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Performance Analysis on the Target Detection of Linear Camera of CCD Vertical Target Coordinate Measurement System

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Abstract: Based on the principle of CCD vertical target measurement system, this article researched the factors of the CCD camera that affects the target detection performance , including CCD sensitivity and exposure, background illumination and target illumination, CCD distinguish ability, contrast between background and objectives and gave the relevant calculation methods. Through theoretical analysis, the article got the relationship among the target length, scan time, image distance, object distance and the detection speed, the detection distance. What's more, the simulation result shows the effectiveness of the analytic conclusions.
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Keywords: Linear camera, Illumination, Contras, Detection capability.

1. Introduction

CCD vertical target coordinate measurement system is on the basis of CCD (Charge Coupled Device) image sensors and it gets objective spatial coordinates of the target over time based on the intersection measurement principle. The CCD vertical target coordinate measurement system is mainly used in the bullet location test, intensive analysis, ballistics analysis and so on. It is one of the important means of testing in modern shooting range and it has important significance to improve the level of shooting range weapons identification test [1-3]. But, there are a few studies on CCD linear camera detection performance both at home and abroad, and there is not a much more completed approach which is systematic and practical. For example, in the case of that the target which has small size and has no light itself is on high-speed flight, the signal-to-noise ratio of the target is quite low, then it is difficult to achieve better detect results.

As one of the important test equipment of shooting range, the target detection capability of CCD linear array camera has became a key factor to evaluate the entire test system.

On the basis of the analysis of works principle of CCD vertical target coordinate measuring system, the essay will research on the main factors that affect target detection performance of camera. Through the analysis of linear CCD camera optical performance, the characteristics of the target's background and surface and the target's characteristics, we can establish linear CCD camera velocity models and detection range models for target detection. According to different light, background brightness and target size, we can analyze the maximum speed of targets and the most distant of targets that the linear array camera can capture within its ability. The

essay will study the linear CCD camera's detection performance through simulation, hoping to analyze and summarize the camera detection capability in theory and improve the system from some practice.

2. The Basic Principle of the System

Vertical target measurement system consists of two linear CCD cameras which are laying on the same baseline and looking up into the sky relatively with a certain angle. The two linear CCD cameras form a virtual target surface in the air. When a target *P* crosses the target surface, it is captured by the two linear CCD cameras. The coordinates of the target through the target surface can be obtained through the intersection of computing, as is shown in Fig. 1. O_1 is CCD1 camera's lens optical center. O_2 is CCD2 camera's lens optical center. Establish a coordinate system with CCD1's lens optical center as the origin of coordinates. Horizontal line is the x-axis and perpendicular to the horizontal is the y-axis.

The two cameras' lens focal length is both *f*. Distance between the optical centers of the lens is *L*. The inclination angles of the two optical axis are α and β. A target point *P* which is in the target surface gets the corresponding image point coordinates in the image plane of CCD1 and CCD2 and then the measured target's coordinates through the target can be obtained.

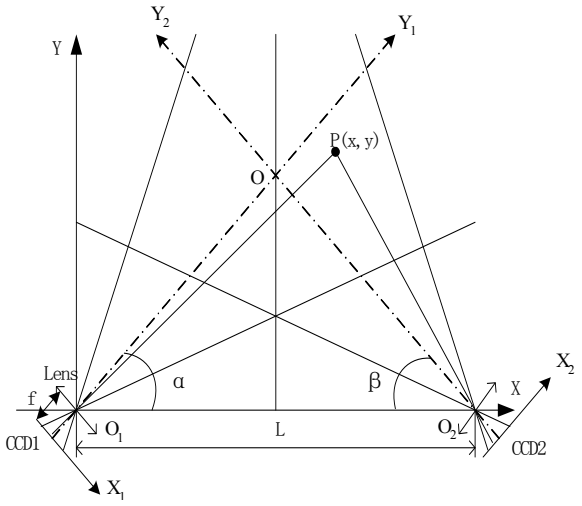


Fig. 1. CCD vertical target basic principle of the measurement system.

