Accurate and Fast Simulation of Laser Scanning Imaging

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Abstract. In order to design a more accurate simulation system of laser scanning imaging, a kind of new simulation method is put forward in this paper. By introducing the accurate laser model, this paper proposes a more precise echo power calculation formula. This method reproduces the edge blur effect in the laser scanning imaging, and can get the realistic simulation effect. At the same time, this method also simplified the calculating process by choosing simple model or accurate model in different cases. The calculation speed and the simulation efficiency are improved. Experiments prove that this method of laser scanning imaging simulation can complete simulation tasks quickly, and get the simulation images which are very close to the real images.

Keywords: Laser scanning imaging. Computer simulation. Echo power. Edge blur effect

1 Introduction

Laser scanning imaging system [2, 6] can get scanning images by the relative motion of seeker and target. This system uses the laser's echo power to create an image of the target, and then gets the target's information and recognizes it. A laser beam is nearly collimated over long distances, so the laser scanning imaging system can be very accurate. This system is widely used in target recognition and detection.

Since the dynamic laser scanning imaging system is affected by the parameters of the seeker, we have to do large number of experiments to adjust the parameters. Besides, the training set of recognition algorithms [1, 4] also needs lots of scanning images. If all the experiments are did actually, too much time will be cost. While, if we simulate the process of laser scanning through simulation software on computers, the scanning images will be got easily, cheaply, and efficiently. As a

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result, it is very important to design a simulation system for dynamic laser scanning imaging.

The simulation systems [8] in the world now include hardware-in-loop simulation system, local static simulation system, global dynamic simulation system and so on. Global dynamic simulation system can simulate the whole process of laser scanning imaging, so that it can test the seeker fully.

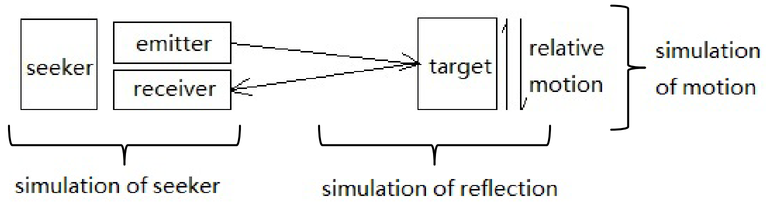


Fig. 1 Global dynamic simulation system

Global dynamic simulation system (Fig. 1) includes movement process simulation, seeker simulation [11] and reflectivity of target's surface simulation [9]. At the same time, graphical user interface will show the scanning process and scanning result on the computer.

This paper focus on global dynamic simulation, the main difficulty of it is the simulation of laser's emission, refection and receiving. In current simulation system, targets and seekers are described by the mesh model (Fig. 2), while the laser is described by line. In simulation, the intersection of lines and mesh model is calculated to simulate the laser's emission refection and receiving.

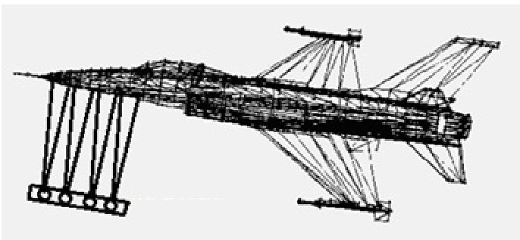


Fig. 2 Mesh model & divergence angle

However, laser is not ideal in practice, laser's divergence angle [3] leads to edge blur effect [5], which has effect on detection or recognition. In order to make the simulation result more close to the truth, a new accurate model of laser is proposed by this paper, and a more precise echo power calculation formula is put forward. Besides, a simplified algorithm is also proposed to avoid too much calculation.

2 Accurate Model of Laser with Divergence Angle

The key step of laser scanning imaging is calculating the echo power received by the seeker.

In the process of calculating echo power, laser is simplified to line, which leads to clear edge in simulation image. However, there exists edge blur effect in actual laser scanning imaging. It is because of the laser's divergence angle. When laser irradiates to the target's edge, only parts of the laser can be reflected. As a result, receiver gets less echo and edge blur effect appears in scanning images.

In order to make simulation more realistic, edge blur effect must be considered. Laser's divergence angle is added as a new parameter. Thus, the model of laser becomes a cone instead of a line, and the formula of echo power becomes an integral.

3 Accurate Calculation of Echo Power

In order to get the distance between target and seeker, we need to calculate the echo power of laser. Echo power of laser without divergence angel can be calculated very easily [10]. Laser is seen as a line, and intersection of lines and mesh model is calculated to simulate the laser's emission refection and receiving. However, laser with divergence angel must be seen as a cone.

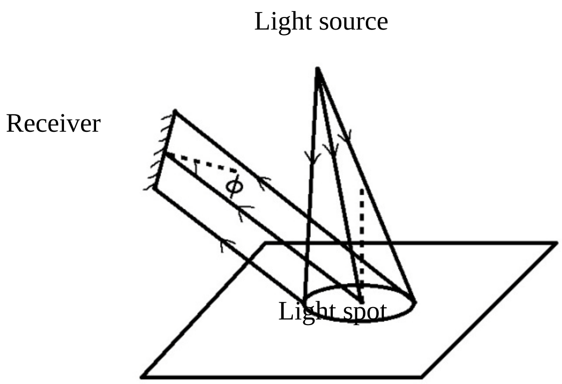


Fig. 3 Reflection of laser beam

Because laser scanning imaging is mainly used in near-field detection, the distance between seeker and target will not be too long, and the attenuation in air can be ignored. Firstly, we assume that the light spot is on one surface in the mesh model (Fig. 3).

