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Study on Tracking and Controlling Algorithm in Moving Object Detection System

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Abstract: In order to solve the problem of tracking instability and poor synchronization, the tracking model in orbit object dynamic tracking system is established by using controllable rotating platform, the basic principles of the orbital object tracking is analyzed and the dynamic tracking algorithm is studied; the geometry tracking algorithm of turntable angle and orbit objects synchronous tracking are analyzed in the object motion, the track logic function of corresponding point is derived; the improved PID control algorithm and influence factor ware analyzed. Through the test and analysis, the Mean Shift tracking algorithm is improved, its application in orbit-style dynamic object tracking is analyzed, object retrieval center position is determined by using its nuclear density estimation and tracking image frame image relationship to reach the dynamic object tracking purposes. The results show that the improved method can overcome the instability of unable to synchronize tracking with low contrast and other problem, which is proposed to be feasible in orbit object dynamic tracking system. *Copyright © 2013 IFSA.*

Keywords: Object, Control, Tracking, Mean Shift algorithm, Interference.

1. Introduction

In object test system, dynamic object tracking parameter measurements have become the important indicators of the weapon system's verification, stereotypes and production, especially with the development of high-speed weapons, instant tracking parameters of high-speed projectile object are the information need to focus on in weapon object, such as the projectile's the activation status, accelerated state, deceleration state and so on [1-5]. Today, in the trajectory tracking aspect of high-speed orbit objects, it is too many using the way to carry out by multiple wide-angle lenses to obtain image. This will bring some new problems: first, the cost is high; second, how to process the data of lens intersections; third, in lens edge image produce the distortion, especially the latter two factors have significant affection on the validity of the test data [6]. Object tracking based on vision is widely used in video surveillance, image compression, 3D reconstruction, robotics and other fields [7-9], because of the sudden movement of objects, external manifestations change of object or background, the non-rigid structure of object, the block between objects, the block between object and the background, and the camera movement make it difficult to achieve the real-time object tracking. The tracking and controlling algorithm based on Mean Shift is proposed for high-speed dynamic object tracking problem according to object tracking theory.

2. Tracking Principle and Controlling Algorithm

2.1. Tracking Principle

Dynamic object tracking system is make up of launch startup device, tracking controlling platform, optical system, controlling device, collection device, tracking image and disposing computer, and so on.

The image tracking of object is mainly based on the optical system, in the certain known conditions, using geometry relation of object and image, the mathematical functions of the object side and the image side can be determined. By using of imaging relationships of the optical system under the dynamic object to measure the speed parameters of moving objects, the mathematical model of camera rotation angle and orbital object motion process is established. In geometrical optics system, since any movement of the space object can be abstracted as linear motion of three-axis and the rotation around three-axis [10-12], according to the movement characteristics of orbital object, the object motion can be simplified as a two-dimensional movement in flat space. The two-dimensional movement of orbital object tracking can be described as shown in Fig. 1, it is assumed that A is the start point of object movement, B is the stop point, and O is the observation position of tracking system.

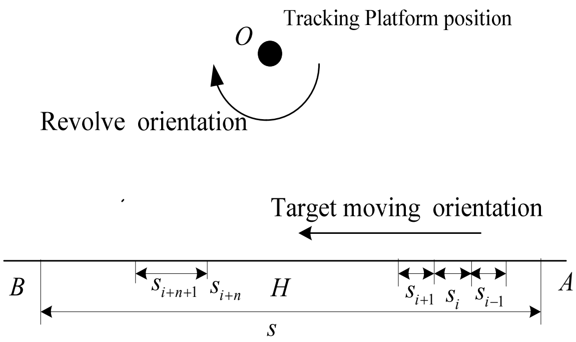

Fig. 1. Schematic of orbital object tracking.

