Modeling and Analysis of a Dense Array Weapon System

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Abstract: The interception of anti-ship missiles is modeled mainly for the "dense array" system. Generally, in the process of penetrating the carrier formation of anti-ship missiles, the anti-ship missiles will be attacked jointly by various firepower of the formation, especially in the short-range defense area, the target ship formation will adopt the joint attack of the near-defense missiles and the "dense array". The research focuses on the defense of anti-ship missile by a single dense array, so only the position relationship between a single dense array and an anti-ship missile is studied.

1. Introduction

As a part of multi-layer interception, short-range anti-missile weapons play an important role in intercepting anti-ship missiles that break through medium and long-range defense. Short-range hard kill interception weapons mainly include short-range air defense missiles and naval guns. Short-range air defense missile is an effective short-range defense weapon system, but there are some inherent shortcomings, such as short-range (about 1000m) shooting dead zone, low launching rate, etc. The use of anti-missile naval gun weapon system can destroy the anti-ship missile at the end of its flight trajectory [1-6]. Short-range anti-missile naval gun has the advantages of long combat duration, strong anti-jamming ability and high cost-effectiveness ratio. At present, there are more than ten kinds of anti-missile naval gun weapon systems developed abroad. The most typical and equipped weapon system is the "Dense Array" weapon system of the United States. So far, more than 700 systems have been equipped with more than 10 national navies. The system was developed by General Dynamics Corporation of the United States in 1969. It was tested at sea in 1973 and put into service in 1980.

As the most famous shipborne short-range weapon system in the world, the "Dense Array" system is a short-range defensive naval gun weapon system [7-12], which is mainly used to deal with anti-ship missiles flying over the sea. The main features are fast reaction speed, high firing speed, high density of projectile curtain and full automation. It can automatically complete the whole process of target detection, threat judgment, tracking and locking, launching attack, damage assessment and fire control.

2. Brief Introduction of Dense Array System

The Dense Array System was conceived in 1967 and tested on the USS Bigelow in 1977. Production began in 1978 and was officially commissioned in 1980.Fully automatic defense can be designed, that is to say, given the data of the target, it can rely entirely on the built-in radar search, tracking, target threat assessment, locking and firing.

The advantage of this design is that it is easy to install, the platform only needs to provide electricity, and it can operate without integration with the combat detection system on board. The deck position of the installation also needs to ensure enough structural strength, and it does not need to dig holes on the deck.

But in contrast, the characteristic of "single combat" of "dense array" system is also a

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disadvantage, relying only on its own radar fire control system to engage in battle, and there is no cooperation with other systems on board. Even if the shipborne radar has accurately captured and locked the target, the dense array system must re-search the airspace with its own radar, which not only wastes time, but also increases the possibility of missing the target.

In addition, due to the limitation of the platform, the radar of the "Dense Array" system can only share the same gyration/elevation angle with the aircraft gun, and can not independently perform wide-area search, so the system can only attack one target at a time after booting. This disadvantage has been improved by integrating with the Shield combat system.

3. Mathematical Model Analysis of Ships

The "dense array" is installed on the ship, so the movement of the ship has a great influence on the "dense array" and operational efficiency. In battle, according to the situation of battlefield, warships usually make regular or irregular maneuvers. In order to simplify the work, the warships are set to move in a uniform straight line with a speed of $[v_{tx}, v_{ty}, v_{tz}]$. So the motion equation of warships is programmed as follows:

$$\begin{cases} v_{tx} = v_{tx} + a_{tx}\Delta t \\ v_{ty} = v_{ty} + a_{ty}\Delta t \\ v_{tz} = v_{tz} + a_{tz}\Delta t \end{cases} \tag{1}$$

$$\begin{cases} s_{tx} = s_{tx} + v_{tx}\Delta t \\ s_{ty} = s_{ty} + v_{ty}\Delta t \\ s_{tz} = s_{tz} + v_{tz}\Delta t \end{cases} \tag{2}$$

Where a_{tx}, a_{ty}, a_{tz} are acceleration of ships with unit m/s^2, and s_{tx}, s_{ty}, s_{tz} are position of ships , and Δt means time of anti-ship missiles.

4. Mathematical Model Analysis of Anti-ship Missile

The initial position coordinates of anti-ship missile terminal maneuver are set as $[s_{mx}, s_{my}, s_{mz}]$, the future point attack of anti-ship missile on target ship is set in the simulation, so the initial velocity components of anti-ship missile along three axes in the ground coordinate system can be calculated according to the relative position relationship.

$$\begin{cases} v_{mx} = v_{fj}\cos\theta\sin\varphi \\ v_{my} = v_{fj}\cos\theta\cos\varphi \\ v_{mz} = v_{fj}\sin\theta \end{cases} \tag{3}$$

Where v_{fj} is the initial velocity of the terminal maneuver of an anti-ship missile.

