An Modeling and Simulation Method Research Based on Lidar Imaging

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Abstract

The research of imaging lidar has always been an important research topic at home and abroad. The content involves many aspects and the research methods are also different. However, the research and design of imaging lidar is a complicated and tedious problem. Compared with non-imaging lidar, the research of imaging lidar costs much higher than that of non-imaging lidar, in addition to the functional difference. In order to design and develop an imaging lidar system flexibly and effectively, and to improve the performance of the imaging lidar system, computer simulation methods is a very effective way that can solve the costly problem of experiments. This paper studied the lidar imaging simulation method to solve the high cost of carrying out targeted actual measurement experiments under normal circumstances, come up with the imaging simulation process, and maintain the Lidar imaging simulation results of typical targets.

***Keywords**: Target detection and recognition, lidar imaging, modeling and simulation, noise simulation, range gate mechanism, contour sawtooth simulation*

I. Introduction

The so-called imaging lidar system simulation is to use computer software and hardware to build a model of the lidar system, and then reproduce the dynamic working process of the imaging lidar system on the computer[1]. It is the product of the combination of digital simulation technology and lidar technology. Specifically, the simulated object is an imaging lidar system, including the imaging lidar, atmospheric environment, target and background environment characteristics.

The simulation tool is a digital computer, including software and hardware[2].

In the design and application of lidar systems, there are a large number of non-linear factors and random factors[3]. The influence of these factors on the system requires a large number of experiments to observe and study. If the software is used to establish a model in the system design process, and the relevant parameters of the lidar system, laser transmission medium, lidar target and target radar cross-section are used to simulate the detection results of imaging lidar under various conditions. Then, the results obtained can enable the designer of the imaging lidar system to choose the optimal design path purposefully, and have a complete understanding of the performance of the system before the actual system is completed[4]. The parameters of these models can be input and given, which are hardly restricted by any conditions. Therefore, imaging lidar system simulation is an effective method for lidar system design and analysis that can provide a reference for the optimization design and analysis of imaging lidar systems, shorten the design cycle and improve work efficiency. It is an indispensable link when we design and research the imaging lidar system[5][6].

Non-imaging laser-guided bombs have been equipped with troops at home. And pre-research and key technology research on laser imaging guidance has been conducting for many years, which have made important progress. However, in terms of devices, theory, methods, and algorithms, the current progress and level are far from those of Europe and the United States, and they do not meet the urgent needs of our military's weapons and equipment.

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It can be seen from above that laser imaging guidance is an important direction for the research and development of precision guidance at home and abroad. In order to promote the development of related technologies, the research and development of algorithms and technologies for automatic detection and positioning of laser imaging targets must be carried out as soon as possible.

II. Lidar simulation

In general, for imaging lidar system, several main indexes should be considered, including operating range, single frame pixel size, range resolution and image resolution. For some applications, it may also meet the requirements of volume and weight. Then, the parameters such as laser pulse repetition frequency, pulse energy, pulse width, data acquisition rate, scanning waveform and scanning frequency are determined according to the above indexes. Imaging lidar system can generally be divided into three parts, including imaging system, image processing system and image display system[7].

In the simulation of lidar system, the first thing is to establish the three-dimensional simulation model of the actual scene to be simulated, and the second most important work is to establish the mathematical model describing the environment. The simulation process is shown in Figure 1. Imaging lidar will be affected by various noises in the imaging process, of which the more important is the irregular pulse amplitude modulation caused by atmospheric scintillation effect, resulting in the random fluctuation of laser beam intensity, which will have a negative impact on the signal reception. In addition, there is the noise of the receiver, such as shot noise, background light noise, detector dark current, thermal noise and the noise caused by the radiation of the target itself. These noises have an important impact on the imaging quality. The intensity image and range image are often polluted by noise, and even can't identify the target in special cases.