3. Camera Detection Capability Analysis

Linear CCD with high sensitivity, wide dynamic range, fast work, high precision measurement has many advantages [4]. When the target gets through the detection area of the linear array camera, whether the line scan camera can capture the goals and objectives and extract the target from the background depends on the camera's features, background illumination, target characteristics and detection distance [5, 6].

3.1. Effects of CCD Camera Features

In a certain background light, selecting the appropriate CCD camera must be considered to make the biggest difference between the target signal and the background signal.

3.1.1. Time to go Through the Target and CCD Pixel Size

The integration time is the time which the CCD image sensor of an optical signal spends on charge accumulation. In the dynamic test target, as the target signal strength is weak, the integration time should be longer. Extending the integration time can cause blurred image and people can not see the image information. Thus, to increase the light intensity of the background and contrast enhancement and to control the effective integration time can improve the ratio of the useful signal.

Since the charge accumulation and transfer of CCD has a time limit, generally, CCD line camera has a scan rate range of normal use. The phenomenon of that goal goes through the target has two situations: one situation, the time that the target spends on going through the target is less than two times the integration time; another situation, the time that the goal uses to go through the target is more than or equal two times the integration time. In the second case, target within once integration time is under full exposure, the target's signal in the case of that other conditions have no change can reach maximum. In the first case, Target within once integration time may be exposed in a part-time. That is, in the integration both the target energy and the background energy are involved in integration. Then it leads to the difference between the target signal and the background signal to be reduced, and the signal to noise ratio gets lower, thus it is not good to the capture of the target. So High-speed Camera should be used to catch high-speed target to make the time that the goal spends on going through the target and camera integration time match. According to the CCD camera the integral time, we can determine the line scan cycle of cameras and get the best SNR. For a target whose target time is very short, its target time is far less than the integral time, line scan cycle and integration time should be made as close as possible to reduce the non-integral time gap between two scans, avoiding the case of targets being undetected.

Pixel size of the CCD camera determines the amount of light energy that can be received by the camera [7]. In the case that the goal spends a much long time (longer than 2 times the integration time) to go over the target and the target image size is much larger, The camera with large pixel size conducive to

the expansion of the difference between the target and background and it is easier to do the target detection. Pixel size corresponds with spatial resolution. The smaller the pixel size is, the higher the spatial resolution is. But the small size makes the area of light surface reduced, which will reduce the capability of CCD camera for target detection. Therefore, we must make the resolution of the system and the amount of exposure of the camera match, or it would be difficult to meet the requirements of weak target detection.

3.1.2. CCD's Sensitivity and Exposure

The higher sensitivity of CCD camera means smaller minimum light energy that can be detected by the camera. High sensitivity is conducive to detection of small-sized and high-speed targets. Spectral response range of the CCD camera especially the peak spectral response range should coincide with the target detection's reflectance spectra to make sure that CCD camera can obtain the maximum signal response while the target reflected light intensity is determined in certain circumstances. Also, the system in use should adjust the camera's aperture size to make sure that the target signal and the background signal are always in the camera linear amplification region, avoiding the case that too weak energy causes a loss of signal or too strong energy causes signal saturation.

General sensitivity of CCD camera uses CCD-working minimum power density E_m (target imaging minimum illumination on the CCD, unit: Lx) to represent.

$$E_m = \frac{H_P}{DR \times T}, \tag{1}$$

where Hp is the CCD saturated exposure; DR is the CCD available dynamic range (saturation exposure / noise equivalent exposure); T is the frame integration time.

CCD image plane target minimum illumination shall be not less than the minimum illumination of CCD target surface. Namely: $E \geq E_m$. Hi of CCD exposure amount calculated by the formula.

$$H_i = E_i \cdot T_i, \tag{2}$$

where E_i is the incident light intensity to the CCD; T_i is the integration time.

3.2. Background Illumination and Target Illumination

That whether CCD vertical target coordinate measurement system can get target image mainly depends on the contrast size between the sky background brightness and target's brightness. The scattering light irradiating on the target is mainly caused by reflection of sunlight from target and ground.

