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Training Simulator of Camera Supported Manual Command to Line of Sight Guidance of Antitank Missiles

Slobodan Mandić[1)]
Miloš Pavić[1)]
Srđan Stojković[1)]
Bojan Pavković[1)]

Manual Command to Line of Sight (CLOS) guidance systems of antitank missiles require a human operator in the guidance loop. His task is to track both the target and the missile, and to generate commands in order to bring the missile into the Line of Sight (LOS). The efficiency of the guidance depends on the skill of the human operator. One type of the training simulator for manual LOS guidance, the realization of which is based on the simulation of the missile silhouette over the prerecorded videos of the background with fixed and moving targets, is given in the paper. The coordinates of the targets, read from the recorded videos of the background, are transformed into the real positions of the targets in the space. These target positions in a function of time are the input to the mathematical model of the missile movement relative to the target. The calculated coordinates of the missile are transformed into the missile silhouette position on the screen display of the training simulator. The complete mathematical model and the description of the hardware realization with the results of the characteristic simulation are given in the paper.

Key words: **antitank missile, guided missile, TV training simulator, TV visor.**

Notation and symbols

$\boldsymbol{V}_K$	- Kinematic velocity (velocity relative to the Earth)
U_K, v_K, w_K	- Components of the missile kinematic velocity
p, q, r	- Missile angular rates
Φ, Θ, Ψ	- Roll, pitch and yaw angle
x, y, z	- Missile coordinates in the inertial axis system
X, Y, Z	- Components of the aerodynamic force in the semi-fixed axis system
Q	- Dynamic pressure
V	- Missile velocity relative to the air
ρ	- Air density
$S=\pi d^2/4$	- Reference area
C_x, C_y, C_z	- Aerodynamic coefficients of the forces
L, M, N	- Rolling, pitching and yawing moments
C_l, C_m, C_n	- Rolling, pitching and yawing coefficients
C_{Ao}, C_{A_2}	- Derivatives of the axial force coefficients
$C_{N\alpha}, C_{Nq}$	- Derivatives of the normal force coefficients
C_{lo}, C_{lp}.	- Derivatives of the rolling moment coefficients
$C_{m\alpha}, C_{mq}$	- Derivatives of the pitching moment coefficients
α, β	- Angle of attack and sidslip angle
$p^* = p\, l / V$	- Normalized rolling angular rate
$q^* = q\, l / V$	- Normalized pitch angular rate
$r^* = r\, l / V$	- Normalized yaw angular rate
u_w, v_w, w_w	- Components of the wind velocity in the semi-fixed axis system
w_x, w_y, w_z	- Components of the wind velocity in the Earth axis system
$\boldsymbol{C}(\Psi, \Theta, \Phi)$	- Transformation matrix from the Earth to the semi-fixed axis system
η_j, ζ_j	- Commands generated by joystick
η_g	- Compensation of the gravity
η_c, ζ_c	- Commands in the vertical and horizontal planes
v_c, φ_c	- Magnitude and direction of the command in polar form
T_d, T_i	- Compensator time constants
λ	- Trust vector steering command (TVC)
$F_{L\max}$	- Maximum TVC lateral force
F_y, F_z	- TVC control forces
M_y, M_z	- TVC control moments
l_{TVC}, l_{CM}	- Trust vector control and the centre of mass positions from the apex of the missile
x_T, y_T, z_T	- Target coordinates in the inertial axis system
χ_{LOS}, γ_{LOS}	- Line of sight angles
x_l, y_l, z_l	- Missile coordinates in line of sight axis system
$\varepsilon_V, \varepsilon_H$	- Angles of the missile line of sight position relative to the target line of sight (LOS)
ΔX_{or}^m	- Distance between the two fixed landmarks in meters

1) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA

ΔX_{or}^{pix}	- Distance between the two fixed landmarks in pixels
R_{pix}^{m}	- Video ratio between meters and pixels
X_T^{pix}, Y_T^{pix}	- Target coordinates in pixels in the video frame
x_T^c, y_T^c, z_T^c	- Target coordinates in the camera axis system
D_T	- Distance from the camera to the target
$\varepsilon_V, \varepsilon_H$	- Angle between the missile and the target LOS
y_{MP}^l, z_{MP}^l	- Coordinates of the missile projection on the target plane relative to the LOS axis system
$X_{MP}^{pix}, Y_{MP}^{pix}$	- Position of the missile relative to the left border of the video frame

