Real-time target recognition system simulation based on laser near-field detection*

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This paper constructs a simulation system of near-field laser imaging for 3D grid model of target, provides some methods for the key problems, such as the modeling of target and laser transceiver, the calculation of laser echo power, the imaging algorithms and so on. A target image library is established by a new imaging method in any rendezvous conditions. The four real-time recognition algorithms which are efficient and suitable for hardware implementation are presented at the conditions of the image incompleteness, intensive noise and arbitrary attitude of target. The experimental results show that all the four algorithms can independently recognize the target effectively and a better recognition effect is obtained by the integration of four algorithms.

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Laser near-field imaging is a hot point in the laser fuse development[1]. It can be used to identify targets, clouds and mist effectively and to reduce the false alarm rate of target recognition by the laser line-scanning imaging. There are several difficult problems in this technology, such as the image incompleteness, intensive noise, arbitrary attitude, and there is not a good method to balance the recognition rate and the speed. The simulation system based on laser near-field detection can provide effective theoretical methods and data support for the laser near-field imaging development. This article explains the establishment of simulation system based on laser near-field detection. and several real-time algorithms for incomplete image.

The mechanism of laser near-field detection image is demonstrated in Fig.1. By receiving the echo signals of narrow pulse laser beams, the laser near-field detector can form target image itself. The transmitting and receiving system of narrow pulse laser beams (it is also called “optical system” for abbreviation) is located in the cylinder place at the back of warhead with field angle of 360°. Laser beams are emanated vertically toward the cylinder. v_p and v_m represent the flying speed of airplane and missile respectively. Δa stands for the field angle of the receiving part.

It is supposed that the optical system has n receiving parts,

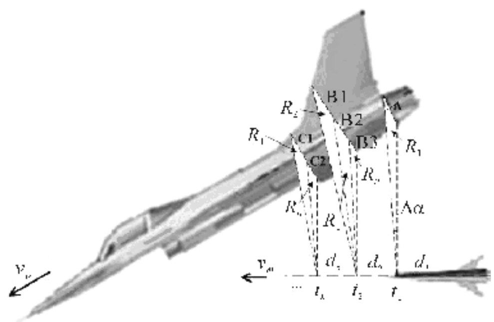

Fig.1 Principle of near-field laser detection imaging

each one (R_x) has m circuits to output. We can get the amount of $n \times m$ by scanning a whole cycle—that is the column of image. In the process of missile target rendezvous, the missile is supposed to be located at the spatial position of d_1 at the time of t_1, when A part of fuselage enters the viewing field of detector and the laser echo signals are received by the receiving part R_1. After a period of Δt, the missile arrives at the spatial position d_2. At this moment, A part of the fuselage retreats from the viewing field of fuse and the part of B1, B2 and B3 of the fuselage enters the fuse viewing field. Also correspondent echo signals are received by the receiving part of R_2 , R_1 and R_n. This is the same case until the

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target completely retreats from the detector's viewing field. Therefore, in the process of missile target rendezvous, the two-dimensional image of the target can be obtained by scanning the target. The number of image column is decided by the scan cycle (Δt) and relative speed of warhead($v_p \pm v_m$).

In present documents[1-2], target models adopted by image simulation are usually combinations of big triangle and curved surfaces. Such model is difficult to show the true features of target surface in the process of short range laser detection. In order to get more reliable and objective features of the target surface, this article adopts the 3D grid model of target airplane[3], which is made up of 1173 triangle surfaces and over 2500 acmes and can demonstrate the reflection features of the target surface very well. The 3D grid model after visual processing shown is as Fig.2.

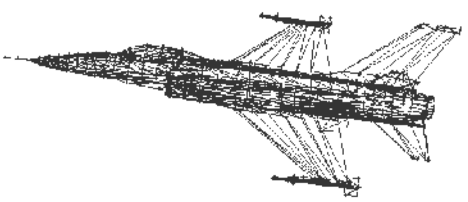

Fig.2 The 3D grid model of target

The Ref.[4] holds that within a narrow surface roughness, object surfaces are close to the ideal Lambert body. Apparently, the aircraft skin located at a narrow emanation viewing field can be regarded as a Lambert body. The geometric model of aircraft can be replaced by the similar model shown in Fig.2. Therefore, the laser echo power that can be received by the laser near-field detector can be calculated by the following eq.[1]:

$$P_s = P_e \tau_1 (\rho / \pi) \tau_2 A_s (\cos\phi / R_l^2) \ , \tag{1}$$

where P_e is the power of laser emitter, τ_1 is the optical transmittance of laser emitter, τ_2 is the optical transmittance of laser receiver, ρ is the diffuse reflectance of the target surface, A_s is photosurface area of laser receiver, ϕ is the angle between the central legato oo' and the photosurface normal line n' and R is the missile target distance.