3.2.1. Background Brightness at the Surface of the CCD Image Irradiance

Through the analysis on the optical properties of linear array camera imaging system, the background center illuminance formula which shows the sky background brightness on the CCD as the irradiance of E_b is [2, 4]:

$$E_b = B_b \cdot \frac{\pi}{4} \cdot (\frac{D}{f})^2 \cdot \tau \cdot (\frac{\beta_0}{\beta_0 - \beta})^2, \tag{3}$$

Relations between the illumination axis illumination point and as the center point $E' = E\cos^4\omega$,

That is to say, the light axis of the background image of the point is:

$$E_b' = B_b \cdot \frac{\pi}{4} \cdot (\frac{D}{f})^2 \cdot \tau \cdot (\frac{\beta_0}{\beta_0 - \beta})^2 \cdot \cos^4\omega, \tag{4}$$

Target image point on the axis of the formula indicates the illuminance:

$$E_m = \frac{\rho}{\pi}(E_1 A_S + E_2 k A_P) \cdot \frac{\pi}{4} \cdot (\frac{D}{H})^2 \cdot \frac{\tau \cdot K_0 \cdot K_t}{(N_m A_0)}, \tag{5}$$

Target illumination on the axis image point:

$$E_m' = \frac{\frac{\rho}{\pi}(E_1 A_S + E_2 k A_P)\frac{\pi}{4}(\frac{D}{H})^2 \tau K_0 K_t \cdot (\cos\omega)^4}{(N_m A_0)}, \tag{6}$$

Among them, B_b is the background brightness, f' is the image distance of the optical system, D is the effective aperture of the optical system, τ is the rate of transmission system, β_0 is the vertical axis at a magnification of pupil (Common target canopy structure that is double Gauss lens are double symmetrical structure $\beta_0 = 1$), β is the vertical axis magnification images, H is object distance of the optical system, ω is field angle, ρ is the target reflectance of sunlight as a target effective reflection, A_S is the effective area of sunlight on the target illumination, E_1 is the illumination light on the target surface, and E_2 is the observation target in the direction of the projection area, k is the face of

sunlight reflectance, A_0 is the single pixel area, N_m is the imaging target system as the number per share, A_P is the projection area of the target in the observation direction. K_0 is the system point spread due to attenuation, K_t is attenuation due to the moving target.

$$K_t = \frac{l}{vT + l}, \tag{7}$$

where L is the length of the target; V is the target speed; and T is the frame integration time.

3.2.2. Resolution and the Contrast of Target and Background

In linear camera work zone, the bigger the difference between the target signals and the background is, the easier it is to detect the target. That is, the higher signal-to-noise ratio, the higher probability of target detection [6]. To maximize this difference, it should make the difference between objective's background brightness and itself's brightness difference largest from the angle of the light energy.

The CCD resolution is related to optical system, the detecting distance, the size of target and other factors. To the Linear CCD camera, detection ability embodies on CCD imaging width than one pixel when passing the optical system. But in practice, in order to ensure a high capture rate, general requirements on CCD target through the optical system imaging is much bigger than the width of 2 pixels [8].

The definition of the contrast and illumination of the target to background illumination is C.

$$C = \frac{\left|E_m' - E_b'\right|}{E_b'} \tag{8}$$

After the target passing the CCD field of view, in order to extract the target signal from the background, the target and background contrast should reach a certain level C_0 (general $C_0 = 0.02$) [9].

If $C > C_0$, the target can be extracted from the background; if $C < C_0$, the target will be submerged in the background noise.

3.2.3. Impact on the Detection Capability of the Target Speed

According to the definition of the contrast above, we can see contrast is related to the background illumination and target illumination and from the relationship between the target illumination and background illumination, it can be divided into the following two cases.

