High-speed Target Recognition Algorithm and Simulation

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ABSTRACT: The purpose of this paper is devoted to finding a method to recognize the high-speed target for missile in a certain distance. Based on the quasi-electrostatic field characteristics of the capacitance detector, this paper analyzed the output voltage of detection circuit from a capacitance detector. It can be found that, when a high-speed target getting close to the detector, the output voltage of detection circuit changes with certain rules. Our research applied a low-speed static test to obtain the static characteristic data of the target, proposed a high-speed target recognition algorithm and set threshold values based on starting voltage, second derivative and signal duration. The result showed that the algorithm is effective to recognize high-speed missile target.

KEYWORD: quasi-electrostatic field; high-speed target recognition; capacitance detector; algorithm

1 INTRODUCTION

It is well known that laser detector or infrared detector is common used in detection unit in active protection system[1]. With the development of anti-armor weapons, it need to react in the work area which is about 1m away from target to achieve the goal of effective against anti-armor projectile which velocity is higher than 1000 m/s. This requires very short reaction time for detection. The laser or infrared system is difficult to quickly and accurately measure such motion parameters of high-speed projectile targets as distance and speed, while the capacitance detection with mature technology can do it well. In this way, the capacitance detection is a good choice for our research.

Based on the experiment for the static characteristics of target and background characteristics, we proposed high-speed target recognition algorithm, which feasibility is verified by the simulation.

2 THEORY OF CAPACITANCE DETECTOR

When applying alternating voltage to two induction electrodes of oscillation circuit of the capacitance detector, a detection physical field is established in a free space. Based on Electromagnetic theory, we can get:

$$R_{max} << \frac{\lambda}{2\pi} \tag{1}$$

Where R_{max} is the maximum detection range in capacitance detection, λ is the wavelength of capacitance detector. It shows that capacitance detection physical field is near-field area (Static area). In near-field area, the characteristic of field is mainly acted as electric field[2]. It knows that Quasi-static field within capacitance detector work area is mainly acted as quasi-electrostatic field.

This quasi-electrostatic field will be disturbed when target is near the capacitance detector and the capacitance amount between detector electrodes will be changed. The target detector can pick up the capacitance variety in the form of voltage in order to realize the target identification[3]. The function principle of capacitance detector is shown in figure 1. This detector is composed of regulator circuit, oscillation circuit, electrode voltage divider coupler and detector circuit. The variation of capacitance amount ΔC_{ad} between induction electrode A and ground electrode D will be generated in missile-detector encounter, the variation of oscillation circuit output voltage ΔU_A(ΔU_A<0) is caused by ΔC_{ad}. At the same time, impedance ratio *Kr* of electrode voltage divider coupler formed from detection electrodes A, B and D. *Kr* is defined as:

$$K_r = \frac{c_{bd} + \Delta c_{bd}}{c_{ab} + \Delta c_{ab}} \tag{2}$$

Where C_{bd} is the capacitance between induction electrode B and ground electrode *D*, C_{ab} is the mutual capacitance between induction electrode A and B, ΔC_{bd} and ΔCab are the variation.

ΔKr leads to the variation ΔK_R of Coupled divider ratio K_R, the relation of K_R and Kr is as bellows:

$$K_R = \frac{c_{ab}}{c_{ab} + c_{bd}} = \frac{1}{1 + K_r} \tag{3}$$

When a target encounters the capacitance detector, we can get:

$$U_{im} = K_R \bullet U_A \tag{4}$$

$$U_d = K_{dd} \bullet U_{im} + K_{ss} \tag{5}$$

Here, U_{im} is the input voltage of detector circuit, U_d is the output voltage of detector circuit, K_{dd} and K_{ss} are constants dependent on the structure of detector circuit. The variation and variation rate of U_d constitute the target characteristics in missile-detector encounter[4].

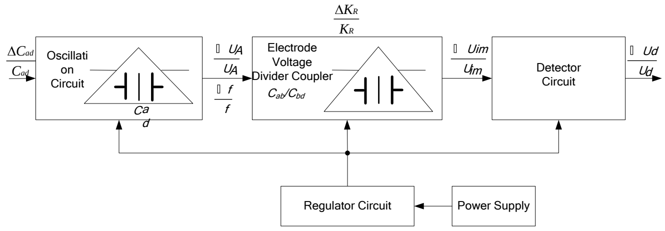

Fig.1 The schematic block diagram of capacitance detector.