Introduction

The Manual Command to Line of Sight (MCLOS) guidance system of antitank missiles requires a human operator in the guidance loop. The operator must track the missile and the target simultaneously and guide the missile to the target. The missile is steered with a joystick, and its path is observed through a periscope-type telescopic sight. Missiles are usually equipped with a magnesium flare in the base that ignites automatically upon launch and allows the gunner to track the fast-moving missile visually [1-3].

Electro-optical (EO) sensors (cameras) allow reliable visual identification at ranges beyond those necessary to even detect the target with the naked eye. They are entirely passive, sensing energy emitted by the target or reflected from the target. With increasing performance and decreasing cost, EO systems are also used into the area of missile guidance. A new generation of low-cost inertial stabilization modules (ISMs) provides an integrated solution for low-cost inertial Line of Site (LOS) stabilization of any payload for mobile platforms including ground, air, and sea. Inertial stabilization improves camera images while the camera platform is on the move. The ISM allows real-time computer control during stabilization, enabling closed loop systems for tracking. The stabilization provided by the ISM allows the use of higher zoom cameras for tracking and detection systems aboard moving platforms.

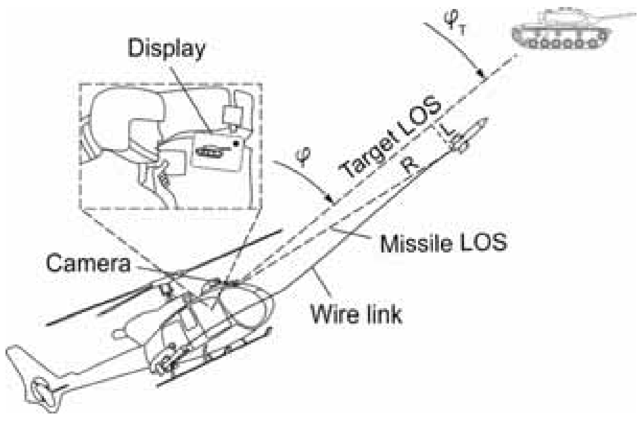

Figure 1. Camera supported manual CLOS guidance

These low-cost inertial LOS stabilized cameras are used for the improvement of existing MCLOS guided antitank missiles lauched from helicopters. The operator tracks the missile and the target on the display in the cockpit. Based on the difference between the target and the missile on the camera display, the operator generates the stearing commands by a joystick in order to minimize this difference (Fig.1). The zoom law of the camera is programmed in advance in order to track the missile and the target efficiently for all target positions from the minimum range to the maximum one.

The angles φ and φ_T are the angular positions of the missile and the target line of sights in the inertial space. Position of the missile relative to the target LOS is proportional to the angular misalignment between the missile and the target line of sight $L = R\left(\varphi_T - \varphi\right)$, where R is the distance from the camera to the missile.

A block diagram of an MCLOS guidance system is given in Fig.2. Since this guidance loop is unstable, it is necessary to add a compensator in the guidance loop [2-6].

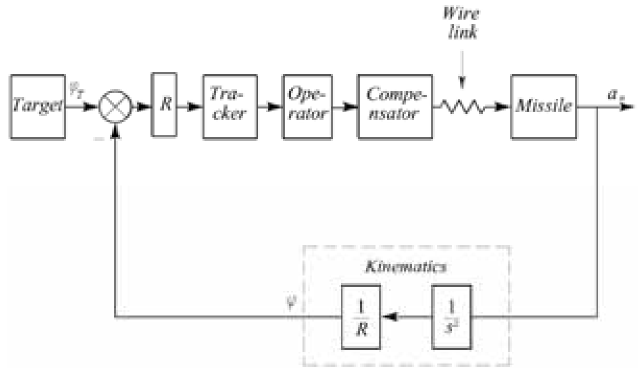

Figure 2. Block diagram of a manual CLOS guidance closed loop.

