Optic–electronic aims coordinate switch and orientation research based on many vehicle systems

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An integer coordinate commutation project is advanced which leads the aim angle information form optic–electronic detecting system to aim map orientation system and then to countermine system under the middle precision GPS orientation section. This way can we solve the difficult problem that the warning aims coordinate commutation among many optic–electronic vehicle systems. The aim orientation is realized by neat matrix principle. First, the 12 coordinate systems of optic–electronic detecting vehicle system and laser countermine system are defined. Then, the aim coordinate transform mode is changed from the warning system to the countermine system. It seems that this mode can satisfy the "360" error request of the two vehicle optic–electronic system aim coordinate leading orientation under the complexion of without regarding to the relatively position and angle of the optic–electronic detecting vehicle and laser countermine vehicle.

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At present conditions, the single vehicle system cannot realize the detection, tracking, confrontation, recovery, power supplying, and command functions on the optic–electronic confrontation field. In huge optic–electronic countermine system, the detecting and warning functions always integrate to one vehicle system and the laser countermine system always integrates to another vehicle system. So one key function of the system is high-precision induction to another[1–3]. Here we discuss, how to take the aim coordinates of the warning vehicle system conversion to the light axis coordinates of the optic–electronic countermine system. The coordinate transposition was put forward under the condition that the warning system and countermine system can nicety seek north. The coordinate transposition is based on 12 coordinate systems. By this way the exact coordinate can be used to the efficiency induction to the countermine system. And the relatively ubiety of the warning and countermine systems need not regard in this way.

The functions of the whole optic–electronic system consist of warning and tracking to the aims and proved the high-precision leading information for other weapon systems. All of the detecting information should be exchanged to suit the campaign required. There are two main systems, one is the warning system which is put on the warning vehicle and the other is the countermine system which is put on the countermine vehicle. The work of the warning vehicle is detecting the aims' azimuth and pitching angles. The work of the countermine vehicle is shock the coming aims which need the angle information of the aims. The position interspaced relation of the two main vehicles is not identical when they are disposed on some place. So the position

relationship of the two vehicles is a dynamic relationship. In this condition how to change the warning system's detecting aim angle to the countermine system's angle information is a very important technology in this system[4–6]. The mast optic–electronic detecting equipment is similar to the optic-measure equipment whose coordinate system contains pitching axes, azimuth axes, and watching axes. The inducting data of the optic–electronic warning and detecting system should be changed to the coordinates of the optic–electronic countermine system's azimuth and pitching angles. In this course, the interspaced positions of the aims, the optic–electronic warning and detecting system, the warning vehicle, the optic–electronic countermine system, and the countermine vehicle should be known. And these data come from the global positioning system (GPS) orientation, the north fight orientation, and the pointing north system. The azimuth angle and pitching angle of the coming aims come from the optic–electronic coder, pointing system, and undershoot measure data. The measure of the coordinate exchanging will be used to high-precision orientate the coming aims while the vehicles being any position on the earth.

The coordinate and code were defined[7,8]. The warning and detecting system uses GPS to orientate whose coordinate system is called WGS-84 coordinate system. In our country, the BJ-54 earth coordinate system is usually used to orientate the space aims. Now let us talk about the changing coordinate systems which are being used to change by meat matrices. The a–i coordinate systems are used to change the center horizon coordinate system to aim coordinate system. Using the nine coordinate systems can get the aims' exact

position. And the next three coordinate systems are used to change the unification aim coordinate to the servo and tracking angle of the optic–electronic countermine system. The two coordinate changing modes were put forward in a creative way. Figure 1 shows horizon coordinate system and Fig. 2 shows vehicle equipment coordinate system.

a. Center horizon earth coordinate system: $A(a_1, a_2, a_3)$
  a_1 pointing positive north, a_2 and other direction being right-hand coordinate connection, a_3 pointing roof direction.

b. The earth's core coordinate system: $B(b_1, b_2, b_3)$
  The origin of the coordinate system is at the center of earths mass. b_1 is at the deal line between the universal chronometer seed surface and equator face. b_2 and other two directions are right-hand coordinate connection. b_3 points to north and posits with earth rotation climaxes.

c. Optic–electronic detecting and tracing vehicle coordinate system: $C(c_1, c_2, c_3)$
  The meaning of the coordinate system is the position of the vehicle at some time. c_1 is the running direction of the vehicle. c_2 and other two directions are right-hand coordinate system relationship. c_3 points roof direction.

d. Optic–electronic detecting vehicle coordinate system (its coordinate system is superposition with c when the three axes gesture being 0): $D(d_1, d_2, d_3)$
  The three-axes gesture angles of the vehicle horizon coordinate system separately are $\theta_{dc}(t)$, $\phi_{dc}(t)$ and $\psi_{dc}(t)$ which separately being the corners rolling the c_1, c_2, and c_3 axes.