The meanings of parameters are as follows.

P_e: power of emitter;

τ_1: transmission of emitter;

τ_2: transmission of receiver;

ρ: diffuse reflectance of target surface;

A_s: surface area of receiver;

ϕ: angel as the fig. 3 shows;

R: distance between seeker and target。

Ignoring the attenuation in air, we can get the echo power [10]

$$P = \rho P_e \tau_1 \tau_2 A_s \cos\phi / \pi R^2 \quad (1)$$

Without considering laser's divergence angel, R in formula (1) is a constant, and we can calculate the echo power directly. But R becomes a variable when considering laser's divergence angel. This leads to error if we still use formula (1) or treat R as a constant. Especially in the cases in Fig. 4, R varies a lot when the laser irradiates to the target's edge or the laser irradiates to the target in a small angel. So, we should calculate the echo power by integral.

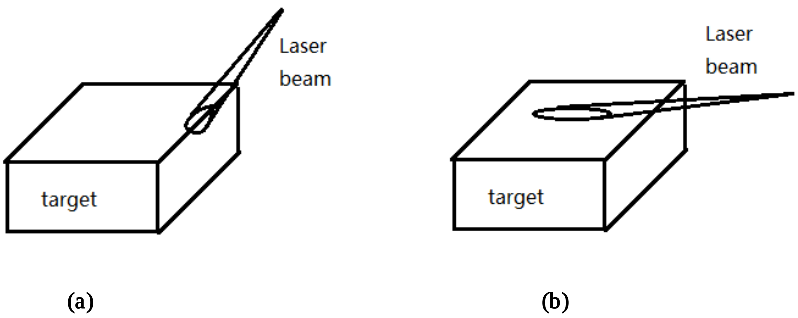


Fig. 4 Two cases having big error

If divergence angel is Ω_e, we can get the echo power by integral as formula (2).

$$P = \int_{\Omega}\int \rho (P_e/\Omega_e) \tau_1 \tau_2 A_s \cos\phi / \pi R^2 \, d\Omega \quad (2)$$

In order to calculate echo power of laser with divergence angel in computer, we firstly discrete the laser beam. A laser beam is treat as n lines. n (the number of lines) depends on the distance of target and seeker. The farther the distance is, the bigger n need to be. In simulation, n is decided by d, which is the distance between seeker and light spot. $n = kd^2$. Here, parameter k depends on accuracy and efficiency required in simulation. Bigger k means more accurate and less efficient simulation. After discretion, the echo power of each line is added up, so that to get the total echo power.

4 Efficient Calculation of Echo Power

If accurate model is used, number of lines is n times as much as original, and more time is cost. In order to avoid this case, we need to simplify the simulation model and make it more efficient. Without considering divergence angel, there exist only two cases having big error (Fig. 4). In fact, laser's divergence angel is not big, thus most lasers only intersect with one triangle in mesh model. Only few lasers irradiate to the target's edge and cause edge blur effect. As a result, we can use accurate model only when error is big.

When the model without divergence angel has big error, distance R of laser's different parts varies a lot. So, we can decide whether to use accurate model through the difference of R in one laser beam. We calculate the distance R of four points to get the difference of R fast. These four points is the vertices of the light spot's external rectangle. Then, we set a threshold. When the difference is bigger than the threshold, accurate model is used, or simple model is used.

The distances between four vertices and seeker are R_1~R_4, then Δ can tell us how big the relative difference is.

$$\Delta = (\max(R_1,R_2,R_3,R_4) - \min(R_1,R_2,R_3,R_4)) / \min(R_1,R_2,R_3,R_4) \qquad (3)$$

When laser irradiates to the edge, $\max(R_1,R_2,R_3,R_4)$ becomes ∞, thus Δ is ∞ too. In another case, laser irradiates in a small angel, and Δ is big too. (Table 1)

We set a threshold Δ_{th} to decide whether to use accurate model. Δ_{th} depends on the accuracy and efficiency required in simulation. The flowchart of this algorithm is as Fig. 5 shows.

Table 1 A normal case (shown in Fig. 3), and two cases when error is big (shown in Fig. 4)

Cases	1	2	3
Figures	Fig. 3	Fig. 4 (a)	Fig. 4 (b)
Δ	small	∞	big
Error if not using accurate model	small	big	big

This algorithm calculate two different cases in different way. Efficient calculation method is used when error is little, while accurate calculation method is used when error is big. Because there are few cases which have big error in simulation, the result can be more accurate without spending much more time when using this algorithm.