When calculating echo power, it is a need to calculate the central point of facula formed by laser in the target surface (represented by the intersection spot P_i) . The angle ϕ and R_1 can be obtained by the central point, the central point of the photodetector and the normal vector of the photodetector. The diffuse echo power P_s of the target surface can be got by putting the two angles in the equation. Fig.3 shows the position relationship between some receiver and the facula on the aircraft skin.

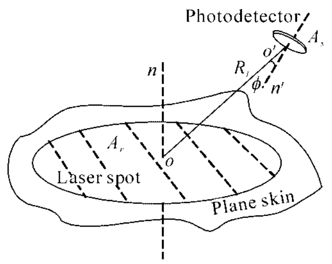

Fig.3 Relative position between receiving unit and laser spot

In the process of missile target rendezvous, only laser emitted by some detectors can produce echoes on the aircraft skin. Therefore, it is necessary to judge the intersect condition of rays and triangular-patches in the process of simulation. Fig.4 shows the whole process of simulated laser imaging based on laser near-field detection. Among which, hidden process (judgement of the intersect condition of rays and triangular-patches) is the key point in the imaging algorithm. It decides the quality of the simulation algorithm to a great extent. Concerning about needs of different simulation precision, this article brings forward two different kinds of hidden surface removal algorithm.

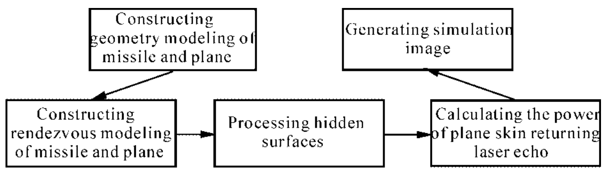

Fig.4 Flow chart of simulated laser imaging

Missile target is supposed to be located at the missile coordinate system. The vectors from the laser emitting center point O' to the triangular-patch ΔABC in the target model are $\vec{a}$, $\vec{b}$ and $\vec{c}$ respectively. The laser emitting line is R_i.

The hidden surface removal algorithm Ⅰ is as follows:

(i) If Eq.(3) meets Eq.(2), then the emitting ray can intersect with the triangular-patch ΔABC, among which, $\vec{n} = (\vec{a} - \vec{b}) \times (\vec{b} - \vec{c})$, $\vec{r}$ is the ray vector.

$$a \,\&\, ((b \,\&\, c \,\&\, d) \,|\, (e \,\&\, f \,\&\, g)) \ . \tag{2}$$

(ii) If R_i intersects with triangular-patch ΔABC , then the intersect point P_i can be calculated.

(iii) Angle ϕ and R_l can be calculated with the rays that meet Eq.(2). With the help of Eq.(1), the echo power can be obtained. Also according to the preset threshold, we can judge whether there is pixel output.

$$\begin{cases}(\vec{a}\cdot\vec{n})\times(\vec{r}\cdot\vec{n})>0,\\(\vec{a}\times\vec{b})\cdot\vec{r}>0,\\(\vec{b}\times\vec{c})\cdot\vec{r}>0,\\(\vec{c}\times\vec{a})\cdot\vec{r}>0,\\(\vec{a}\times\vec{b})\cdot\vec{r}\le 0,\\(\vec{b}\times\vec{c})\cdot\vec{r}\le 0,\\(\vec{c}\times\vec{a})\cdot\vec{r}\le 0.\end{cases}\tag{3}$$

In this algorithm, there are a few multiplications and additions. Therefore, the calculating speed is fast. Judging whether intersect or not before calculating the intersect point can largely reduce the complexity of calculation.

The hidden surface removal algorithm Ⅱ:

(i) If Eq.(5) meets Eq.(4), then the emitting beam can intersect with the triangular-patch ΔABC, among which, θ is the angle of laser beam,

$$a\,\&\,(((b\,|\,h)\,\&\,(c\,|\,i)\,\&\,(d\,|\,j))$$
$$|\,(e\,|\,h)\,\&\,(f\,|\,i)\,\&\,(g\,|\,j))\ , \tag{4}$$

$$\begin{cases}(\vec{a}\cdot\vec{n})\times(\vec{r}\cdot\vec{n})>0,\\(\vec{a}\times\vec{b})\cdot\vec{r}>0,\\(\vec{b}\times\vec{c})\cdot\vec{r}>0,\\(\vec{c}\times\vec{a})\cdot\vec{r}>0,\\(\vec{a}\times\vec{b})\cdot\vec{r}\le 0,\\(\vec{b}\times\vec{c})\cdot\vec{r}\le 0,\\(\vec{c}\times\vec{a})\cdot\vec{r}\le 0,\\\pi-\theta<ang((\vec{a}\times\vec{b}),\vec{r})<\pi+\theta,\\\pi-\theta<ang((\vec{b}\times\vec{c}),\vec{r})<\pi+\theta.\\\pi-\theta<ang((\vec{c}\times\vec{a}),\vec{r})<\pi+\theta\end{cases}\tag{5}$$