e. Optic–electronic detecting mast and flat roof coordinate systems (calling mast-roof coordinate system): $E(e_1, e_2, e_3)$
  There is a mast structure between the optic–electronic detecting equipment and the vehicle. It can be thought that the E and D coordinate systems are superposition when the manufacture and
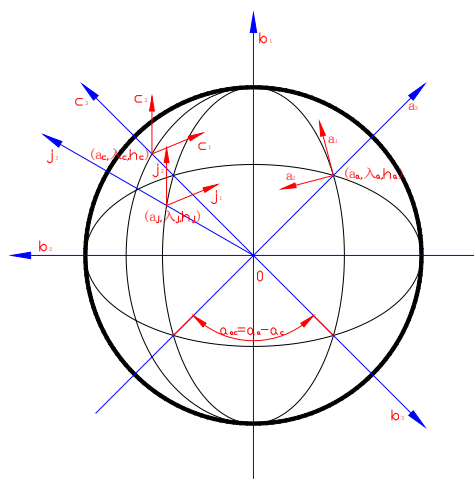

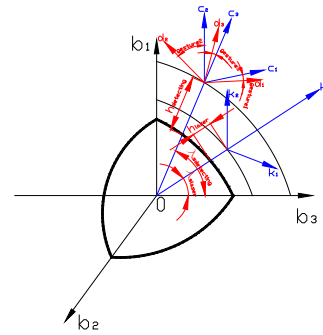Fig. 1. Earth centric coordinate system of the detecting and countermine vehicle system.

Fig. 2. Detecting and countermine equipment coordinate system.

installing error are zero. There are some three-axes gesture angles which being E relative to D coordinate system when the mast falling under the wind or libration influence. And the three-axes gesture angles can be separately shown by $\theta_{de}(t)$, $\phi_{de}(t)$ and $\psi_{de}(t)$. The 3 three-axes gesture angles are the corners rolling d_1, d_2, and d_3 axes.

f. Optic–electronic detecting equipment collimating part coordinate system: $F(f_1, f_2, f_3)$
  The collimating part and pitching axes are joined one another by the axletree. The rotational angle of the pitching axes was shown by λ. The collimating part can do gyring movement rolling the azimuth axes. And its rotational angle is called azimuth angle which being denotation by α.

g. Optic–electronic detecting equipment plane axes coordinate system: $G(g_1, g_2, g_3)$
  The coordinate system which being fixed to the plane axes is called plane axes coordinate system. The space position of the detecting system's scouting frame plane axes is shown by the plane axes coordinate system. Its coordinate origin is at the point of intersection position between the plane axes and light axes of the system. g_1 and g_2 are at the level plane which being just bargain. g_3 points earth and being just bargain right-hand coordinate relationship with other two axes.

h. Optic–electronic detecting equipment telescope coordinate system: $H(h_1, h_2, h_3)$
  This coordinate system quotes the optic–electronic transit's coordinate system. And it can show the space position of the telescopic. The coordinate origin is at the corner of the telescope's light axes and the tracking fight's plane axes. h_1 is the telescope's light axes and is pointing forward. h_2 is just bargain right-hand coordinate system relationship with other two axes. The axes of h_3 and h_2 are just bargain and pointing the roof.

i. The coming aim's coordinate system: $I(i_1, i_2, i_3)$
  The axes of i_1 is superposition with the light axes of the detecting system. The directions of i_2 and i_3 are same with the direction of the telescope coordinate system. And its aim position is at the coordinate origin.

j. The vehicle center horizon coordinate system: $J(j_1, j_2, j_3)$

     The means of the coordinate is the same as vehicle horizon coordinate system of the detecting system. And they are all provided by the GPS system. The j_1 is the traveling direction of the countermine vehicle system. The j_2 is right-hand right-angle coordinate system relationship with other two directions. The j_3 points the roof direction.

k. Vehicle coordinate system: $K(k_1, k_2, k_3)$

     The optic–electronic countermine vehicle does adopt the mast structure, so the flat stability being better than warning and detecting vehicle system. At the same time, in order to predigest the mode it is thought that there being not error between the optic–electronic countermine equipment and the vehicle. So the coordinate systems of countermine equipment and vehicle are thought the same one. The relatively three-axes gesture angles of the vehicle horizon coordinate system with the vehicle coordinate system are $\theta_{kj}(t)$, $\phi_{kj}(t)$ and $\psi_{kj}(t)$. And the three gesture angles are the corner rolling the j_1, j_2, and j_3 axes whose corner values are zero.

l. The telescope coordinate system of the optic–electronic countermine system: $L(l_1, l_2, l_3)$

     The value of the coordinate system is very important to the servo system's movement corner of the optic–electronic countermine system. And it means the telescope coordinate system of the optic–electronic countermine system. The value can be calculated by the utterly coordinate system or gained by the relatively space position relationship of the optic–electronic detecting system. Here we used the utterly coordinate system to gain the value. In this system, l_1 is telescope light axes pointing forward, l_2 and other two axes are just right-hand coordinate system. l_3 and l_2 are just dealing and point roof when the light axes of the countermine system is at level position.