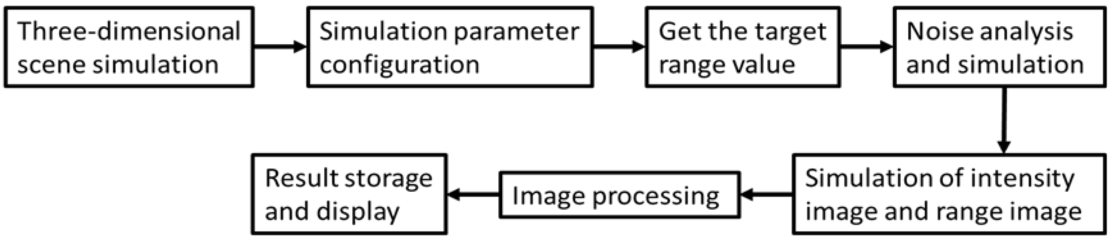

Fig 1: Simulation process of laser imaging radar system

In the simulation system, firstly, the actual scene data needs to be simulated according to the actual needs, and the subsequent simulation research is carried out according to the three-dimensional information of the simulation scene. Then, the parameters of each module of the imaging lidar system need to be input, such as transmission wavelength, pulse width, repetition frequency, divergence angle and pulse energy in the transmitter module, average refractive index, absorption coefficient, scattering coefficient and logarithmic intensity variance of scintillation in the atmosphere module; The target parameters include target distance and target reflectivity. Users can change these parameters as needed. In fact, imaging lidar is a very complex system, each module is also very complex, and many factors need to be considered[8]. For example, the target background characteristics and atmosphere module are a very complex part, many factors need to be considered, and more are the actual measurement results and empirical formulas, which need to be specially studied and expanded. Only simple simulation is carried out here.

For imaging lidar, it is necessary to measure the range, velocity and position of the target. We can identify and recognize the target through the intensity image and range image of the target. When simulating the performance of lidar system, the model should be established according to the function of lidar system. According to the above basic principles, the established imaging lidar system model software is divided into four modules: scene simulation module, imaging module, image processing module and display module.

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2.1 Scene simulation module

In the lidar image simulation, the first thing is to simulate the 3D scene according to the actual 3D scene data, and then study the simulation algorithm of range image and intensity image on this basis. Here, Multigen Creator 3D visual simulation software is used to simulate the 3D scene, which output file format is $*.flt$. And PolyTrans software of Okino company is used to convert $*.flt$ into a high-quality standard $*.3ds$ file to provide the 3D scene information required for the input of the imaging module.

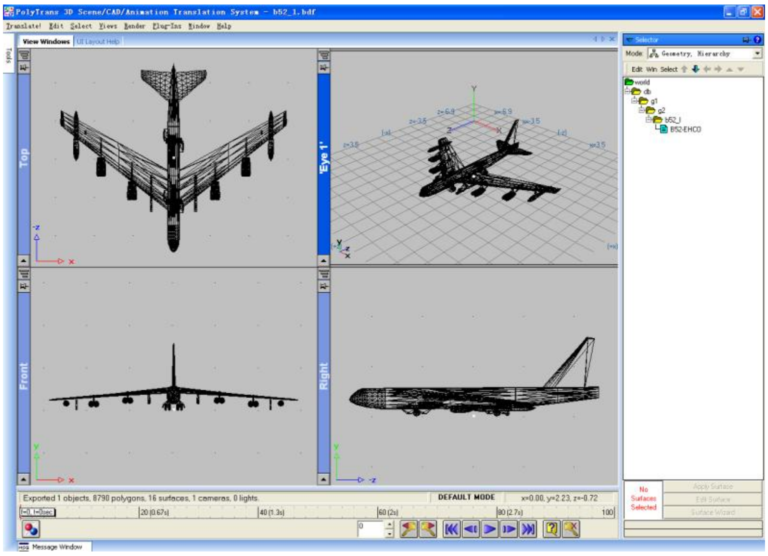

Fig 2: Transformation of flt file to 3ds file

3ds files are point cloud data in the form of meshes. The 3D model in ".flt " format built by Multigen Creator can be converted to ".3ds " format by Okino PolyTrans software, as shown in Figure 2.

Next, taking an aircraft model (as shown in Figure 3) as an example to illustrate the data structure of the model used in the simulation process.

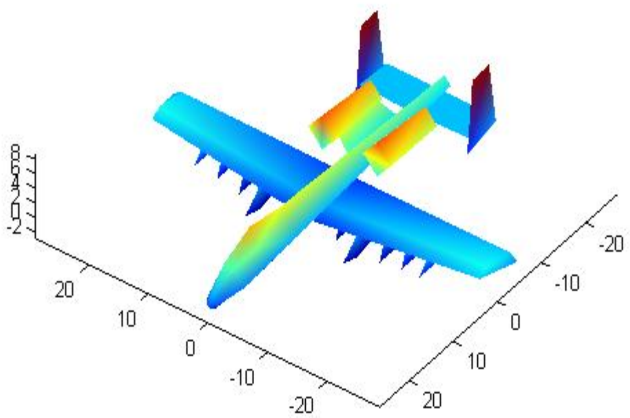

Fig 3: Rendering of a10.3ds model

After the 3ds file is read in through the custom class "@ model3d", after parsing, it can be seen that the model is

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composed of the following fields: name, vertices, facetidx, facets, ambient, diffuse, special, shinness, shinystrength and transparency. For the simulation process, the domains actually used are vertices and facetidx. Vertices represent the three-dimensional coordinates of vertices, and facetidx represents the triangle plane index, that is, of which three vertices of a triangle are composed.