When the target outside the shaft as the point of luminance is less than that of background, that is $E_m' < E_b'$, using the formulas (4), (6), (7) in the formula (8):

$$\frac{-[\frac{\rho}{\pi}(E_1A_S + E_2kA_P)\cdot\frac{\pi}{4}\cdot(\frac{D}{H})^2\cdot\frac{\tau\cdot K_0\cdot\cos^4\omega\cdot l}{(vT+l)\cdot(N_mA_0)}]}{B_b\cdot\frac{\pi}{4}\cdot(\frac{D}{f'})^2\cdot\tau\cdot(\frac{\beta_0}{\beta_0-\beta})^2\cdot\cos^4\omega} + \frac{B_b\cdot\frac{\pi}{4}\cdot(\frac{D}{f'})^2\cdot\tau\cdot(\frac{\beta_0}{\beta_0-\beta})^2\cdot\cos^4\omega}{B_b\cdot\frac{\pi}{4}\cdot(\frac{D}{f'})^2\cdot\tau\cdot(\frac{\beta_0}{\beta_0-\beta})^2\cdot\cos^4\omega} > C_0, \tag{9}$$

After finishing we get:

$$v > \frac{l}{T}[\frac{M}{(1-C_0)B_b(\frac{H-f'}{f'})^2} - 1], \tag{10}$$

Among them $M = \frac{\rho}{\pi}(E_1A_S + E_2kA_P)/(N_mA_0)$.

When the target outside the shaft as the point of luminance is greater than that of background, that is $E_m' > E_b'$, using formulas (4), (6), (7) in the formula (8):

$$\frac{[\frac{\rho}{\pi}(E_1A_S + E_2kA_P)\cdot\frac{\pi}{4}\cdot(\frac{D}{H})^2\cdot\frac{\tau\cdot K_0\cdot\cos^4\omega\, l}{(vT+l)(N_mA_0)}]}{B_b\cdot\frac{\pi}{4}\cdot(\frac{D}{f'})^2\cdot\tau\cdot(\frac{\beta_0}{\beta_0-\beta})^2\cdot\cos^4\omega} - \frac{B_b\cdot\frac{\pi}{4}\cdot(\frac{D}{f'})^2\cdot\tau\cdot(\frac{\beta_0}{\beta_0-\beta})^2\cdot\cos^4\omega}{B_b\cdot\frac{\pi}{4}\cdot(\frac{D}{f'})^2\cdot\tau\cdot(\frac{\beta_0}{\beta_0-\beta})^2\cdot\cos^4\omega} > C_0, \tag{11}$$

After finishing we get:

$$v < \frac{l}{T}[\frac{M}{(C_0+1)B_b(\frac{H-f'}{f'})^2} - 1], \tag{12}$$

Among them $M = \frac{\rho}{\pi}(E_1A_S + E_2kA_P)/(N_mA_0)$.

Down from above we get the two equations of (10) and (12). When the background illumination is less than the target illuminance, we get equation (10). Equation (10) means the target maximum speed that a camera can capture. When the background illumination is larger than the target illuminance, we get equation (12). Equation (12) means the target minimum speed that a camera can capture.

3.3. Target Detection Distance Analysis

According to the analysis of the target detection limit velocity model, we know that the limit of detection range model is related to the object distance. Deeper analysis is as follows:

When the target outside the shaft as the point of luminance is less than that of background, that is $E_m' < E_b'$, a new formula was deduced from formula (10):

$$H > f'(1+\frac{Qw}{2(vT+l)\cdot(1-C_0)B_b}) + \frac{f'}{2}\sqrt{[\frac{Qw}{(vT+l)\cdot(1-C_0)B_b}]^2+\frac{4Qw}{(vT+l)\cdot(1-C_0)B_b}}, \quad (13)$$

where $Q=\frac{\rho}{\pi}(E_1A_S+E_2kA_P)/A_0$.

When the target outside the shaft as the point of luminance is greater than that of background, that is $E_m' > E_b'$, a new formula was deduced from formula (12):

$$H < f'(1+\frac{Qw}{2(vT+l)\cdot(1+C_0)B_b}) + \frac{f'}{2}\sqrt{[\frac{Qw}{(vT+l)\cdot(1+C_0)B_b}]^2+\frac{4Qw}{(vT+l)\cdot(1+C_0)B_b}}, \quad (14)$$

Down from above, we get the two equations (13) and (14). When the background illumination is less than the target illuminance, we get equation (13). Equation (13) is a camera can capture the target minimum distance. When the background illumination is more than the target illuminance, we get equation (14). Equation (14) is a camera can capture the target maximum distance.