The orbital dynamic object's parameters are mainly about to find out the dynamic changes of measured object on the rail during the discharge process, the optical tracking system is placed on the side of the rail for real-time object monitoring. The optical tracking system is mainly composed of imaging optical lens, tracking aircraft, launch controlling device and monitoring platform. L_1 is the distance of between the tracking platform and the starting point of the object movement, L_2 is the distance of between the tracking platform and the ending point of the object movement, in Fig. 1, θ_i , θ_{i+1} and θ_{i+n+1} are the control angle uniform change of the tracking platform, which correspond to the respective time moment, s_{i+1} , s_i , s_{i-1} and s_{i+n+1} are the displacement of the uniform change of control platform in the orbit around the observation point, OH is the perpendicular to the vertical trajectory.

In the system, when the camera center horizontal is parallel or coincident to the main movement of the object, by simplifying or ignoring the minor movement influence, the object movement can be considered linear one of one-dimensional. Camera as the image capture device is an optical device, in accordance with principle of optical imaging. In order to real-time monitoring of the object dynamic process, optical tracking system must move synchronously with the moving object. In a certain period of time, if the image of the object is always in a small area, it can be identified that the object is in sync with platform at this time, which is certain proportional relationship of platform's rotation angle and high-speed object's displacement on the rail in unit time.

If the speed of object movement is v , in the premise of the known theoretical trajectory, the theoretical trajectory is divided into a number of units of displacement by the same time, which is the time-division trajectory in the s distance on the rail. s_i is the displacement of before or after each point trajectory, s is the total length.

It is assumed that in each unit time Δt , the theoretical rotation angle composite of object and observation points is θ_i , then during the entire trajectory, the total angle is θ that the tracking system needs to rotate.

To meet the track conditions, it just need to determine the theoretical angle corresponded to the angle of tracking platform in each unit time to track the image of ballistic object in the corresponding moment, monitoring the image of the object's corresponding time on the rail, the corresponding parameters message is provided by the image processing.

2.2. Controlling Algorithm

The tracking controlling platform is the core of the object tracking, it is needed to rationally calculate the controlling of the tracking platform in order to accurately track and lock the object's center location in the field of image view. Optical imaging system is the image forming device loaded in the tracking platform [13], in order to make the optical imaging field contain dynamic object, the requirements of tracking platform's real-time are high. Therefore the controlling of the tracking platform must be cautious. If the controlling commands are changed or the controlling program is disabled, it will make the whole tracking system failed. In the system, if tracking platform's rotation rate is too large, it may miss the tracking object; conversely, if the tracking platform's rotation rate is too small, it may lose the object's information because of not keeping pace with tracked object, which result in the system failure tracking. Therefore, it must be set a reasonable rotation strategy for tracking platform in order to effectively improve the tracking capture rate of target.

In the controlling system, the tracking platform is controlled by the DSP-processing chip [13-15], and the integral separation PID controlling algorithm is used to track the entire tracking path, the controlling flow is shown in Fig. 2.

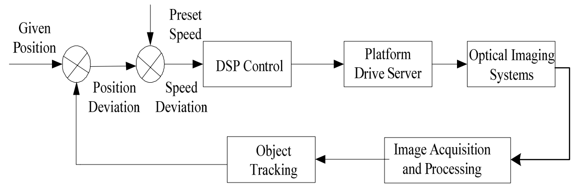

Fig. 2. Principle diagram of object tracking controlling system.

In the controlling flow, according to the given object tracking starting position, preset speed parameters, and the target pre-processing algorithms, DSP controlling module control drive tracking turntable, by using optical imaging system the target image of the path is tracked, in accordance with the detection and recognition technology, the target image is analyzed, based on feature of target, the locating center is chosen to complete the system tracking.

Integral separation PID controlling algorithm can rectify the system, it introduces integral separation algorithm, which maintaining the integral action and reduces the overshoot, so that the controlling performance has greatly improved. Assuming integral separation PID algorithm's integral separation threshold is E_0, its controlling system can be expressed by Fig. 3.

