Research on Ammunition Simulation Method

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Abstract. This paper introduces a kind of ammunition simulation method. Based on this method, the ammunition simulation software is implemented. The software includes air to ground missile simulation model, bomb simulation model and rocket simulation model. The simulation model of air-to-ground missile simulates the ballistic model of air-to-ground missile and the process of flying, searching and finding targets, hitting targets, damaging equipment and personnel, etc. The bomb simulation model simulates the ballistic model of the bomb and the process of flying, hitting and damaging the target. The rocket simulation model simulates the rocket trajectory model and the process of flying, hitting and damaging the target. In this paper, the motion equation, coordinate transformation formula, data interface and hit damage algorithm of ammunition are introduced in detail. The method of ammunition simulation not only considers the relevant elements of the whole process of ammunition simulation, but also is convenient for software realization and rapid simulation.

1. Simulation Model of air to ground missile
At the same time, there may be one or more ammunition flying in the air, which needs to be considered in the software design.

The input parameters are the simulation time t, the initial position of the missile \((X_1, Y_1, Z_1)\), the strike target position \((X_2, Y_2, Z_2)\).

Order

\[
\alpha_{t-1} = \tan^{-1} \frac{Z_1 - Z_2}{\sqrt{(X_{t-1} - X_2)^2 + (Y_{t-1} - Y_2)^2}}
\]  

(1)

\(t-1\) represents the last simulation time, \((X_{t-1}, Y_{t-1}, Z_{t-1})\) is the position of missile at \(t-1\) time. If \(\alpha_{t-1} < 30\), assuming that the missile is level at time \(t\), the position is:

\[
\begin{align*}
X_t &= X_{t-1} + V_t \cdot \Delta T1 \cdot \cos \beta \\
Y_t &= Y_{t-1} + V_t \cdot \Delta T1 \cdot \sin \beta \\
Z_t &= Z_{t1}
\end{align*}
\]

(2)

\(\beta = \tan^{-1} \frac{Y_2 - Y_1}{X_2 - X_1}\)

\(\Delta T1\) is the simulation step length of the missile, \(V_t\) is the flight speed of the missile at time \(t\), which is obtained by querying the missile flight status file.

If \(\alpha_{t-1} \geq 30\), after the time of \(t\), the missile dives at an angle of 30 degrees, the position is:
X_i = X_{i-1} + V_i \cdot \Delta T_1 \cdot \cos \beta \cdot \cos 30 \\
y_i = Y_{i-1} + V_i \cdot \Delta T_1 \cdot \sin \beta \cdot \cos 30 \\
z_i = Z_{i-1} + V_i \cdot \Delta T_1 \cdot \sin 30 
(3)

Order

D_i = \sqrt{(X_i - X_2)^2 + (Y_i - Y_2)^2 + (Z_i - Z_2)^2} 
(4)

If $D_i \geq 50$ meter, publish the missile entity status information, exit the simulation model, if $D_i < 50$ meter, publish the explosion information, delete the missile entity, simulate the missile hit and damage the target.

Calculate the acquisition area of the seeker, as shown in the figure below, the search range of the seeker distance $L$ and the search range of the seeker azimuth $H$. The coordinates of the four vertices in the acquisition area of the seeker in the O1—X1Y1 coordinate system are $\left( -\frac{L}{2}, -\frac{H}{2} \right)$, $\left( \frac{L}{2}, -\frac{H}{2} \right)$, $\left( \frac{L}{2}, \frac{H}{2} \right)$, and the conversion relationship between the O1—X1Y1 coordinate system and the O—XY coordinate system is as follows:

$$
\begin{bmatrix}
X \\
Y
\end{bmatrix} = \begin{bmatrix}
X_2 \\
Y_2
\end{bmatrix} + \begin{bmatrix}
\cos \beta & -\sin \beta \\
\sin \beta & \cos \beta
\end{bmatrix} \cdot \begin{bmatrix}
X_1 \\
Y_1
\end{bmatrix}
$$
(5)

Use the above formula to calculate the coordinates (XX1, YY1), (XX2, YY2), (XX3, YY3), (XX4, YY4) of the four vertices of the capture area in the O—XY coordinate system.