4. Theoretical Simulation and Analysis

When the target reflectivity $\rho = 0.8$, the number of pixels in the target is $N_m = \frac{lf'}{Hw}$ [10, 11], pixel size $w = 10\ \mu m$, single pixel area is $A_0 = w^2$, this essay will analyze the relationship among the limit detection speed and the target length, frame integral time, image distance, object distance in both cases and the result is shown in the Fig. 2, Fig. 3, and Fig. 4.

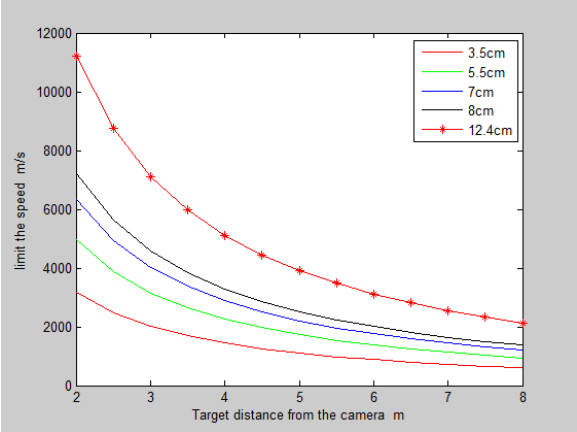


Fig. 2. In different of target length, limit speed followed object distance changes.

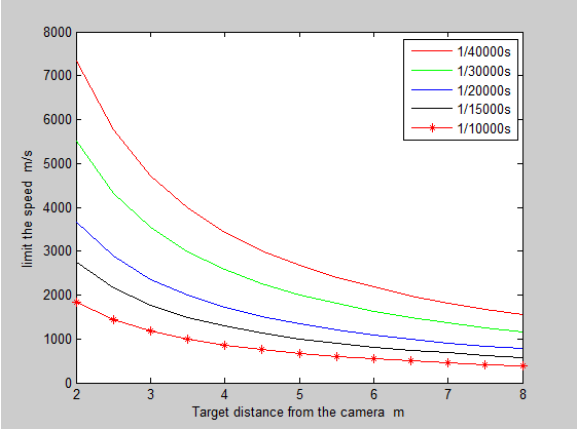


Fig. 3. In different of scan rate, limit speed followed object distance changes.

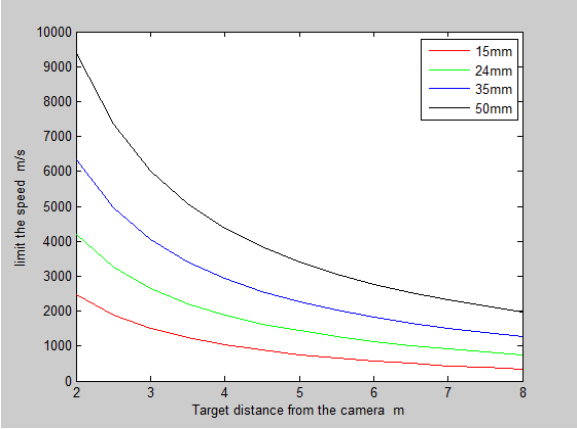


Fig. 4. In different of image distance, limit speed followed object distance changes.

As shown in Fig. 2, in the target length is 3.5 cm, 5.5 cm, 7 cm, 8 cm and 12.4 cm, the limit speed of target decreases with the increase of object distance; when the object distance is certain, the target length is greater, the faster of the target limit speed is.

As is shown in Fig. 3, when the scan rate respectively is 1/40000 s, 1/30000 s, 1/20000 s, 1/15000 s and 1/10000 s, the limit speed of target decreases with the increase of object distance; when the object distance is certain, as target length is greater, the slower of the target limit speed is.

As shown in Fig. 4, when the image distance respectively is 15 mm, 24 mm, 35 mm, 50 mm, the limit speed of target decreases with the increase of object distance; when the object distance is certain, as image distance is greater, the target limit speed is greater.