MCLOS requires considerable training and practice to master, since even a minor disruption in the operator's concentration is likely to cause a miss. These guidance systems have marginal accuracy on tank-sized targets, even with a perfect line-of-sight obtained by the operator.

Therefore, this type of guidance requires a training simulator to increase the skill of the human operator [2, 7-8]. This paper presents one type of the training simulator for MCLOS guidance, based on the drawing of the missile silhouette over the prerecorded videos of the background with fixed or moving targets.

The coordinates of the target, read from the recorded videos of the background, are transformed to the real position of the target in the space. These target coordinates in function of the time are input to the mathematical model of the missile movement relative to the target. The calculated coordinates of the missile are transformed into the missile silhouette position on the screen display of the training simulator.

The complete mathematical model of the training simulator of the MCLOS guidance of antitank missiles is given in the paper.

Concept of the training simulator

The concept of the simulator treated in the papers [7-9] is related to the transformation of the target position from the target plane to the image formation plane. This image formation plane is the plane normal to the axis of the camera. The position of this plane is defined by the missile position relative to the camera axis system and moves with the missile.

Since the concept of the training simulator considered in this paper is based on the video recorded by camera, the target plane is a plane normal to the camera axis, located at the target position in the space. A simulator of the manual LOS guidance of antitank missiles with prerecorded videos of the background requires the image formation of the missile on the target plane. The missile position relative to the line of sight is transformed to the missile projection on the target plane (Fig.3). The target (T) and the missile projection (MP) are given on the target plane. The position of the camera axis and the line of sight relative to the inertial basic axis system $Ox_0y_0z_0$ are defined by the angles χ_K, γ_K, χ_{LOS} and γ_{LOS}.

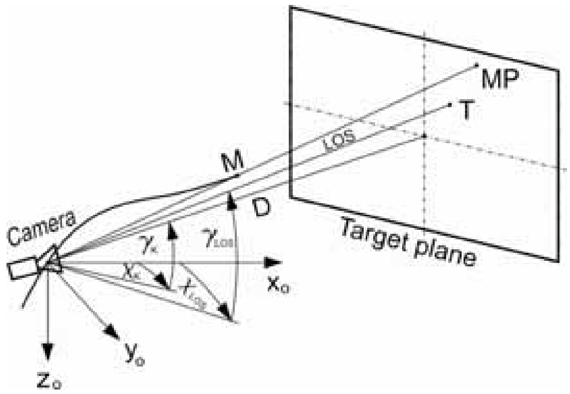

Figure 3. Image formation on the target plane.

The training simulator of the manual command to line of sight (MCLOS) guided antitank missile consists of:

- Stand-alone computer,
- Two displays (instructor and operator),
- Operator joystick,
- Acquisition interface,
- Electronics interface device.

The block diagram of the training simulator is given in Fig.4.

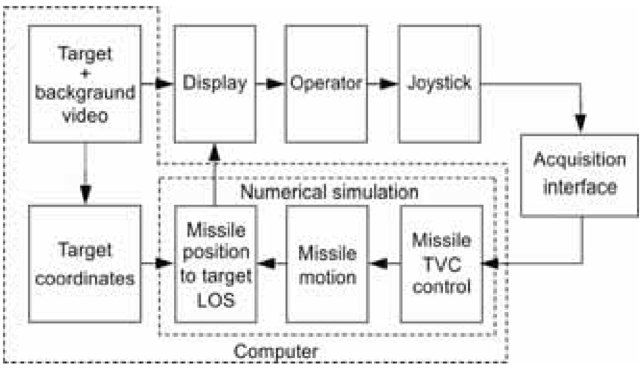

Figure 4. Training simulator block diagram.

The missile steering commands from the operator joystick are led to the electronic interface device and the acquisition interface. These commands are the input to the numerical simulation of the missile flight. Based on the calculated missile coordinates in the space, the missile silhouette is drawn on the display monitor over the prerecorded video.