3 ALGORITHM IMPLEMENTATION

The change of U_d and ΔU_d can be used as recognition information for detector. In terms of the trend of detector circuit output voltage, target characteristics tested in laboratory conditions is in accord with detector encounters a real high-speed target. We do experiments to get the relationship between distance and detector circuit output voltage in missile-detector encounter with different orientations, the data shows as tables 1.

Table 1. The static characteristic data of approaching target in different orientations.

H (cm) \ *U* \ *O*	Encounter Center of detector		Encounter Middle of the left of detector		Encounter Top of the left of detector		Encounter Below of the left of detector	
	Ud (v)	△ *Ud* (mv)	*Ud* (v)	△ *Ud* (mv)	*Ud* (v)	△ *Ud* (mv)	*Ud* (v)	△ *Ud* (mv)
100	10.534	–1	10.505	0	10.557	–1	10.598	0
90	10.533	–2	10.504	–1	10.555	–3	10.597	–1
80	10.532	–3	10.503	–2	10.554	–4	10.596	–2
75	10.53	–5	10.502	–3	10.553	–5	10.594	–4
70	10.528	–7	10.5	–5	10.551	–7	10.592	–6
65	10.526	–9	10.497	–8	10.549	–9	10.589	–9
60	10.523	–12.5	10.494	–11	10.546	–12.5	10.585	–13
50	10.51	–25	10.484	–21	10.54	–18	10.579	–19
45	10.5	–35.5	10.473	–32	10.532	–26	10.573	–25
40	10.483	–52	10.461	–44	10.522	–36	10.564	–34
35	10.461	–74.5	10.44	–65	10.511	–47	10.553	–45
30	10.415	–120	10.397	–108	10.491	–67	10.534	–64
25	10.337	–198	10.354	–151	10.464	–94	10.508	–90
20	10.192	–343	10.269	–236	10.428	–130	10.475	–123
10	9.282	–1253	9.945	–560	10.339	–219	10.4	–198

In table 1, *O* is the orientation in which target encounters the detector, *H* is the vertical distance between the target and the capacitance detector, *U* is the output voltage of detector circuit. Comparing data of the table, we can find out that output voltage U_d of detector circuit decreases and the variable of ΔU_d increases when missile target gets close to the detector. In comparison with other three orientations, decreases trend of U_d is faster when target encounters the center of detector. The decreases trend of U_d is equally common between the situation of target encountering top of the left of detector and that below of the left of detector.

Based on the detector circuit output voltage, we use matlab curve fitting target Characteristics to make it more clearly. It shows obviously in figure2.

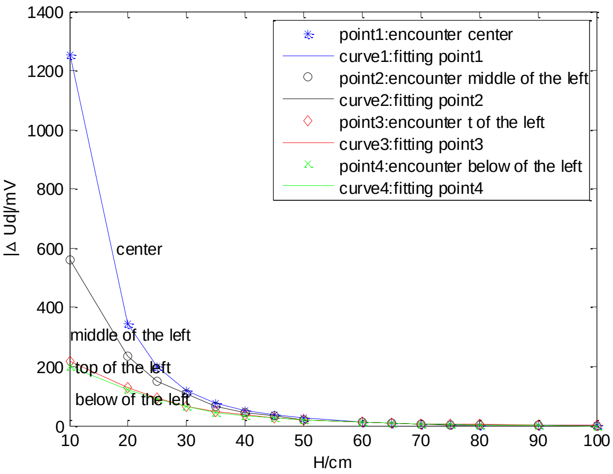

Figure 2. The static characteristics of target which approach detector in four orientations.

Here, $|\Delta U_d|$ is the absolute value of ΔU_d. From analysis of capacitance detection theory, the detector circuit output voltage when electrodes and the target at a distance 100cm measured as target far away from electrodes infinitely. In figure 3, with target coming near in the same orientation, time rate of change $|\Delta U_d|$ of the detector circuit output voltage gradually increase. The slope of $|\Delta U_d|$ increase little by little. In other words, second Derivative of detector circuit output voltage increase.