Figure 1. Schematic diagram of seeker capture area

Calculate the number of equipment entities $N$ in this area. If $N = 0$, exit the simulation model. If $N > 0$, calculate the entity closest to $(X_2, Y_2)$. This entity is the target hit by the missile. Query the probability of the target captured by the seeker $P_2$, and extract the random number $\eta$ evenly distributed between $(0, 1)$. If $n = 0$, exit the simulation model

$$\eta \leq P_2$$

It is considered that when the target is captured, the probability of missile hitting the target $P_3$ is queried, and the random number $\eta$ is evenly distributed among $(0, 1)$ samples

$$\eta \leq P_3$$

Consider that the missile hit the target, publish the direct hit target information. The data structure is:

Firing entity code, hit target code, ammunition type, ammunition model, hit time, the thickness of armor piercing / armor breaking $H$, armor piercing bounce angle $\alpha_1$, hit position, angle between normal vector of incoming ray and hit position, whether the missile has two missiles launching anti
active protection capability at the same time, attack angle, projectile storage speed, missile flight direction

Among them, the thickness of armor piercing / armor breaking H, the angle of armor piercing projectile \( \alpha_1 \), the angle between the incoming ray and the normal vector of the hit position, whether the missile has the anti active protection ability of launching two missiles at the same time, the attack angle, the storage speed of the projectile and the flight direction of the projectile do not need to be filled in.

Suppose that the hit position is the top of the target, and there are \( N \) protection surfaces of the target, query the \( Z \) equal surfaces of 4 vertices, set \( N_1 \), and calculate the average value \( a \) of \( N_1 \) \( Z \), assume that the surface whose \( Z \) value is greater than \( a \) is the top surface, and set \( N_2 \) top surfaces, extract the random number \( \eta \) evenly distributed between \((0, 1)\), if

\[
\frac{i}{N_2} < \eta \leq \frac{i+1}{N_2}
\]

It is considered that the \( i+1 \) surface of the hit target, \( i < N_2 \), the surface is the hit position (damage position).

If the damage degree (light damage, medium damage, heavy damage, scrap) of the target changes, the method of random number is used to simulate the casualties of the target and publish the damage information. The data content is as follows:

Firing entity / mine code, destroyed entity code, time of damage, location of destroyed entity, damage degree (light damage, medium damage, heavy damage), damaged part, number of uninjured personnel, number of minor injuries, number of serious injuries, number of casualties.

If there is no equipment entity in the area, the damage area of the standing combat personnel is calculated, the calculation method is similar to that of the seeker capture area. There are a warfighter to query the standing warfighter \( A_1 \), who is damaged. According to the proportion of minor injury, serious injury and death, the casualties of the target are simulated by taking random numbers. If a fighter has a lie in position, according to the front damage distance and depth damage distance under the lie in position of the fighter, recalculate the damage area, and calculate the fighters and damage conditions entering the area. If a combatant has personnel in the trench, then calculate the damage of the combatant in turn \([1]-[2]\).

If the damage degree of the projectile to the warfighter changes, publish the damage information.

2. Bomb simulation model
At the same time, there may be one or more ammunition flying in the air, which needs to be considered in the software design.

The input parameters are simulation time \( t \), start time \( t_1 \), initial position \((X_1, Y_1, Z_1)\) and bomb landing point \((X_2^i, Y_2^i, Z_2^i)\).

The horizontal velocity of the bomb is:

\[
V = \sqrt{VX^2 + VY^2}
\]

The vertical velocity of the bomb is:

\[
V_{1z} = VZ + g \cdot (t - t_1)
\]

\( t_1 \) is the start time of dropping.

The position of the bomb at any moment is

\[
X_i = X_{i-1} + V \cdot \cos \beta \cdot \Delta T1
\]

\[
Y_i = Y_{i-1} + V \cdot \sin \beta \cdot \Delta T1
\]

\[
Z_i = Z_{i-1} - V_{1z_{i-1}} \cdot \Delta T1
\]

\( \Delta T1 \) is the simulation step.

Order
\[ D_t = \sqrt{(X_t - X'_t)^2 + (Y_t - Y'_t)^2 + (Z_t - Z'_t)^2} \] (9)

If \( D_t \geq 50 \) meter, publish the bomb entity status information, exit the simulation model, if \( D_t < 50 \) meter, publish the explosion information, delete the bomb entity, simulation the situation of bomb hit and damage the target.