With the top surface coordinates and plane index, we can draw all the surfaces of the model through the patch function, and the results are shown in Figure 4.

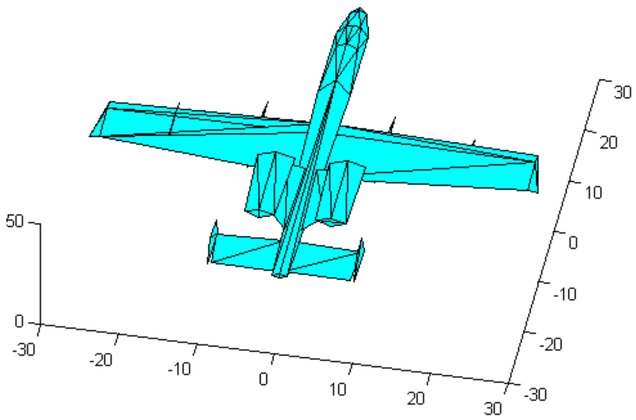

Fig 4: Patch of a10.3ds model

The 3D simulation process consists of the following two steps.
(1) According to the input imaging attitude parameters, the translation and rotation model is composed of the following three links, they are shown in Figure 5.

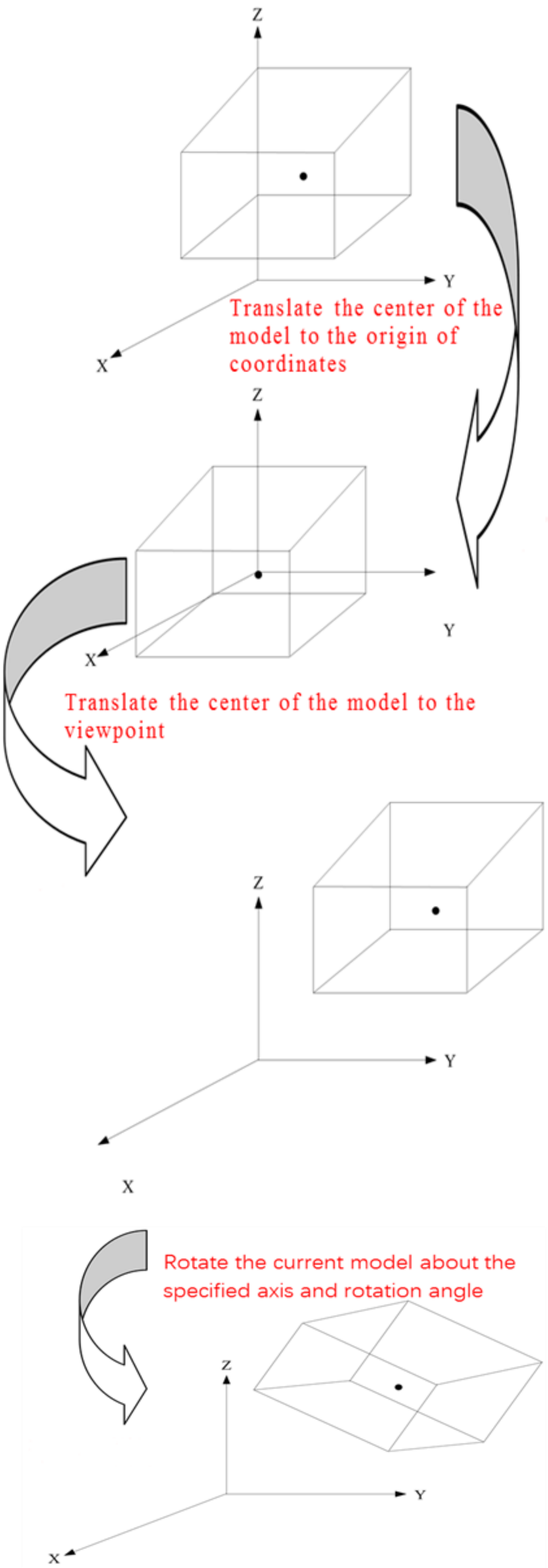

Fig 5: Rotation process of 3D model

(2) The focal plane array is filled pixel by pixel according to the rotated model.