Mathematical model of the missile flight

The major missile subsystems were modeled: the vehicle dynamics, aerodynamic data, thrust vector control and compensator in the forward loop.

Missile model

The missile model developed in this study was a full nonlinear dynamic model with nonlinear aerodynamic data. The motion of a missile in the space with 6 degree-of-freedom (6 DOF) is described by twelve differential equations [2-3, 10]. The equations of motion in the semi-fixed axis system for a cruciform missile are:

$$\dot{U}_K = rv_K - qw_K + (X + F_x)/m - g\sin\Theta$$

$$\dot{v}_K = pw_K - rU_K + (Y + F_y)/m + g\sin\Phi\cos\Theta$$

$$\dot{w}_K = qU_K - pv_K + (Z + F_z)/m + g\cos\Phi\cos\Theta$$

$$\dot{p} = L/J_x$$

$$\dot{q} = (J_y - J_x)/J_y pr + (M + M^F)/J_y$$

$$\dot{r} = (J_x - J_y)/J_y pq + (N + N^F)/J_y$$

$$\dot{\Phi} = p + q\sin\Phi\tan\Theta + r\cos\Phi\tan\Theta$$

$$\dot{\Theta} = q\cos\Phi - r\sin\Phi$$

$$\dot{\Psi} = q\sin\Phi/\cos\Theta - r\cos\Phi/\cos\Theta$$

$$\begin{aligned}\dot{x} &= U_K\cos\Theta\cos\Psi + v_K(\sin\Phi\sin\Theta\cos\Psi - \\ &-\cos\Phi\sin\Psi) + w_K(\cos\Phi\sin\Theta\cos\Psi + \sin\Phi\sin\Psi) \\ \dot{y} &= U_K\cos\Theta\sin\Psi + v_K(\sin\Phi\sin\Theta\cos\Psi - \\ &-\cos\Phi\sin\Psi) + w_K(\cos\Phi\sin\Theta\sin\Psi - \sin\Phi\cos\Psi) \\ \dot{h} &= -\dot{z} = U_K\sin\Theta - v_K\sin\Phi\cos\Theta - w_K\cos\Phi\cos\Theta\end{aligned} \tag{1}$$

where: U_K, v_K, w_K are the components of the missile velocity $\boldsymbol{V}_K$ relative to the Earth in the semi-fixed system; p,q,r are the roll, pitch and yaw rates in the semi-fixed system; Φ,Θ,Ψ are the roll, pitch and azimuth angle; x,y,z are the coordinates of the missile position in the Earth-fixed reference frame (inertial system).

The aerodynamic force components along the three semi-fixed axes are represented by X,Y,Z in terms of the aerodynamic coefficients:

$$\begin{aligned}X &= C_xQS \\ Y &= C_yQS \\ Z &= C_zQS \\ Q &= \rho V^2/2\end{aligned} \tag{2}$$

with ρ being the air density, V the missile velocity relative to the air, $S=\pi d^2/4$ the reference area and Q the dynamic pressure. The alternative symbols for the axial force are $C_A = -C_X$, and for the normal force $C_N = -C_Z$.

The components of the aerodynamic moment about the semi-fixed axes are defined as the rolling moment (L), the pitching moment (M) and the yawing moment (N) in terms of the corresponding coefficients C_l, C_m and C_n:

$$\begin{aligned}L &= C_lQSl \\ M &= C_mQSl \\ N &= C_nQSl\end{aligned} \tag{3}$$

where l is the reference length, usually $l=d$.

The following form of the force and moment coefficients are used in this study:

$$
\begin{aligned}
&C_A = C_{Ao} + C_{A_2}\left(\alpha^2+\beta^2\right)\\
&C_N = C_{N\alpha}\cdot\alpha + C_{Nq}\cdot q^*\\
&C_Y = -C_{N\alpha}\cdot\beta + C_{Nq}\cdot r^*\\
&C_l = C_{lo} + C_{lp}\,p^*\\
&C_m = C_{m\alpha}\cdot\alpha + C_{mq}\cdot q^*\\
&C_n = C_{m\alpha}\cdot\beta + C_{mq}\cdot r^*
\end{aligned}
\tag{4}
$$

The angular velocities are normalized by V/l:

$$
p^* = \frac{p\cdot l}{V},\; q^* = \frac{q\cdot l}{V},\; r^* = \frac{r\cdot l}{V} \tag{5}
$$

All derivatives of the force and moment coefficients in equations (4) are the functions of the Mach number.

