|_{y=const} =x(N,K-1)+ z(N,K)tg\psi(N,K)$,

where angle ψ is determining by formula
$\psi = \arccos[1-0,67M^{1/6}_7 \cos(0,33arctgM_8)/g +M_9]$,

where
$M_7 = [18(1-U_0) +(1-U_0)^3]^2 – [(1-U_0)^4+ +11(1-U_0)-1]^2$,
$M_8 = [(1-U_0)^4+11(1-U_0) -1]/[18(1-U_0)+(1-–U_0)^3]$,
$M_9 = (1-U_0)/3g$.

Conclusion

1.There is developed the thermal imager block diagram, which permits to determine the target shape on base of it optical properties.

2.3D target shape will increase a probability of target recognition and classification by both unmanned complex artificial intelligence and UC operator.

3.There is shown, two Cartesian coordinates of the surface elements are determining by dimensions of target heat image and depth calculation is carrying out due to polarization rate P_ψ of every image element dependence on orientation angle ψ of target irradiating elementary small surface.

4.There are considered four variants for angle ψ determination: on base of linear polarizer and four or three azimuths of it position; on base of combined polarizer and two or one azimuth of it position. Option choose should be done by thermal imager designer on base of UC developer requirements.

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The article has been sent to the editors 09.11.22
After processing 30.11.22