Assuming that the pitch angle is 45 degrees, the azimuth angle is 45 degrees and the imaging distance is 2000 meters, the rotated model and its corresponding focal plane array are as shown in Figure 6.

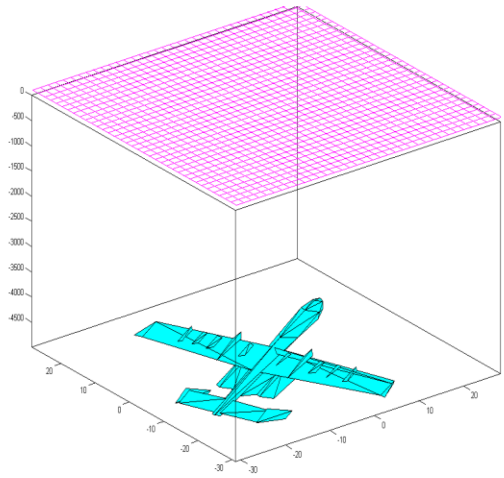

Fig 6: Focal plane array of rotated model

As shown in Figure 7, each grid of the focal plane corresponds to a pixel position. The next thing to do is to fill each grid with the correct pixel value. The specific filling method is described below by taking one of the surfaces as an example.

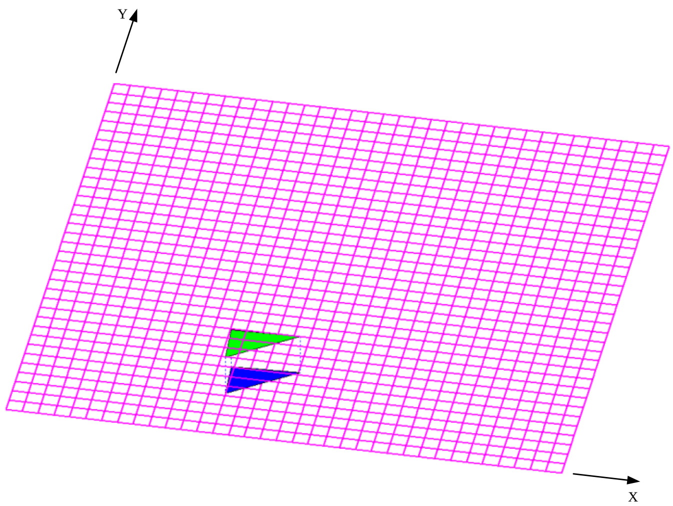

Fig 7: Vertical projection of a surface

(1) The green surface is projected onto the XOY surface to obtain the blue polygon.
(2) Scan along the X direction (column direction). If the X coordinate of the current scanning point enters the outer rectangle range of the green polygon, start the scanning in the Y direction (row direction).
(3) Scan along the Y direction. If the Y coordinate of the current point enters the outer rectangle range of the green polygon, judge whether the point entering the outer rectangle is within the blue polygon. If it is within the polygon, obtain an effective pixel and use the height value of the current point (after a series of operations mentioned above, the original distance value has been converted to the height value) to fill the distance matrix cell. At the same time, the laser reflection intensity of the current vertex is obtained, and the intensity matrix cell is filled with the obtained intensity value.
(4) Repeat steps (2) and (3) until the end.

2.2 Imaging module

The imaging module mainly configures the transmitter parameters and receiver parameters, and then generates the corresponding intensity image and range image according to the three-dimensional scene information and imaging viewpoint. The main indexes of the transmitter design are the parameters of the laser and the characteristics of the output laser beam of the optical system. Such as: laser emission power, optical efficiency, pulse repetition rate, emission gain, etc. The receiver is mainly composed of APD avalanche diode array. Its main indicators include single frame pixel size, pixel spatial resolution, working mode and ranging mode[9].

2.3 Image processing module

A significant advantage of imaging lidar different from passive imaging is that it can form both intensity image and range image. The intensity image information and range image information constitute the complete three-dimensional information of the target. Image processing module is an important part of imaging lidar simulation. An original imaging lidar image is inevitably affected by various noises. In addition, the target is in the background of different complexity. Especially when the target signal is weak and the background is complex, the imaging quality is poor and the target information is hidden in the noise, which makes it very difficult to detect, identify and identify the target. Therefore, feasible signal processing methods and target detection and recognition algorithms are needed to improve the image signal-to-noise ratio, highlight the target and suppress the background, so as to achieve reliable target detection and recognition[10].

2.4 Storage display module

The storage and display module is mainly responsible for storing and displaying the input and output result information of the image processing module to achieve friendly human-computer interaction.