For the combat personnel in standing position, the front damage distance is \( H \), the depth damage distance is \( L \), the damage area is rectangular, the damage area schematic diagram is shown in the figure 1, \( O_1 \) is the center of the damage area, the center is the bomb landing point, and the coordinate is \((X'_1, Y'_1)\).

The coordinates \((X_1, Y_1)\) of the four vertices in the damage area in the \( O_1-X_1Y_1 \) coordinate system are \((-\frac{L}{2}, -\frac{H}{2}), (-\frac{L}{2}, \frac{H}{2}), (\frac{L}{2}, \frac{H}{2}), (\frac{L}{2}, -\frac{H}{2})\), and the conversion relationship between the \( O_1-X_1Y_1 \) coordinate system and the \( O-XY \) coordinate system is as follows:

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix} = \begin{bmatrix}
\cos \beta & -\sin \beta \\
\sin \beta & \cos \beta
\end{bmatrix} \begin{bmatrix}
X' \\
Y'
\end{bmatrix} + \begin{bmatrix}
\tan \alpha
\end{bmatrix} \begin{bmatrix}
1 \\
0
\end{bmatrix} \begin{bmatrix}
1
\end{bmatrix}
\] (10)

The coordinates \((XX_1, YY_1), (XX_2, YY_2), (XX_3, YY_3), (XX_4, YY_4)\) of the four vertices of the damaged area in the \( O-XY \) coordinate system are calculated by the above formula.

Calculate the number of fighters entering the area, set \( N \) fighters, query the standing status of the fighters, such personnel are damaged, according to the proportion of minor injury, serious injury and death, through the method of random number extraction to simulate the casualties of the target. If there are \( N \) fighters in the lying position, according to the front damage distance and depth damage distance of the fighters in the lying position, recalculate the damage area, and calculate the fighters and damage conditions entering the area. If there are people in the trenches among the \( N \) fighters, the damage of the fighters will be calculated in turn [3].

If the damage degree of the bomb to the warfighter changes, publish the damage information.

Calculate the number \((I, J)\) of the box where the bomb fall point \((X'_1, Y'_1)\). Query the box \((I-1, J-1), (I-1, J), (I-1, J+1), (I+1, J-1), (I+1, J), (I+1, J+1)\) to find weather there are armored and blockhouse targets. If there are no targets, the bomb can’t hit the targets. Exit the simulation model. If there are \( M \) targets. For the \( M \) targets, call the basic simulation model of the distance between the drop point of the projectile and the target during indirect fire, calculate the distance \( D_i \) between the drop point of the bomb and the target, and publish the information of the missed target. The data structure is as follows:

Firing entity code, striking target code, ammunition type, ammunition model, distance between bullet landing point and target, bullet landing point, target location.

3. Rocket simulation model

At the same time, there may be one or more ammunition flying in the air, which needs to be considered in the software design.

The input parameters are the simulation time \( t \), the initial position of the rocket \((X_1, Y_1, Z_1)\), the strike target position \((X_2, Y_2, Z_2)\).

Order

\[
\alpha = \tan^{-1} \frac{Z_1 - Z_2}{\sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}} \] (11)

When the rocket dives, the position at time \( t \) is:
The position of the rocket at time t-1, $V_t$ is the speed of the rocket at time t, which is obtained by querying the rocket's flight status file.

Order

$$D_t = \sqrt{(X_t - X_2)^2 + (Y_t - Y_2)^2 + (Z_t - Z_2)^2}$$

If $D_t \geq 50$ meter, publish the rocket entity status information, exit the simulation model, if $D_t < 50$ meter, publish the explosion information, delete the rocket entity, and simulate the impact and damage of the rocket.

Read the front damage distance, depth damage distance, minor injury, serious injury and death ratio of personnel in standing position, lying position and trench from the combat unit performance data file.