So the motion equation of anti-ship missile is programmed as follows:

$$\begin{cases} v_{mx} = v_{mx} + a_{mx}\Delta t \\ v_{my} = v_{my} + a_{my}\Delta t \\ v_{mz} = v_{mz} + a_{mz}\Delta t \end{cases} \tag{4}$$

$$\begin{cases} s_{mx} = s_{mx} + v_{mx}\Delta t \\ s_{my} = s_{my} + v_{my}\Delta t \\ s_{mz} = s_{mz} + v_{mz}\Delta t \end{cases} \tag{5}$$

Where a_{mx}, a_{my}, a_{mz} are acceleration of anti-ship missile with unit m/s^2, and v_{mx}, v_{my}, v_{mz} are position of anti-ship missile, and Δt means time of anti-ship missiles.

5. Mathematical Model Analysis of Dense Array Projectile

Because the Dense Array defense system is installed on the warship, it is assumed that the initial position coordinates of each. Dense Array projectile before launching are the same as the position coordinates of the warship. That is, when each "dense array" projectile is fired, there are:

$$\begin{cases} s_{ax} = s_{tx} \\ s_{ay} = s_{ty} \\ s_{az} = s_{tz} \end{cases} \quad (6)$$

Where s_{ax}, s_{ay}, s_{az} are the initial position of Dense Array defense system.

In the simulation process, the components of the distance difference between the anti-ship missile and the target ship in the three coordinate axis are as follows:

$$\begin{cases} dx = s_{mx} - s_{tx} \\ dy = s_{my} - s_{ty} \\ dz = s_{mz} - s_{tz} \end{cases} \quad (7)$$

Where dx, dy, dz are the component of the distance difference between the anti-ship missile and the target ship on the three coordinate axis.

The above analysis establishes the mathematical model of space motion relationship between ship, anti-ship missile and dense array projectile, which provides basic mathematical conditions for subsequent analysis.

6. Conclusion

The "Dense Array" system is a short-range defensive naval gun weapon system, which is mainly used to deal with anti-ship missiles flying over the sea. The basic mathematical model is needed to study the damage and interception effect. The model of "dense array" intercepting anti-ship missile is studied. Starting from the setting of coordinate system, the mathematical models of ship, anti-ship missile and dense array projectile are analyzed, which provide basic conditions for matlab simulation.

References

[1] Feigenbaum M J.Quantitative universality for a class of nonlinear transformations [J], J. Stat. Phys. 1978, 19: 25-52.

[2] Pecora L M and Carroll T L. Synchronization in chaotic systems [J], Phys. Rev. Lett.1990, 64:821-824.

[3] GE S S, Wang C, Lee T H. Adaptive backstepping control of a class of chaotic systems[J]. Int J Bifurcation and chaos. 2000, 10 (5): 1140-1156.

[4] GE S S, Wang C, Adaptive control of uncertain chus's circuits [J]. IEEE Trans Circuits System. 2000, 47(9): 1397-1402.

[5] Alexander L, Fradkov, Markov A Yu. Adaptive synchronization of chaotic systems based on speed gradient method and passification [J]. IEEE Trans Circuits System 1997, 44(10):905-912.

[6] Andrieu, V., Praly, L., & Astolfi, A. (2008). Homogeneous approximation, recursive observer design, and output feedback. SIAM Journal on Control and Optimization, 47, 1814-1850.

[7] Astolfi, D., & Marconi, L. (2015). A high-gain nonlinear observer with limited gain power. IEEE Transactions on Automatic Control, 60, 3059-3064.

[8] Bhat, S. P., & Bernstein, D. S. (2005). Geometric homogeneity with applications to finite-time stability. Mathematics of Control, Signals, and Systems, 17, 101-127.

[9] Freidovich, L. B., & Khalil, H. K. (2008). Performance recovery of feedbacklinearization-based designs. IEEE Transactions on Automatic Control, 53, 2324-2334.

[10] Gao, Z. (2003). Scaling and bandwith-parameterization based controller tuning. In American control conference, (pp.4989-4996).

[11] Guo, B. Z., & Zhao, Z. L. (2011). On the convergence of an extended state observer for nonlinear systems with uncertainty. Systems & Control Letters, 60, 420-430.

[12] Han, J. Q. (2009). From PID to active disturbance rejection control. IEEE Transactions on Industrial Electronics, 56, 900-906.