From analysis of the same target-missile encounter in different orientations, when target encounters the center of capacitance detector, values of $|\Delta U_d|$ and slope of $|\Delta U_d|$ are the maximum for the same distance. When target encounters top or below of the left of capacitance detector, values of $|\Delta U_d|$ and slope of $|\Delta U_d|$ are the minimum for the same distance. The measuring result is in good agreement with capacitance detection theory. And values of $|\Delta U_d|$ and slope of $|\Delta U_d|$ must be between the two limits when target encounters capacitance detector in other orientations. For this reason, target recognition signal is given if required distance between target and detector is from15 cm to 25 cm, values of $|\Delta U_d|$ and slope of $|\Delta U_d|$ can be regarded as discriminant criterion. Therefore, we can set change amount of $|\Delta U_d|$ within a certain time to be a threshold value. In the case of target encounters the center of detector and the distance is 25 cm, threshold is met. And in the case of target encounters the top or below of the left of detector and the distance is 15 cm, threshold should also be met. According to structure symmetry of capacitor detector, threshold will be met when target encounters detector in other orientations and distance between them is from 15 cm to 25 cm.

In order to eliminate the affection of interference signal, we set target duration and the initial value of the change amount of detector circuit output voltage to be a threshold value. Common interfering objects such as tree branches, human, vehicles, small bullets. Compared with 1000 m/s high speed targets, branches, the human body and the vehicle belong to the larger objects, the speed of closing to the detector is very low. Detector circuit output voltage amplitude caused by the larger objects changes greatly, but values of $|\Delta U_d|$ and slope of $|\Delta U_d|$ are small. In this case, we can set the continuous change amount of $|\Delta U_d|$ within a certain time to identify target and larger interfering objects at low speed. Comparing of 1000 m/s high-speed target and small bullet, we can find out that the change rate of detector circuit output voltage caused by small bullet is relatively close to that of high-speed missile target. However, the bullet is small in size, the change amount of detector circuit output voltage is small when small bullet is coming near. In this case, we can set initial value of detector circuit output voltage within a predetermined distance range to be a threshold value, which is used to identify target and small interfering objects at high speed.

For these reasons, we can get high-speed target identification criterion. With the missile target coming near, detector circuit output voltage U_d decreases, the change amount and the second derivative of U_d increase. Within a predetermined distance range from 15 cm to 25 cm, the change amount of U_d should be greater than threshold value A. The continuous change amount of $|\Delta U_d|$ within a certain time should be greater than threshold value B. For the setting of threshold value A, in figure 2, we can get the change amount $|\Delta U_l|$ of detector circuit output voltage when missile target encounters the top or below of the left of detector and the distance is 15cm. And we can get the change amount $|\Delta U_c|$ of detector circuit output voltage when target encounters the center of detector and the distance is 25 cm. $|\Delta U_l|$ is relatively close to $|\Delta U_c|$. We can set $|\Delta U_l|$ to be threshold value A. Threshold value A will be met when high-speed missile target encounters detector in other orientations and distance range between them is from 15 cm to 25 cm. Considering the interfering signal and the possibility with a low probability of occurrence that missile target encounters top or below of the left of capacitance detector, threshold value A can be greater than $|\Delta U_l|$ appropriately. For the setting of threshold value B, when missile target encounters the detector at speed of 1000 m/s, Target motion distance is 3 cm for 30 s. When the distance range between missile target and detector is from 15 cm to 25 cm, minimum value of change amount of $|\Delta U_d|$ for 3 cm is set to be threshold value B. In figure 2, when missile target encounters the top or below of the left of detector and the range between them is from 15 cm to 18 cm, we can get the minimum value 60 mV of continuous change amount of $|\Delta U_d|$, which is set to be threshold value B. Considering the targets speed may be less than 1000 m/s, threshold value B can be less than 60 mV appropriately.

For the sake of recognition high-speed missile target accurately, the signal conditioning circuit will give a signal $K\ |\Delta U_d\ |$ ($K > 1$) by a reverse amplification process of ΔU_d. $K\ |\Delta U_d\ |$ ($K > 1$) is the input of target recognition algorithm. The algorithm implementation is shown as below:

1) Take t_w μs as the duration of input data. Assumed that M data points have been detected before t μs ($t > t_w$), then we can get (M + 1) data points: $x(t)$, $x(t - t_s)$, $x(t - 2\ t_s)$, …, $x[t - (\mathrm{M} - 1)\ t_s]$, $x(t - \mathrm{M}\ t_s)$. Here, f_s is the sampling frequency of $K\ |\Delta U_d\ |$, $\mathrm{M} = t_w \times f_s$, $t_s = 1/\ f_s$.