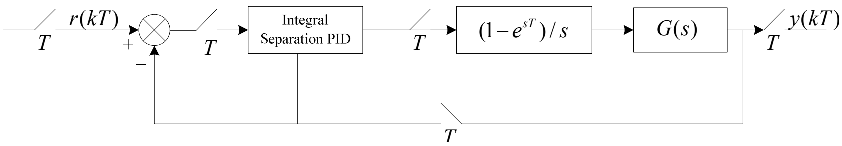

Fig. 3. Controlling system.

When $|e(kT)| \le |E_0|$, while the deviation $|e(kT)|$ is relatively small, the integral separation PID controlling algorithm can ensure the system's controlling precision. When $|e(kT)| > |E_0|$, while the deviation $|e(kT)|$ is relatively more, the integral separation PID controlling algorithm can significantly reduce the overshoot [12]. Integral separation PID controlling algorithm can be expressed by formula (1).

$$u(kT) = K_p e(kT) + K_l K_i \sum_{j-0}^{k} e(jT) + K_d[e(kT) - e(kT-T)], \quad (1)$$

where K_p is the proportional coefficient, K_l is the logic coefficient, and its logic relationship is shown by formula (2).

$$K_l = \begin{cases} 1, |e(kT)| \le |E_0| \\ 0, |e(kT)| > |E_0| \end{cases} \quad (2)$$

In the control system, the influence of K_p has two major aspects, the firstly, K_p can affect the dynamic characteristic, if K_p is increased, the system is highly responsive; if K_p is too large, the vibration of system is increased, adjusting system will spend a lot of time, if K_p is maximum, the system tends to unstable. Contrarily, K_p is smallest, the system is slow responsive. The secondly, K_p can affect the stabilization characteristic, in the case the system is steady, if K_p is increased, the system can reduce the steady state error and increase the precision, but the system can not eliminate the steady state error.

3. The Principle of Optic Imaging on Object Tracking

In order to track simultaneity infrared object, we must set up whole optic imaging framework, thus the object should be in the imaging field. Optical image system on object tracking can be show by Fig. 4.

In Fig. 4, u is object distance, f is focus of lens, if u' is image distance, according to the optical image system principle, u' equal to f, L' is the length of the imaging area, L is the view size. β is the half field of the optic lens. The value of β can be obtained by the formula (3).

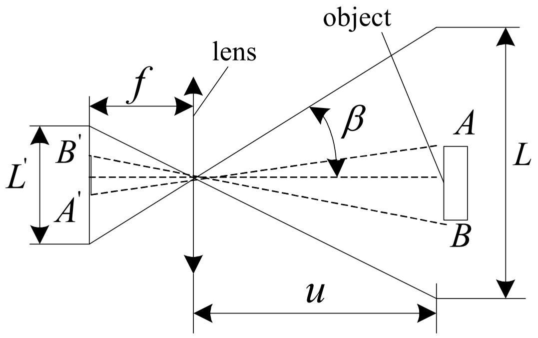

Fig. 4. Optical imaging system on object tracking.

$$\beta = arctg\frac{L^{'}}{2f}, \tag{3}$$

where AB is the length of moving object, $A^{'}B^{'}$ is the image length of AB. If the velocity of moving object is v, we can calculate their relation base on optical image principle and detrude the dynamic parameter.

4. Tracking Algorithms of Object Tracking

To reduce the calculation amount to meet the real-time requirements, first to quantify the gray value of the infrared object [16, 17], assuming that the object tracking point is y, the detection area is the rectangle where the center is y and the window width is h, position of the pixel in the region is in terms of $\{x_i\}_{i=1\ldots n}$, and its value is quantized values of m, which the function $b(\bullet): R^2 \rightarrow \{1\ldots m\}$, is the pixel gray index mapping of x_i. In order to obtain the characteristics amount of the dynamic object, in this paper, the Mean Shift object tracking algorithm is used, which mainly use the statistical distribution of gray and texture features to describe the object, and track the target by gradient descent of the mean shift vector.