(ii) By calculation, the triangular-patch ΔABC intersected with beam B_i can be identified(it is possible that there might be several triangles).

(iii) Divide the beam B_i into k concentric halo equally within the field angle θ, and then the beam B_i is equivalent to k^2 rays. Calculate intersect point p_{ij} between equivalent ray B_{ij} and triangular- patch ΔABC (it is possible that there might be several triangles) and then calculate ϕ_j and R_{ij} of each equivalent ray.

(iv) Calculate echo power with Eq.(6) and judge whether there is pixel output according to the pre-set threshold.

$$P_s=\frac{1}{k^2}\sum_{j=1}^{k^2}P_{sj}=\frac{1}{k^2}\sum_{j=1}^{k^2}P_e\tau_1(\frac{\rho}{\pi})\tau_2A_s(\frac{\cos\phi_j}{R_{ij}^2})\ . \tag{6}$$

In the laser imaging process in reality, laser emitted from the laser apparatus is laser beam with certain angle rather than laser ray. Also the laser beam can radiate several triangular-patches on the target surface. The amount is changing with the change of R_l. The echo power P_s can be got by stacking scattering powers of the several patches. In the algorithm Ⅰ, laser beams are abbreviated into laser rays, which make that each laser ray R_i can only intersect with one triangle Δ_x in the target surface, with one ϕ. Therefore, the calculated P_s is the diffused result of the triangle on the target surface. In the algorithm Ⅱ, laser beams are introduced. The echo power produced by Eq.(6) is more close to reality by average the stacking echo power of each laser ray. But the computational complexity is increasing correspondently. Such kind of algorithm should be adopted when high quality of simulation image is required.

Tab.1 compares the two hidden surface removal algorithms (other parameters please see Tab.2). Fig.5 is the aircraft image produced by corresponding algorithm.

Tab.1 Performance of 2 imaging algorithms

Items \ SN		1	2	3
Initial position (m)		15,-5, 0	15,-4, 3	15,-4, 3
Initial (angle/°)	Deflection	0	150	45
	Elevation	0	30	45
	Roll	0	30	45
Time of generating an image(s)	Algorithm Ⅰ	28.4	17.5	15.9
	Algorithm Ⅱ	89.6	50.2	49.6

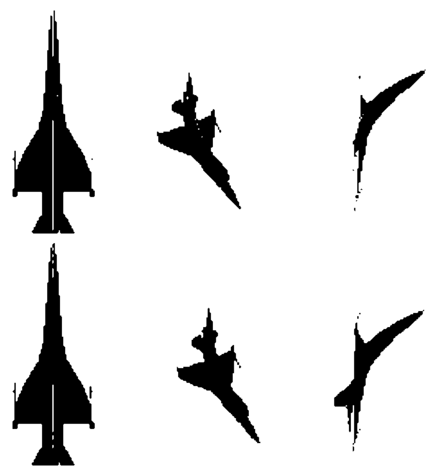

Fig.5 Simulation images of various algorithms

By studying the mechanism of laser near-field detection imaging and imaging environment, it can be found that on the condition of high speed, the time of missile target rendezvous is very short—usually milliseconds level, which needs that the target identification should be completed in the target detection process at the same time. That is target identification should be finished before producing the complete target image. Therefore, the images produced by laser near-field detection are real-timely incomplete. Secondly, missile target rendezvous are various, which make the effective scattering surface of aircraft skin toward laser various, and miss distance different. Therefore, the line-scanning images obtained at every time are different, that is arbitrary attitude imaging. Then because of the limited threshold of receiver, only laser echoes that are above the limited threshold can be taken in by the receiver to produce effective pixels and laser echoes below the limited threshold will be omitted, which make strong noise features such as loopholes and discrete points exist in the produced image (see Fig.6).