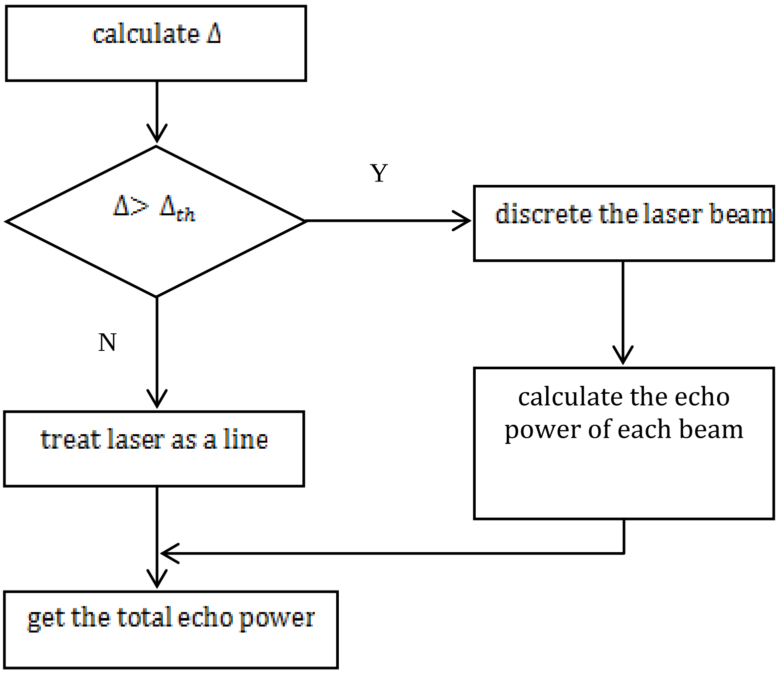
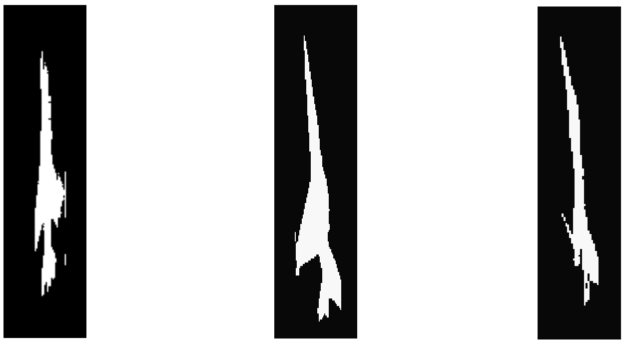


Fig. 5 Fast calculation algorithm

5 Experiments



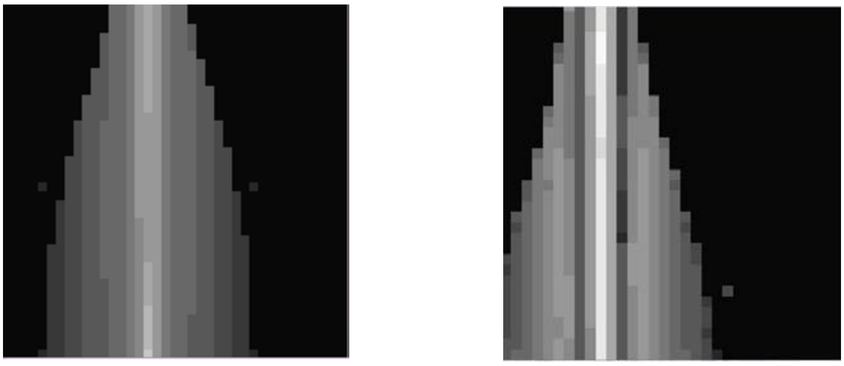
（a） actual image （b） simple model （c） accurate model

Fig. 6 Simulation results in binary image

Figure (a) in Fig.6 shows the result getting by laser scanning imaging in fact. Figure (b) is the simulation result without using accurate model, while figure (c) is the simulation result using accurate model with divergence angel.

Images got in simulation are better when they are closer to the reality. Smooth edge in figure (b) doesn't appear in figure (a), which is got in fact, while figure (c) shows the edge blur effect which figure (a) also shows. Figure (c) is closer to the reality.

Laser scanning imaging system also uses gray images to show results some times [7] . We get some results shown by gray images to test the accurate model. In gray images, gray scale shows the echo power. Fig. 7 shows the result scanning upside the target 3 meters away. Comparing these two figures to the real model in Fig. 2, figure (b) clearly shows the cabin, while the cabin in figure (a) is not clear enough. Using accurate model can get more useful result for training set in recognition.



(a) simple model **(b)** accurate model

Fig. 7 Simulation results in gray image

Table 2 shows the average time of scanning one line in simulation. We can see that accurate model without simplification costs too much time. While using this efficient method in this paper, only about 3% more time is cost.

Table 2 Average time of scanning a line

Simple model	Accurate model without simplification	Accurate model with simplification
51.97μs	194.70μs	53.70μs

6 Conclusion

By introducing the accurate laser model and using accurate echo power formula, this paper provides a laser scanning imaging simulation system, which is much more precise and closer to the reality, so we can get more reliable data for detection or recognition. At the same time, a simplified method is put forward to reduce the complexity of calculation by sacrificing little accuracy. The methods in this paper can be widely used in all kinds of laser scanning imaging system.

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