Assuming the center of the target area is x_0, there are n pixels expressed by $\{x_i\}_{i=1\ldots n}$, the number of feature-values is m. Then the probability density of the object model's feature-value u is shown by formula (4).

$$Q = k\sum_{j=1}^{m} a \cdot (\left\|\frac{x_0 - x_j}{h}\right\|)^2 \delta[b(x_j) - r], \tag{4}$$

where $k(x)$ is the outline function of the kernel function, since the influence of occlusion or the background, the pixels near the center of the target model are more reliable than the foreign ones, $k(x)$ gives a large weight to the center pixel and a little one away from the center. The role of the function $k(x)$ is to eliminate the influence of different sizes of the calculation object, and normalize the object expressing as ovals to a unit circle. $\delta(x)$ is a function of Delta, $\delta[b(x_i) - r]$'s overall effects is to determine whether the gray value of the pixel x in the object area belongs to the u feature-value. C is the gray value belongs to the a standardized constant coefficient, which makes $\sum_{u-1}^{m} q_u = 1$, then, kernel density estimation expressions based on the outline function of the kernel function is shown by formula (5).

$$k = 1 / \sum_{j=1}^{m} a(\left\|\frac{x_0 - x_j}{h}\right\|)^2 \tag{5}$$

The area which may be contained the moving object in the second frame and each subsequent frame is called the candidate area, it's the center coordinates is y and also is the center coordinates of the kernel function. The pixel of in the candidate model area is expressed as $\{x_i\}_{i=1\ldots n_j}$, the probability density of feature-value $u = 1 \ldots m$ in the candidate model area is shown by formula (6).

$$Q_u(y) = k_h \sum_{j=1}^{n_k} a(\left\|\frac{x_0 - x_j}{h}\right\|)^2 \delta[b(x_j) - r] \tag{6}$$

Similarity function describes the degree of similarity between the object model and the object candidates, Bhattacharyya coefficient is used as the similarity function, and it is expressed by formula (7).

$$R_u(y) = \sum_{u=1}^{m} \sqrt{Q_u(y) \cdot U}, \tag{7}$$

where the value of $\hat{\rho}(y)$ is between 0 and 1. The larger the value of $\hat{\rho}(y)$, which means that the more similar the two models, if the candidate model which is calculated by the different candidate areas in the current frame make the $\hat{\rho}(y)$ maximum, it is the position of the object in this frame.

In order to make the maximum of $\hat{\rho}(y)$, positioned the center of the object position y_0 in the previous frame as the center of the object in the current frame, and begin to find the optimal matching destination from this point, its center is y_0. First calculate Taylor expansion at the object candidate model $\hat{\rho}(y_0)$, find out the maximum of $\hat{\rho}(y)$ to determine the location of the object point. In order to determine the target location, and completes the purpose of tracking, *Mean Shift* method is started from y_0 and in the direction based on biggest changes of gray-scale between two models move.

5. Random Interference Analysis in Tracking System

5.1. Probability Distribution Function and Probability Density Function of Random Variables

Assumed that the stochastic process $X(t)$ is sampled at the moment $t = t_k$, every function of the sample forms a random variable $X_k = X(t_k)$, then, according to the defined of random variables' probability distribution functions, the probability distribution function of X_k is shown by formula (8).

$$F(x_k) = P[X(t_k) \le x_k] \quad (8)$$

where x_k is the value of random variable X_k, P represents the probability. If the first derivative of x_k to the random variable on the probability distribution function [18, 19] $F(x_k)$ exist, then probability density function of the random variable X_k is shown by formula (9).

$$p(x_k) = \frac{dF(x_k)}{dx_k} \quad (9)$$

5.2. Probability Distribution Function and Probability Density Function of Stochastic Processes

If the sampling time t_k is derived to the whole point of the timeline, then the one-dimensional probability distribution function of random process $X(t)$ at any time can be obtained by formula (10).