III. Noise analysis

3.1 Noise simulation

According to the characteristics of range profile noise, by artificially adding noise, it is possible to obtain simulated images that are closer to the real range profile of laser imaging radar under different conditions, and then design different algorithms to process them to facilitating the development of algorithms[11].

Taking the discrete output of the analog square rate envelope detector as its starting point, the discrete result is N distance units, of which one is the distance unit corresponding to the actual distance value, and the remaining N-1 are noise unit without the actual distance value. For each pixel to be simulated, the peak detection function is mainly completed by generating two random variables X1 and X2. X1 represents the intensity of the distance unit N0 where the actual distance value is located, and is a random variable that obeys an exponential distribution with a mean value of 2+SNR (SNR represents the signal-to-noise ratio); X2 represents the maximum value of the intensity of the remaining N-1 noise units, which The intensity values of the N-1 noise units are all random variables that obey the exponential distribution with a mean value of 1, and are independent and identically distributed.

X1 and X2 can be obtained through the following ways: the computer generates two independent and identically distributed random variables U1 and U2 that obey a uniform distribution in the interval, as shown in the following formula.

$$X_1 = -(2+SNR)\times ln(1-U_1) \quad (1)$$

$$X_2 = -ln\left(1 - U_2^{\left(\frac{1}{N-1}\right)}\right) \tag{2}$$

For the intensity image, the intensity value of the nth pixel is $In = \max(X_{1n}, X_{2n})$. And for the distance image, it is necessary to judge whether there is an abnormal distance.

If X2n>X1n, a distance anomaly has occurred, and the distance value is evenly distributed among the remaining N-1 noise units except N0. If X2n<X1n, no distance anomaly has occurred, and the distance value is the actual distance value N0.

3.2 Type analysis of distance noise

The range image is mainly disturbed by two types of noise, namely, missing information and outliers. When the received echo energy is lower than the threshold, missing information is generated. Specifically, there are three situations of missing information.
(1) The situation where the laser pulse has no echo. There is no reflective surface (such as the sky) on the transmitting pulse channel or the signal reflected from the surface cannot be reflected on the lidar.
(2) The echo intensity is lower than the response threshold of the detector.
(3) The echo time exceeds the lidar receiving window.
When the background or detector noise peak value exceeds the missing information threshold and exceeds the true echo signal peak value, an escape value is produced, which is also called distance anomaly.

IV. The execution mechanism of range threshold

A very significant advantage of laser imaging over infrared imaging is that the former is active imaging, while the latter is passive imaging. The characteristic of active imaging makes the imaging process under the laser system with a certain degree of intelligence, that is, it can carry out targeted screening of the target scene, so as to filter out a large amount of The background interference, which simplifies the subsequent information processing tasks such as detection and identification to the greatest extent. Figure 8 is a schematic diagram of the range threshold. After the simulation process, we have obtained a matrix that characterizes the distance information of the target model. For the current range unit, whether it remains valid depends on the following judgment. If the current range value is between the lower limit and the upper limit of the range threshold, it is considered retained, otherwise, it is considered invalid (the distance value is forced to be the lower limit of the range threshold). Figure 8 shows the pseudo-color image display, and the achromatic printing effect will be significantly reduced.

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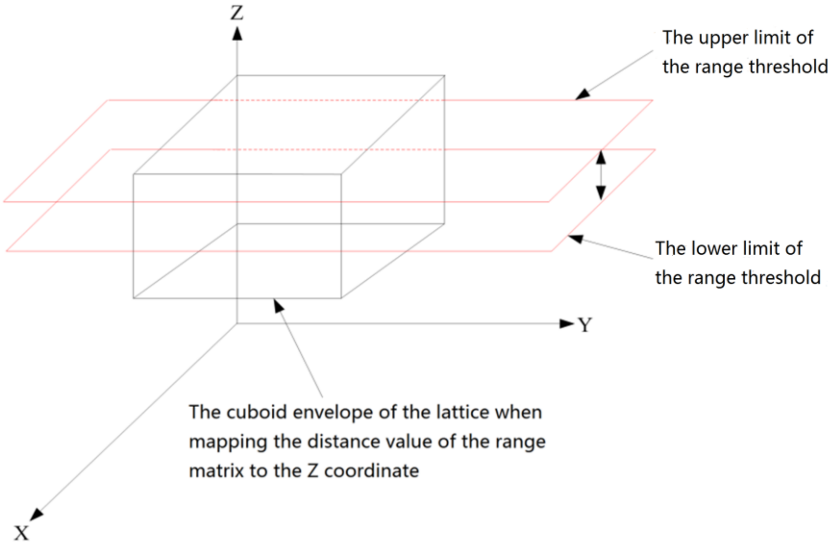

Fig 8: Diagram of range threshold

Figure 9 shows the comparison before and after the range threshold operation is performed on an airplane model. From the image after operation, we can find that some of the scenes in the upper left and lower right corners have been filtered out. Figure 9 shows the pseudo-color image, and the achromatic printing effect will be significantly reduced.