In the above equations, the aerodynamic forces and moments are calculated for the missile velocity relative to the air:

$$
\begin{aligned}
&\begin{bmatrix} U\\ v\\ w\end{bmatrix} = \begin{bmatrix} U_K\\ v_K\\ w_K\end{bmatrix} - \begin{bmatrix} u_w\\ v_w\\ w_w\end{bmatrix}\\
&V = \sqrt{U^2+v^2+w^2}
\end{aligned}
\tag{6}
$$

Having in mind the components of the wind velocity in the Earth axis system, we can determine its components in the semi-fixed axis system:

$$
\begin{bmatrix} u_W\\ v_W\\ w_w\end{bmatrix} = \boldsymbol{C}\left(\Psi,\Theta,\Phi\right)\begin{bmatrix} w_x\\ w_y\\ 0\end{bmatrix} \tag{7}
$$

where **C** is the transformation matrix [10].

Compensator

Based on the angular difference between the target line of sight and the missile line of sight, the human operator generates the command by a joystick in two perpendicular directions (η_j, ζ_j). The command in one direction corresponds to the vertical plane of the missile flight (η_j) and the second one to the horizontal plane (ζ_j). Compensations of the gravity (η_g) must be added to the command generated by the joystick in the vertical plane.

$$
\begin{aligned}
&\eta_c = \eta_j + \eta_g\\
&\zeta_c = \zeta_j
\end{aligned}
\tag{8}
$$

These commands can be written in the polar form.

$$
\begin{aligned}
&\nu_c = \sqrt{\eta_c^2+\zeta_c^2}\\
&\varphi_c = \arctan\frac{\zeta_c}{\eta_c}
\end{aligned}
\tag{9}
$$

The maximum value of the commands in the polar form ν_c is limited to the value $\nu_{c\,\max}=1$.

The stability of the guidance loop of the command to the line of sight guidance is realized by a differential compensator in the forward loop

$$
\frac{\lambda(s)}{\nu_c(s)} = \frac{T_d s+1}{T_i s+1} \tag{10}
$$

where λ is the trust vector steering command.

The transfer function of the compensator can be written as a first order differentional function.

$$
T_i\frac{d\lambda}{dt} + \lambda = T_d\frac{d\nu_c}{dt} + \nu_c \tag{11}
$$

Since there is a derivation of the input to the compensator, the previous equation can be written in the canonical form [11].

$$
\begin{aligned}
&\lambda = \lambda_1 + \frac{T_d}{T_i}\nu_c\\
&\dot\lambda_1 = -\frac{1}{T_i}\lambda_1 + \frac{\left(1-T_d/T_i\right)}{T_i}\nu_c
\end{aligned}
\tag{12}
$$

TVC Forces and Moments

The lateral control force, generated by the trust vector control (TVC), is proportional to the steering command λ

$$
\begin{aligned}
&F_y = \lambda\,F_{L\max}\cos\varphi_c\\
&F_z = \lambda\,F_{L\max}\sin\varphi_c
\end{aligned}
\tag{13}
$$

where $F_{L\max}$ is the maximum lateral force.

The TVC control moments are the functions of the trust vector control position

$$
\begin{aligned}
&M_y = F_z\left(l_{TVC}-l_{CM}\right)\\
&M_z = -F_y\left(l_{TVC}-l_{CM}\right)
\end{aligned}
\tag{14}
$$

where l_{TVC} and l_{CM} are the trust vector control and the centre of mass positions from the apex of the missile, respectively.