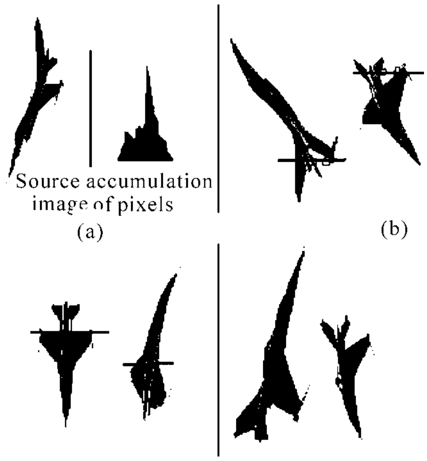

Fig.6 Real-time recognition algorithms

Because of these image features, the image identification algorithm based on global features is not practicable. Therefore, the image identification algorithm based on local features is adopted. What's more, the identification algorithm should be not too complex. From the analysis above, we can find the algorithm in Ref.[5-6] is not suitable for such kind of image. Through experiment tests, this article brings forward 4 kinds of algorithms which are suitable for such kind of image based on statistics and easily operated on present hardware platform. The 4 kinds of algorithms can be used comprehensively to get better identification quality.

Algorithm 1: accumulation of pixels

According to the scattering features of clouds and mists toward laser[7-8], simulation of clouds[9-10] and functional distance of laser near-field detection, it can be inferred that when laser near-field detector flies across clouds, big clouds (geometrical measure is over 10 meters) perform width band-like image, with width corresponding to laser unit's field angle. Small clouds perform ellipse image. Therefore, in cloud image, the change of pixel accumulation plot is stable, while aircraft image is of clear and sharp shape. The pixel accumulation plot in the aircraft image changes suddenly with pinnacles (See Fig.6(a)). Such feature can effectively distinguish clouds and aircrafts.

Algorithm 2: Connected domain detection

In the image produced by laser near-field detection, there are angles between aircraft envelope, flanking and wing empennage and also blank regions surrounded by effective pixels (see Fig.6(b)). While clouds performs band-like images or eclipse images with small blank region. This is also an effective feature to distinguish targets.

Algorithm 3: Abrupt change of image edge

Because of complex geometrical structure, the frame of aircraft images produced by laser near-field detection changes suddenly (see Fig.6(c)). While cloud frames change slowly. Such kind of feature can be used to distinguish aircrafts from clouds.

Algorithm 4: Statistics of central line

In the imaging process of laser near-field detection, aircraft envelope, fuselage and wing empennage always perform bifurcation. By calculation, we can get statistics of central line of different branches. When there is more than one branch in the image produced by laser near-field detection, we can get more than one central line (see Fig.6(d)). There are sloping angles or curves in these central lines. Generally speaking, there is only one statistical central line located at the central of the cloud image. Such kind of feature can be also used to distinguish aircrafts from clouds.

Because of requirements of applicable environment and dealt speed and so on, a real-time identification algorithm has to be realized in FPGA. The algorithm above is easily realized in FPGA.

According to the algorithm above, this article conducts experiment test in the image database produced by the simulation conditions shown in Tab.2 (image producing adopts algorithm 1). The test result of identification rate is shown in Fig.7. Among which, f is narrow pulse laser emitting rate, th is the threshold of receiver. From the picture, we can find that each identification algorithm can identify target effectively. By using the four kinds of algorithms comprehensively, the identification rate is above 95%.

Tab.2 Default parameters setting

	Initial position (m)	(15, 5, 0)	
Target parameter-	Angle range(°)	Deflection	-45-45
		Elevation	-45-45
		Roll	0-360
	Target speed(m/s)	1360	
Missile parameters	Missile speed(m/s)	340	
Other parameters	$P_e/\tau_1/\tau_2/\rho/A_s/f/th$		
Set value	30W/0.85/0.8/0.1/300 mm^2/1kHz/1.8uW		

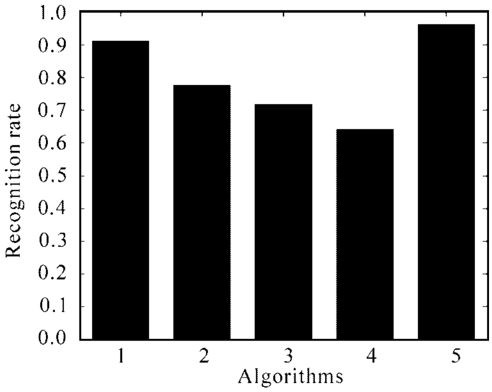

Fig.7 Recognition rate of various algorithms

In conclusion, four algorithms are presented for real-time recognition of target, in which the weight and reliability can be added to different algorithm in the process of algorithms integration. Then it can be evaluated comprehensively to get better and more reliable identification. Research on this aspect needs more experiment tests.

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