As shown in the figure 1, O1 is the shooting point, the shooting error in the azimuth direction is set as $\Delta H$, the shooting error in the distance direction is set as $\Delta L$, the coordinates of the projectile landing point in the O1-X1Y1 coordinate system are ($\Delta L$, $\Delta H$), and the coordinates of the projectile landing point in the O-XY coordinate system are:

$$\begin{bmatrix} X'_1 \\ Y'_1 \end{bmatrix} = \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} + \begin{bmatrix} \cos \beta & -\sin \beta \\ \sin \beta & \cos \beta \end{bmatrix} \begin{bmatrix} \Delta L \\ \Delta H \end{bmatrix}$$

$$\beta = \tan^{-1} \frac{Y_2 - Y_1}{X_2 - X_1}$$

For the combat personnel in standing position, the front damage distance is H, the depth damage distance is L, and the damage area is rectangular. The damage area schematic diagram is shown in the figure 1. O1 is the center of the damage area, which is the drop point of the projectile, and the coordinate is $(X'_1, Y'_1)$.

The coordinates $(X_1, Y_1)$ of the four vertices in the damage area in the O1-X1Y1 coordinate system are $(-\frac{L}{2}, -\frac{H}{2}), (\frac{L}{2}, -\frac{H}{2}), (-\frac{L}{2}, \frac{H}{2}), (\frac{L}{2}, \frac{H}{2})$, and the conversion relationship between the O1-X1Y1 coordinate system and the O-XY coordinate system is as follows:

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} X'_1 \\ Y'_1 \end{bmatrix} + \begin{bmatrix} \cos \beta & -\sin \beta \\ \sin \beta & \cos \beta \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \end{bmatrix}$$

The coordinates (XX1, YY1), (XX2, YY2), (XX3, YY3), (XX4, YY4) of the four vertices of the damaged area in the O-XY coordinate system are calculated by the above formula.

Calculate the number of fighters entering the area, set N fighters, query the standing status of the fighters, such personnel are damaged, according to the proportion of minor injury, serious injury and death, through the method of random number extraction to simulate the casualties of the target. If there are N fighters in the lying position, according to the front damage distance and depth damage distance of the fighters in the lying position, recalculate the damage area, and calculate the fighters and damage conditions entering the area. If there are people in the trenches among the N fighters, the damage of the fighters will be calculated in turn [4-5].

If the damage degree of the projectile to the warfighter changes, publish the damage information.
Calculation of shooting error $\Delta H$ in azimuth direction and shooting error $\Delta L$ in distance direction: according to the mean square deviation $\sigma_1$ of the input shooting error in azimuth of projectile and the mean square deviation $\sigma_2$ of the high and low shooting error, the sampling values gauss1 and gauss2 with the mean value of 0 and the mean square deviation of 1 are obtained. Order

$$
\Delta H = \sigma_1 \cdot |gauss1|
$$

$$
\Delta L = \sigma_2 \cdot |gauss2|
$$

(17)

Calculate the number $(I, J)$ of the box where the projectile falls point $(X'_2, Y'_2)$. Query the box (I-1, J-1), (I-1, J), (I, J-1), (I-1, J + 1), (I + 1, J-1), (I + 1, J), (I, J + 1), (I + 1, J + 1) to see if there are armored and blockhouse targets. If there are no targets, the projectile can't hit the targets. Exit the simulation model. If there are M targets, there are M targets, call the basic simulation model of the distance between the projectile's landing point and the target, calculate the distance $D_i$ between the projectile's landing point and the target, and publish the information of the missed target. The data structure is as follows: Firing entity code, striking target code, ammunition type, ammunition model, distance between bullet landing point and target, bullet landing point, target location.

References

[1] WANG Guang-yan, HU Qi-wei. Damage Effects Simulation for Bomb and the Synthetic Factors Influence Analysis. COMPUTER SIMULATION. 2006, 23(10):5-7,35
[2] WANG Hua, XIN Tengda, CUI Cunyan, etc. Summary of Weapon Damage Assessment Research Methods. Journal of Equipment Academy. 2017, 28(1):105-110
[3] WANG Dan, JI Jian-rong, KONG Lin, YAN Jia-jia. Accurate Evaluation of Explosive Ammunition Attacking Target in Actual Combat. Computer Simulation. 2018, 35(5):31-34
[4] LI Feng, SHI Quan, SUN Zheng. Summary of Technical Research on the Evaluation of Target Mutilation. Journal of Sichuan Ordnance. 2018, 39(9):69-72
[5] CAO Ling-yu, LIU Guo-qing, LUO Xing-bai, etc. Design and Application of Damage Efficiency Evaluation System for Warhead. Fire Control & Command Control. 2019, 44(1):101-104,109