Missile position relative to the target LOS

The line of sight position is defined by the angles χ_{LOS} and γ_{LOS} relative to the inertial axis system (Ox_0, y_0, z_0). These angles are defined by the known position of the target relative to the camera (Fig.3).

$$
\begin{aligned}
&\chi_{LOS} = \arctan\frac{y_T}{x_T}\\
&\gamma_{LOS} = -\arcsin\frac{z_T}{\sqrt{x_T^2+y_T^2+z_T^2}}
\end{aligned}
\tag{15}
$$

The position of the missile (M) relative to the axis system fixed to the LOS is defined by the coordinates x_l, y_l, z_l (Fig.4)

$$
\begin{bmatrix} x_l\\ y_l\\ z_l\end{bmatrix} = \boldsymbol{C}\left(\chi_{LOS},\gamma_{LOS},0\right)\begin{bmatrix} x\\ y\\ z\end{bmatrix} \tag{16}
$$

The position of the missile line of sight relative to the target line of sight (LOS) is defined by the angles ε_H and ε_V.

$$\begin{aligned} \varepsilon_V &= -\arctan\frac{z_l}{x_l} \\ \varepsilon_H &= \arctan\frac{y_l}{x_l} \end{aligned} \tag{17}$$

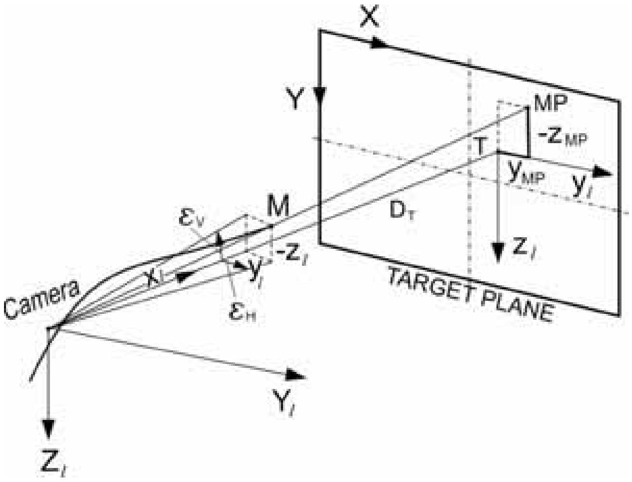

Figure 5. Missile position relative to the LOS.

The cordinates of the projected position of the missile (MP) on the target plane are a function of the known distance to the target (D_T).

$$\begin{aligned} y_{MP}^{l} &= D_T \tan\varepsilon_H \\ z_{MP}^{l} &= -D_T \tan\varepsilon_V \end{aligned} \tag{18}$$

Visualization

In order to simplify the interpretation of the recorded video, it is defined that the target is moved in the target plane (Fig.6). It is also necessary to know the distance between minimum two landmarks in the target plane. These landmarks define the coincidence of the video frame to the space coordinates of the target.

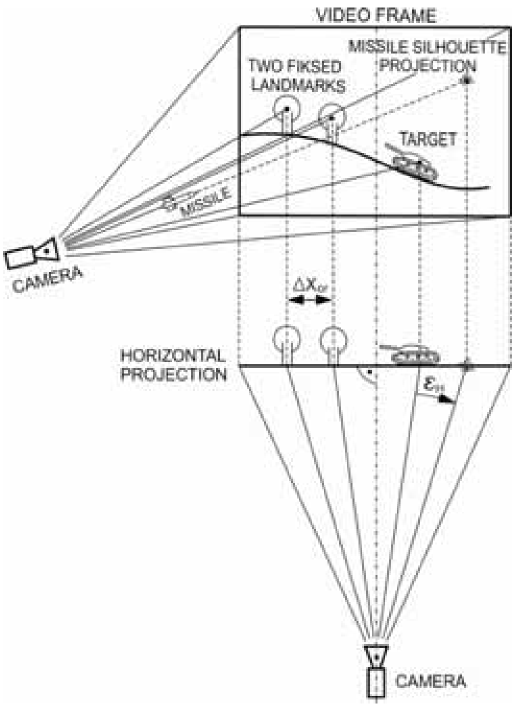

Figure 6. Landmarks and target position in the video frame.