     In this part, the switch from the center horizon coordinate system of the vehicle system to the coordinate system of the coming raiding aim then to the telescope coordinate system of the optic–electronic countermine system will be realized. This switch is based on the 12 coordinate systems which are defined later. And this switch using the neat matrix is as the math tool. The intent of the first switch is providing the exact coordinate of the coming raid aims for the whole countermine system and the real-time electronic map. And the intent of the second switch is providing the exact tracing data for the optic–electronic countermine system. The influence of the earth meridian constringency angle is not considered. At the same time all of the measure and orientation errors are supposed zero.

     Now let us talk about the aim coordinate' switch matrix and switch formula between the two–two coordinate systems.

1) The coming raid aims' position in the center horizon coordinate system is

$$A_i = \begin{bmatrix} A_{i1} & A_{i2} & A_{i3} & A_{i4} \end{bmatrix}^T. \tag{1}$$

2) The coming raid aims' switch can be realized by the A coordinate system to C coordinate system.

$$C_i = M_1 \cdot M_2 \cdot A_i. \tag{2}$$

Where M_1 and M_2 separately are the circumrotating switch matrices of the three-axes shift switch matrix and vehicle direction angle-ψ_{CA}. The two forms are

$$M_1 = \begin{bmatrix} 1 & 0 & 0 & -A_{C1} \\ 0 & 1 & 0 & -A_{C2} \\ 0 & 0 & 1 & -A_{C3} \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{3}$$

$$M_2 = \begin{bmatrix} \cos\psi_{CA} & \sin\psi_{CA} & 0 & 0 \\ -\sin\psi_{CA} & \cos\psi_{CA} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{4}$$

3) The switch of the coming raid aim from C coordinate to D coordinate.

$$D_i = M_3 \cdot M_4 \cdot M_5 \cdot C_i. \tag{5}$$

The three M matrices are separately the switch matrix of the θ_{dc}, ϕ_{dc}, and ψ_{dc}. One of the conditions of the vehicle switch system is that the vehicle being quiescence and dynamic calm estate. So the three-axes angle following the S direction is 0 and the following equations can come into existence

$$M_3 = \begin{bmatrix} \cos\theta_{dc} & \sin\theta_{dc} & 0 & 0 \\ -\sin\theta_{dc} & \cos\theta_{dc} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = E, \tag{6}$$

$$M_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi_{dc} & \sin\phi_{dc} & 0 \\ 0 & -\sin\phi_{dc} & \cos\phi_{dc} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = E, \tag{7}$$

$$M_5 = \begin{bmatrix} \cos\psi_{dc} & \sin\psi_{dc} & 0 & 0 \\ -\sin\psi_{dc} & \cos\psi_{dc} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = E. \tag{8}$$

Thus the formula $D_i = C_i$ can come into existence. Those middle switch matrices are all not the identity matrix when the vehicle being at moving condition. The result can be calculated by those formulas. The figuration appliance mode of the optic–electronic countermine system is the vehicle being quiescence shape. So this switch was introduced to the detecting and tracing vehicle system but not the optic–electronic countermine system. And those middle switch matrices are supposed to be identity matrices.

4) The switch of the coming raid aim from E to D

$$E_i = M_6 \cdot M_7 \cdot D_i. \tag{9}$$

In Eq. (9) the M matrices are separately the switch matrices of the azimuth angle-α and pitching angle-λ. The forms are as follows:

$$M_6 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{10}$$

$$M_7 = \begin{bmatrix} \cos\lambda & 0 & -\sin\lambda & 0 \\ 0 & 1 & 0 & 0 \\ \sin\lambda & 0 & \cos\lambda & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{11}$$

5) The switch of the coming raid aim from H to E

$$H_i = M_8 \cdot M_9 \cdot M_{10} \cdot E_i, \tag{12}$$

where M_8 and M_9 are separately the angle switch matrices rolling h_2 and h_3 axes. The two dates can be denoted separately by φ_{h2} and φ_{h3}. The coordinate switch-M_{10} is at the condition that the light axes moving distance being S. The forms are as follows:

$$M_8 = \begin{bmatrix} \cos\varphi_{h2} & 0 & -\sin\varphi_{h2} & 0 \\ 0 & 1 & 0 & 0 \\ \sin\varphi_{h2} & 0 & \cos\varphi_{h2} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{13}$$

$$M_9 = \begin{bmatrix} \cos\varphi_{h1} & 0 & -\sin\varphi_{h1} & 0 \\ \sin\varphi_{h1} & 1 & \cos\varphi_{h1} & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{14}$$

$$M_{10} = \begin{bmatrix} 1 & 0 & 0 & -S \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{15}$$

The coordinate value of the aim can be gained based on the switch result. But the coordinate of the coming raid aim must be changed to the coordinate of the optic–electronic countermine system when actualizing the exact optic–electronic induction. Now these switches can provide the servo angle tracing information to the laser vehicle countermine system. Here using those switches realizes this kind switch. The relatively position from the coming raid aim to the optic–electronic countermine system's light axes by the converse dispel of these switches.