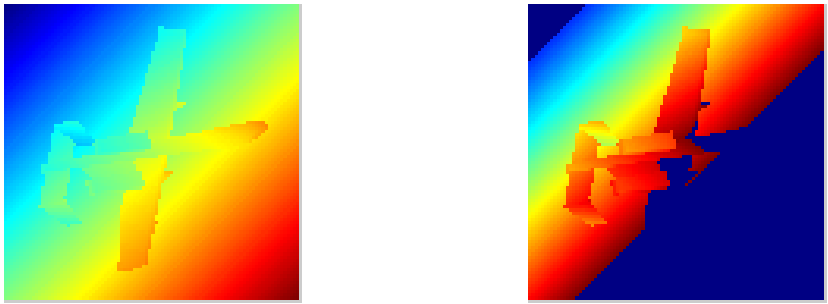

Fig 9: Process result using range threshold. (a) Before operation; (b) After operation

V. Contour sawtooth simulation

The characteristics of the laser determine that it may be inaccurate at the edge of the target, which is reflected in the image as a jagged edge at the edge of the image. We have adopted the following method to simulate the existence of sawtooth. We use the randsrc function to generate a random matrix with values of 0 and 1 and the size consistent with the range image, then scan the range image, if the current position belongs to the outer contour of the range image, take the current position as the center to construct a local neighborhood of k*k size. For pixels located inside the contour polygon, if the value of the random matrix is 1, then the position in the result matrix is assigned to 0, otherwise the original pixel value is retained, as shown in Figure 10. At the same time, the intensity of sawtooth can be controlled by controlling the probability of taking 1. Figure 10 shows the pseudo-color image display, and the achromatic printing effect will be significantly reduced.

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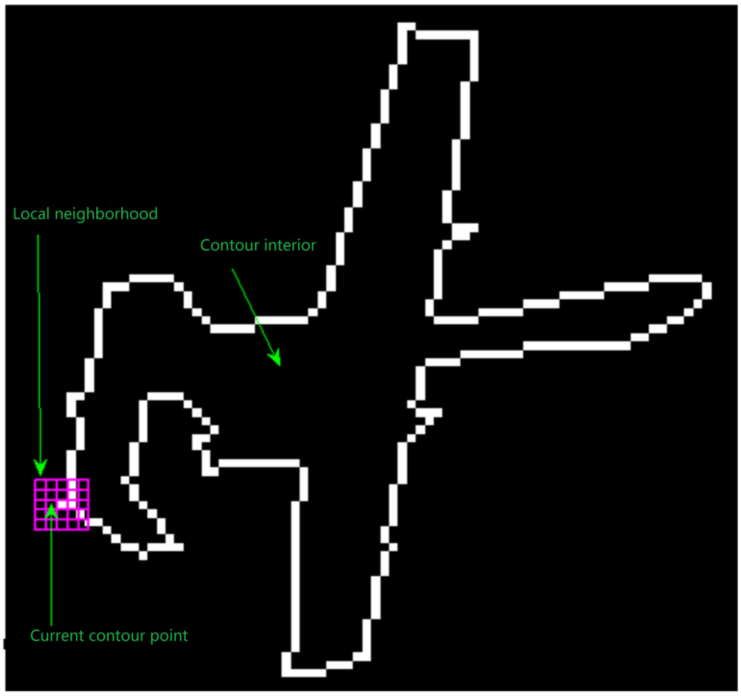

Fig 10: Diagram of contour sawtooth simulation

Figure 11 shows the comparison of the contour sawtooth simulation operation before and after operation on an airplane model. Figure 11 shows the pseudo-color image, and the achromatic printing effect will be significantly reduced.