Video-frame ratio

The ratio (time function) for a recorded video is determined as a quotient of a known distance between two fixed landmarks at the target distance, expressed in real-space meters and video-frame pixel coordinates (Fig.6).

$$R_{pix}^{m} = \frac{\Delta X_{or}^{m}}{\Delta X_{or}^{pix}} \tag{19}$$

Target coordinates

The target coordinates are read in pixels (X_T^{pix}, X_T^{pix}) from the recorded videos in the axis system AXY fixed to the upper left corner of the video-frame (Fig.7).

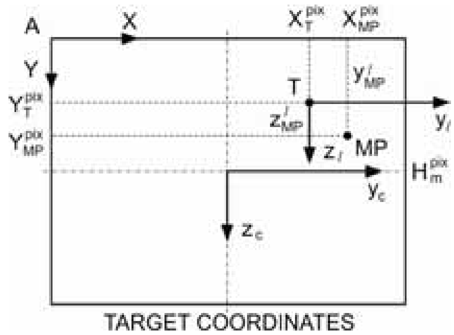

Figure 7. Target and missile silhouette in the video-frame axis system.

As the width and height of the video-frame are known (W_m^{pix}, H_m^{pix}), the target coordinates in the camera axis system can be determined based on the video-frame ratio. The distance of the target plane in the camera axis system is D_T^c.

$$\begin{aligned} x_T^c &= D_T \\ y_T^c &= \left(X_T^{pix} - W_m^{pix}/2\right) R_{pix}^{m} \\ z_T^c &= \left(Y_T^{pix} - H_m^{pix}/2\right) R_{pix}^{m} \end{aligned} \tag{20}$$

The target coordinates in the inertial axis system are obtained from the camera axis system by the transformation matrix

$$\begin{bmatrix} x_T \\ y_T \\ z_T \end{bmatrix} = \boldsymbol{C}^T\left(\chi_c, \gamma_c, 0\right) \begin{bmatrix} x_T^c \\ y_T^c \\ z_T^c \end{bmatrix} \tag{21}$$

Missile silhouette coordinates

Since the target coordinates in pixels are known (X_T^{pix}, X_T^{pix}), the coordinates of the missile silhouette (missile projected point) in the video-frame axis system can be determined from the coordinates of the missile projected point in line of the sight axis system (Fig.7).

$$\begin{aligned} X_{MP}^{pix} &= X_T^{pix} + \frac{y_{MP}^{l}}{R_{pix}^{m}} \\ Y_{MP}^{pix} &= Y_T^{pix} + \frac{z_{MP}^{l}}{R_{pix}^{m}} \end{aligned} \tag{22}$$

The operator's display of the missile silhouette presentation over the prerecorded video is given in Fig.8. This example is a visual presentation of the combat simulation of the missile guidance against a fixed target (bunker).

Figure 8. Missile silhouette presentation over the prerecorded video

Conclusion

The training simulator of the manual LOS guidance of antitank missiles analyzed in the paper is based on the display of the missile silhouette over the prerecorded videos of the background with fixed or moving targets. The videos of the background are recorded by a camera fixed to a helicopter as a missile launcher.

The ratio between meters and pixels on the video is based on the relative distance in meters between two reference points at the target plane and the same distance in pixel on the video. Based on this ratio, the real position of the target relative to the inertial reference frame fixed to the camera is determined from the target position on the video.

A six-degree of freedom mathematical model of the missile flight is used for a numerical simulation of the missile flight. The steering command of the trust vector control, obtained with a joystick, is the input to the differential compensator. The mathematical model of the differential cascade compensator is given in the canonical form in order to avoid derivatives of the input.

Based on the missile position in the axis system fixed to the camera view axis, the position of the missile silhouette on the target plane is determined.

The coordinates of the missile silhouette on the target plane are used for the calculation of the coordinates of the missile silhouette on the display window frame of the training simulator.