The target reflectivity at $\rho = 0.8$, the number of pixels in the target is $N_m = \frac{lf'}{Hw}$, the pixel size is $w = 10\mu m$, single pixel areas is $A_0 = w^2$. In both cases, the relationship among the limit of detection range and the target length, frame integral time, image distance, speed is shown in the Fig. 5, Fig. 6 and Fig. 7.

From the Fig. 5, when the target length respectively are 3.5 cm, 5.5 cm, 7 cm, 8 cm, 12.4 cm, the target distance will be all decreased with the increase of the target speed, when the target speed is constant, the larger the target length is, the larger the maximum distance to the target is.

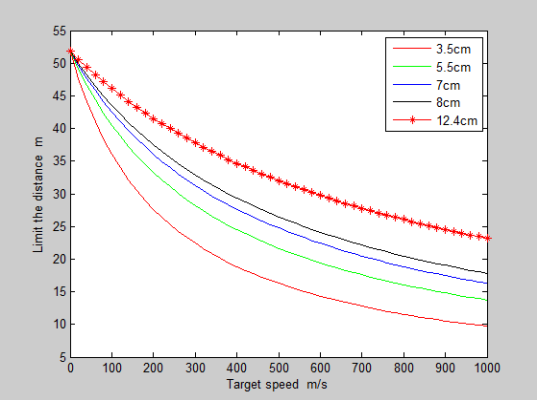


Fig. 5. The change of different target length's limit distance with the change of the target speed.

From the Fig. 6, when the respectively scan rates are 1/40000 s, 1/30000 s, 1/20000 s, 1/10000 s, the target's limit distance will be all decreased with the increase of the target speed, when the target speed is constant, the larger the scan rate is, the smaller of the target's limit distance is.

From the Fig. 7, when the image distance are 15 mm, 24 mm, 35 mm, 50 mm, limited distance of the target will be all decreased within the increase of the target speed, when the target speed is constant, the larger the image distance is, the larger the target limit speed is.

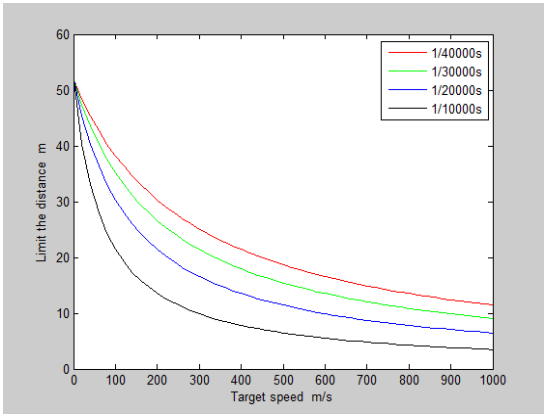


Fig. 6. The change of different scan rate's limit distance with the thange of the target speed.

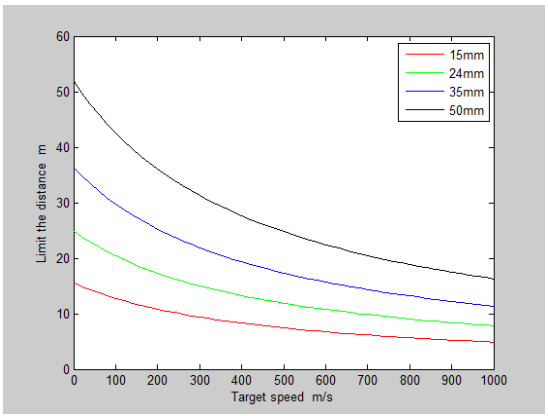


Fig. 7. The change of different image distance's limit distance with the change of target speed.

5. Conclusion

Based on the optical properties of linear CCD camera, the article researches the background characteristics of the target surface, the target's own characteristics, the main factors that affect the ability of the camera to detect. Also it establishes speed mode of linear CCD for target detection, model of linear CCD camera for target detection distance and for different lighting, different background luminance, target size. It also gives analysis of the target maximum speed that line scan cameras and of the target most distant line scan cameras captured. The simulation results of the effectiveness conclusions of the linear array CCD camera detection performance for goals. It has some significance for the range of tests strong background high speed small target detection.

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