2) Data acquisition is implemented every t_s μs. We can get (M + 1) data points: $x(t + j \times t_s)$, $x[t + (j - 1) \times t_s]$, $x[t + (j - 2) \times t_s]$, …, $x[t + (j - \mathrm{M} + 1) \times t_s]$, $x[t + (j - \mathrm{M}) \times t_s]$. Here, the value of j is 0,1,2,3…

3) If the accessed (M + 1) data points in serial meet all the criterion shown as below: $x(t + j \times t_s) > x[t + (j - 1) \times t_s] > x[t + (j - 2) \times t_s] > \ldots > x[t + (j - \mathrm{M} + 1) \times t_s] > x[t + (j - \mathrm{M}) \times t_s]$, $\{ x(t + j \times t_s) - x[t + (j - 1) \times t_s]\} > \{ x[t + (j - 1) \times t_s] - x[t + (j - 2) \times t_s]\} > \ldots > \{ x[t + (j - \mathrm{M} + 1) \times t_s] - x[t + (j - \mathrm{M}) \times t_s]\}$, $x[t + (j - \mathrm{M}) \times t_s]$ > threshold value A, and $\{x(t + j \times t_s) - x[t + (j - \mathrm{M}) \times t_s]\}$ > threshold value B, then we can verify the accessed (M + 1) data points as target signal and recognize high-speed missile target.

4 SIMULATION AND VALIDATION

In order to verify the validity of the high-speed target recognition algorithm, the validation of simulation model based on target recognition process is presented, which is in ISE13.3 environment using the Isim software.

The simulation input is binary code stream ad_data[11:0] converted by data $K\ |\Delta U_d\ |$, which is actually measured when the approximately 1000 m/s high-speed missile target encounters detector. Discrete values of ad_data[11:0] range from 0 to 4095. Each discrete value is represented with 12 bits binary. If input data beyond range of ad_data[11:0], overflow flag is output. The simulation wave is shown as figure 3.

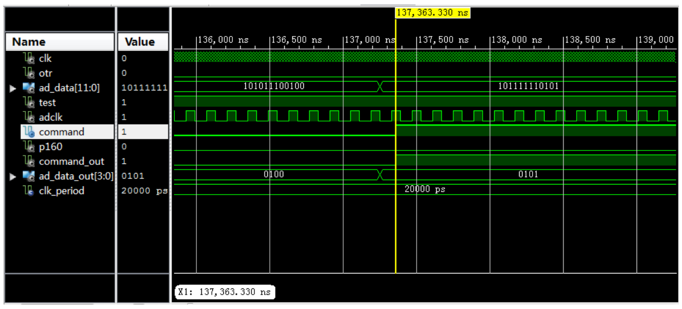

Figure 2. The simulation wave after inputting target signals.

In figure 3, after setting of 50MHz clock signal clk, overflow flag otr and test signal test, we enter high-speed data input target signal ad_data[11:0] into Isim software. Recognition signal command jump to high level 1 from low level 0 according to the algorithm proposed in this paper. In other words, the system recognizes high-speed missile target at the moment of 137.36 μs. At this moment, value of input data ad_data[11:0] is 10111110101, value of $K\ |\Delta U_d\ |$ is 3.7 V, and the distance between missile target and the center of detector is 16 cm. This distance is within the recognition range of 15 cm to 20 cm, which in accordance with the static measurement distance.

5 CONCLUSION

Based on capacitance detection theory and the static test experiment under laboratory conditions for simulating actual missile-detector encounter, this paper analyzed characteristics of high-speed missile target, set the recognition threshold, determined target recognition algorithm and verified the correctness and validity of the algorithm using the measured data. Advantages of method proposed in this paper are as followings: this method takes full advantage of characteristics of precise ranging of capacitance detector; threshold value set in this paper can recognize high-speed missile targets which encounter the detector in different orientations; this paper verifies the algorithm by measured data simulation, which reduces the experiment cost and improves the experimental accuracy. What's more, this algorithm has extensive applicability. Through further optimization, this algorithm can not only recognize the same high-speed missile target which encounters detector in different orientations, but also provide the useful reference to precise recognition in the case of different high-speed missile targets encountering the same detector.

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