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Simulator ručnog telekomandovanog sistema vođenja protivtenkovskih raketa po liniji viziranja

U petlji vođenja ručnih telekomandovanih sistem vođenja protivtenkovskih raketa po liniji viziranja uključen je čovek (strelac) čiji je zadatak da prati cilj i raketu, i da stvara komandu za dovođenje rakete u pravac linije viziranja cilja. Razvoj novog tipa kamera sa stabilizacijom ose, sa softverskim podešavanjem zakona zumiranja i detektorom za praćenje ciljeva u dnevno-noćnim uslovima omogućio je modernizaciju ručnih telekomandovanih sistem vođenja protivtenkovskih raketa. Efikasnost ovog tipa vođenja protivtenkovskih raketa zavisi od veštine i obučenosti strelca, koja se postiže obukom na simulatorima. Razvoj računarske tehnike omogućio je izradu simulatora koji se bazira na simulaciji kretanja siluete trasera rakete preko unapred snimljenog filma sa fiksnim i pokretnim ciljem. Koordinate cilja pročitane sa filma su u pikselima. Na osnovu poznatih koordinata orijentira određuje se položaj cilja u prostoru. Numerička simulacija kretanja rakete je bazirana na matematičkom modelu šest stepeni slobode. U toku numeričke simulacije, u realnom vremenu, se izračunate koordinate rakete u prostoru pretvaraju u položaj siluete trasera rakete na ekranu simulatora

Ključne reči: **PO raketa, vođena raketa, TV trenažer, TV vizir.**

Симулятор ручной эксплуатации ТВ-управляемой системы ведения противотанковых ракет по линии визирования

В петле наведения ручных ТВ-управляемых систем наведения противотанковых ракет по линии визирования включён человек (бомбардир-стрелок), задачей которого является мониторинг цели и ракеты, и создание команды привести ракеты в направление линии визирования цели. Разработка нового типа камеры со стабилизацией оси, со законом масштабирования регулируемого с помощью программного обеспечения, с детектором для сопровождения целей в суточных условиях обеспечила модернизацию ручных ТВ-управляемых систем наведения противотанковых ракет. Эффективность этого типа наведения противотанковых ракет зависит от мастерства и подготовки стрелка, которые достигаются путём обучения на тренажёрах. Развитие компьютерных технологий позволило разработать тренажёр, который основан на моделировании движения силуэта вспышки ракеты через предварительно записанный фильм с неподвижным и движущимся целями. Целевые координаты считываются из фильма в пикселях. На основе известных координат ориентиров определяется положение цели в пространстве. Численное моделирование движения ракеты основано на математической модели с шестью степенями свободы. В течение численного моделирования в режиме реального времени, вычисленные координаты ракеты в пространстве преобразуются в позиции силуэта вспышки ракеты на экране тренажёра.

Ключевые слова: **противотанковые ракеты, управляемые ракеты (командование по линии визирования), ТВ-тренажёр, ТВ-прицел.**

Le simulateur du système manuel télécommandé du guidage des missiles antichars

La commande manuelle sur la ligne de vision du système de guidage chez les missiles antichars exige un opérateur humain pour la boucle de guidage. Sa tâche est de suivre la cible et le missile et de créer la commande pour mener le missile dans la direction de la ligne de vision de cible. Le développement du nouveau type de caméra à l'axe stabilisé, à l'adaptation numérique de zoom et au détecteur de suivi des cibles jour et nuit a permis la modernisation des systèmes manuels télécommandés du guidage des missiles antichars. L'efficacité de ce type de guidage dépend des capacités et de l'entraînement de l'opérateur, ce qu'on réalise pendant l'entraînement sur le simulateur. Le développement de l'informatique a permis la réalisation du simulateur basé sur la simulation du mouvement de la silhouette du traceur de missile à l'aide du film réalisé préalablement aux cibles fixes ou mobiles. Les coordonnées de la cible lues sur l'écran sont exprimées en pixels. La position de la cible dans l'espace est déterminée par des coordonnées connues de l'orientation. La simulation numérique du mouvement de missile est basée sur le modèle mathématique à six degrés de liberté. Pendant la simulation numérique dans le temps réel les coordonnées calculées du missile dans l'espace se transforment en position de silhouette du traceur de missile sur l'écran de simulateur.

Mots clés: **missile antichar, missile guidé, simulateur d'entraînement, ligne de vision.**