6) The switch of the coming raid aim from A to J

$$J_i = M_{11} \cdot M_{12} \cdot A_i, \tag{16}$$

where M_{11} and M_{12} are separately the switch matrices of the three-axes movement switch matrix and the vehicle direction angle-ψ_{JA} of the optic–electronic countermine system. The forms are as follows:

$$M_{11} = \begin{bmatrix} 1 & 0 & 0 & -A_{j1} \\ 0 & 1 & 0 & -A_{j2} \\ 0 & 0 & 1 & -A_{j3} \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{17}$$

$$M_{12} = \begin{bmatrix} \cos\psi_{JA} & \sin\psi_{JA} & 0 & 0 \\ -\sin\psi_{JA} & \cos\psi_{JA} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{18}$$

7) The switch of the coming raid aim from J to K

$$K_i = M_{13} \cdot M_{14} \cdot J_i. \tag{19}$$

In Eq. (19) the two M matrices are separately the switch matrices of the azimuth angle-α' and pitching angle-λ'. The forms are as follows:

$$M_{13} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha' & \sin\alpha' & 0 \\ 0 & -\sin\alpha' & \cos\alpha' & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{20}$$

$$M_{14} = \begin{bmatrix} \cos\lambda' & 0 & -\sin\lambda' & 0 \\ 0 & 1 & 0 & 0 \\ \sin\lambda' & 0 & \cos\lambda' & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{21}$$

8) The switch of the coming raid aim from K to L

$$L_i = M_{15} \cdot M_{16} \cdot M_{17} \cdot K_i, \tag{22}$$

where M_{15} and M_{16} are separately the angle switch matrices rolling l_2 and l_3 axes. The two dates can be denoted separately by φ_{l2} and φ_{l3}. The coordinate switch-M_{17} is at the condition that the light axes moving distance being V. The forms are

$$M_{15} = \begin{bmatrix} \cos\varphi_{l2} & 0 & -\sin\varphi_{l2} & 0 \\ 0 & 1 & 0 & 0 \\ \sin\varphi_{l2} & 0 & \cos\varphi_{l2} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{23}$$

$$M_{16} = \begin{bmatrix} \cos\varphi_{l3} & 0 & -\sin\varphi_{l3} & 0 \\ \sin\varphi_{l3} & 1 & \cos\varphi_{l3} & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{24}$$

$$M_{17} = \begin{bmatrix} 1 & 0 & 0 & -V \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{25}$$

The total switch matrix based on those switches is shown as

$$I_i = \begin{bmatrix} I_{i1} \\ I_{i2} \\ I_{i3} \\ 1 \end{bmatrix} = M_{10} M_9 \cdots M_1 \begin{bmatrix} A_{i1} \\ A_{i2} \\ A_{i3} \\ 1 \end{bmatrix} = M_{17} M_{16} \cdots M_{10} \begin{bmatrix} A_{i1} \\ A_{i2} \\ A_{i3} \\ 1 \end{bmatrix}.$$

$$(26)$$

The angle relationship between the optic–electronic detecting system and optic–electronic countermine system can be calculated by the aim information of the optic–electronic detecting and Eq. (26). The optic–electronic countermine system using azimuth angle- α' and pitching angle- λ' can exact confront the coming raid aims.

By using this kind coordinate switch method to an optic–electronic countermine system, the coordinates of the optic–electronic detecting vehicle to the coming raid aims can be switched to the coordinates of the optic–electronic countermine vehicle to the coming raid aims. The two vehicle systems all used the middling precision seeking north equipment. This kind switch can satisfy the tracing error request that is less than 360°.

In conclusion, a new whole coordinate switch method is put forward. This method is built based on more vehicles condition. Using this method, the aim tracing switch and orientation questions of the optic–electronic warning and detecting system and the optic–electronic countermine system are solved. Using this method the coming raid aims' angle information which being detected by the optic–electronic detecting system is switched to the aim's map orientation information, then is switched to the input angle information of the optic–electronic countermine system. This kind aim orientation by coordinate switch is realized by the neat matrix switch way. This kind mode is used in a complex optic–electronic countermine system and satisfies the error request. This way this kind switch method is proved to be very useful.

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