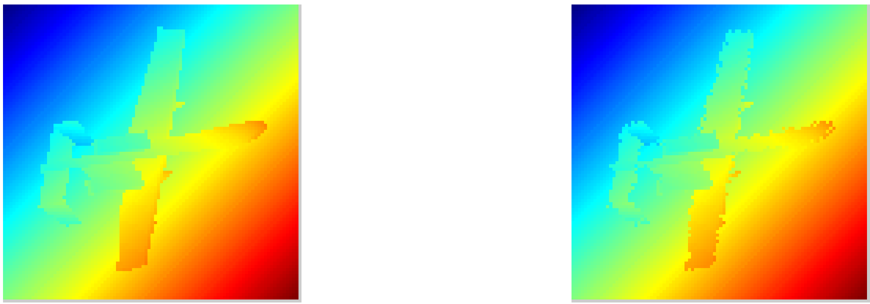

Fig 11: Example of contour sawtooth. (a) Before operation; (b) After operation

VI. Analysis of simulation experiment results

Based on the simulation principle proposed above, experiments are carried out on three types of targets, namely tightly supported targets, extended targets and combined targets, to study the influence of different factors on the simulation results. Among them, tightly supported targets include: aircraft, tanks, armored vehicles, ground vehicles, ballistic missiles, launch vehicles, erected launchers, radars, artillery, small ships and small bridges; extended targets include: power plants, medium-sized ships, ground building targets . Figures 12-16 show pseudo-color images, and the effect of achromatic printing will be significantly reduced.

6.1 different distance

Take the airplane a10.3ds model as an example, as shown in Figure 12.

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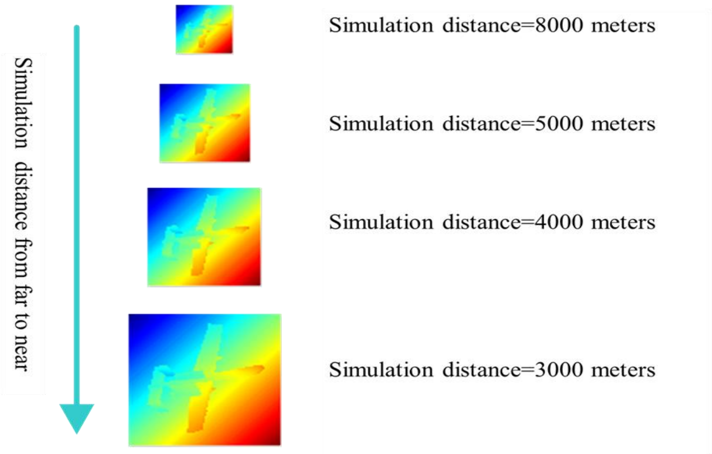

Fig 12: Simulation of different distance

When the distance is very far, the resulting image can only reflect very little information of the target, at this time it corresponds to a large scale. When the distance gradually gets closer, the target detail information becomes more and more abundant, and it corresponds to a small scale at this time. For subsequent recognition and identification tasks, small-scale images can achieve better results, so if there is a higher requirement for recognition probability, consider imaging the target on a small-scale.

6.2 Simulation of distance

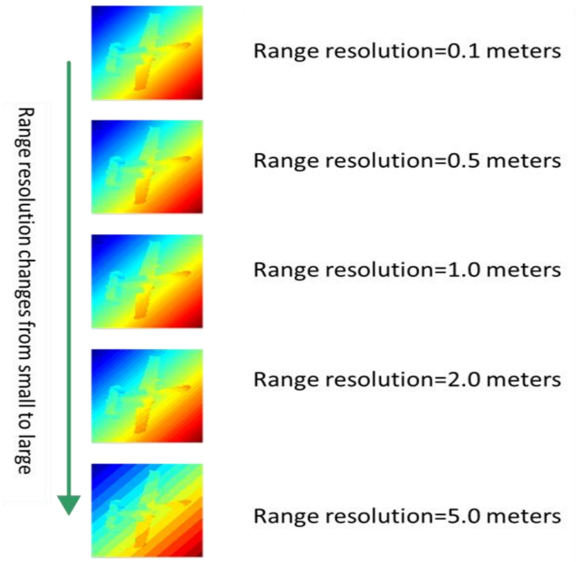

Fig 13: Simulation of range resolution

As shown in Figure 13, the range resolution reflects the level of detail of the target. When the range resolution is very low, the image information obtained by simulation is very small at this time, and the level is not clear enough; when the range resolution gradually becomes higher, the image information more and more abundant, it is reflected in the image that the number of gray levels of the image is increasing, and the distinguishable image features are becoming more and more.Therefore, when there is a higher requirement for the recognition probability, it is recommended to use a higher distance resolution.

6.3 Viewing angle

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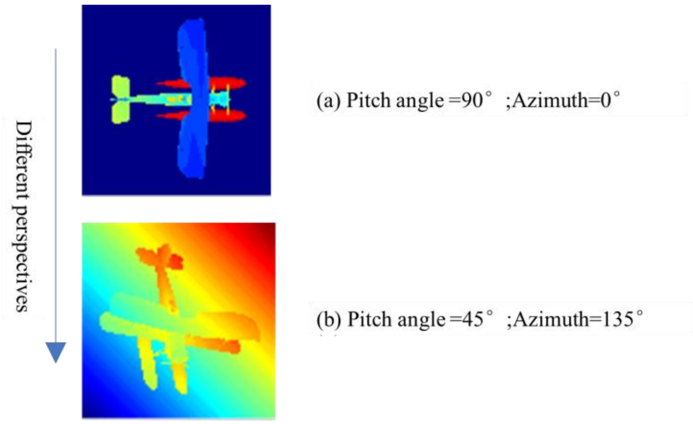

Fig 14: Simulation of different viewing angle

The image information that the target can express is directly related to the viewing angle. As shown in Figure 14, taking the aircraft T_SWOR.3ds model as an example, Figure (a) shows a simulation diagram with a pitch angle of 90 degrees and an azimuth angle of 0 degrees, and Figure (b) shows a simulation diagram with a pitch angle of 45 degrees and an azimuth angle of 135 degrees. The comparison shows that we can get more image information from the figure (b). If there is a higher requirement for the recognition probability, you should try to choose a viewing angle with the least mutual occlusion between the target components for imaging.

6.4 Angular resolution

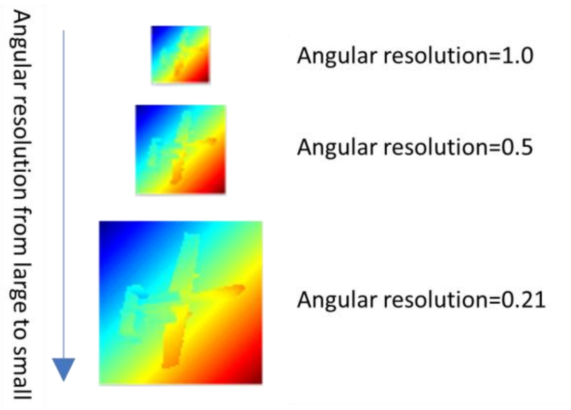

Fig 15: Simulation of angular resolution

As shown in Figure 15, angular resolution reflects the spatial resolution of imaging in the target area. When the angular resolution is low, the spatial resolution of imaging in the target area is correspondingly low; on the contrary, when the angular resolution is high, the spatial resolution of imaging in the target area is relatively higher.

6.5 Signal-to-noise ratio(SNR)

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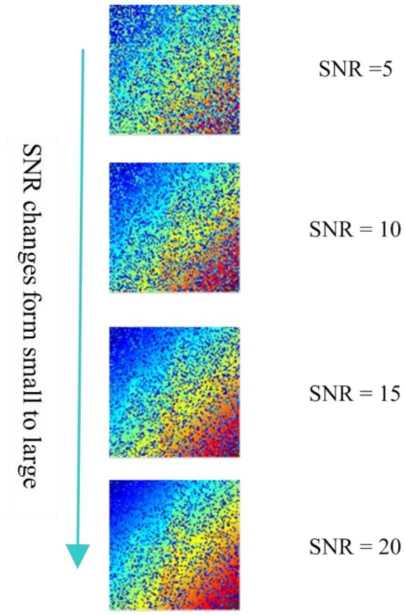

Fig 16: Simulation of different SNR

SNR reflects the degree of contamination of the image during the imaging process. When the imaging conditions caused by atmospheric transmission are relatively bad, the degree of contamination of the image is greater. At this time, a lower SNR must be used to simulate, and vice versa. In the theoretical research stage, it can be assumed that the imaging environment is ideal, and therefore, only a higher SNR is required to simulate.

It can be seen from Figure 16 that the simulation results are affected by the above factors to different degrees, but the quantification of the specific laws needs to be determined according to the specific application background.

VII. Conclusions

Lidar is a product of the combination of lidar and photoelectric imaging technology, and lidar technology is an important part of lidar imaging technology. Lidar can generally be divided into 3 systems, including transmitting system, receiving system and information processing system. This paper studied the Lidar imaging simulation method to solve the high cost of carrying out targeted actual measurement experiments under normal circumstances. First, the generation mechanism of the lidar range image and intensity image is explained, the imaging simulation process is proposed, and then post-processing of the simulation image is discussed, including noise simulation, range gate mechanism and contour sawtooth simulation, etc., and the lidar imaging simulation results of typical targets are given.

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