$$F(x) = P[X(t) \le x] \quad (10)$$

The corresponding probability density function is shown by formula (11).

$$p(x) = \frac{dF(x)}{dx} \quad (11)$$

Considering the random sampling process at two moments t_1 and t_2, two random variables X_1 and X_2 can be got. The joint distribution functions between two random variables X_1 and X_2 at the moment t_1, t_2 are defined by formula (12).

$$F(x_1, x_2; t_1, t_2) = P[X_1 \le x_1, X_2 \le x_2] \quad (12)$$

Defined that the joint probability density function between X_1 and X_2 is shown by formula (13).

$$p(x_1, x_2; t_1, t_2) = \frac{\partial^2 F(x_1, x_2; t_1, t_2)}{\partial x_1 \partial x_2} \quad (13)$$

5.3. Numerical Characteristics of Random Process

Assumed that random process $X(t)$ fixed *N* moments $t = t_k$ $(k = 1, 2, \cdots, n)$ on the timeline, the value of k is $1, 2, ..., n$, then the mathematical expectation of the random process is shown by formula (14).

$$E[X(t)] = m_x(t) = \int_{-\infty}^{\infty} xp(x, t)dx \quad (14)$$

For discrete random sequence $X(n)$, the mean is shown as formula (15).

$$m_x(n) = E[x(n)] = \int_{-\infty}^{\infty} xp(x, n)dx \quad (15)$$

The variance of the random process is used to describe the deviation from the mean level of random process. It's expressed by formula (16).

$$\begin{aligned} E\{[X(t) - m_x(t)]^2\} &= D[X(t)] = \sigma_x^2(t) \\ &= \int_{-\infty}^{\infty} [X(t) - m_x(t)]^2 p(x, t)dt \end{aligned} \quad (16)$$

Then the self-correlation function of the random process is on behalf of the intrinsic link of the value at any two moments. Continuous random process $X(t)$'s correlation function is shown by formula (17).

$$\begin{aligned} R_x(t_1, t_2) &= E[X(t_1)X(t_2)] \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_1 x_2 P_2(x_1, x_2; t_1, t_2)dx_1 dx_2 \end{aligned} \quad (17)$$

The random sequence $X(t)$'s self-correlation function is shown by formula (18).

$$R_x(n,m) = E\left[X(n)X(m)\right] \tag{18}$$

Self-covariance of random process is defined by formula (19):

$$Cov(t_1,t_2) = E\{E[X(t_1) - m_1(t_1)][X(t_2) - m_2(t_2)]\}$$
$$= R_x(t_1,t_2) = m_x(t_1)m_x(t_2) \tag{19}$$

Consequently, if $P_2(x_1,x_2;t_1,t_2) = P(x_1,t_1)P(x_2,t_2)$, The random process $X(t)$ is statistically independent at the moments t_1 and t_2, if $R_x(t_1,t_2) = 0$, then they are orthogonal at the moments, if $COV(t_1,t_2) = 0$, then they are unrelated at the moments.

6. Experiment and Analysis

In order to verify the tracking timeliness of the entire tracking path, using high-precision angle encoders as the contrast real-time reading angle in control turntable [20, 21], the tracking effect is to determine base on the deviation between Theoretical ballistic speed and measured projectile velocity. Table 1 to Table 3 is the part of data measured in a particular experiment and the results based on the analysis of data and images. Tracking platform rotation angle controlling unit time is set to 0.3 s, Table 1 shows the data of the initial dynamic state, Table 2 shows the data of the middle section dynamic state and Table 3 shows the data of close to the end of the segment state, speed error is the difference between the theoretical and measured speed.

Table 1. The test data of the initial dynamic state.

Theory desired angle (°)	Measured angle reading (°)	Speed error (%)
0.108	0.110	1.92
0.198	0.207	1.63
1.809	2.012	4.21
2.988	3.451	5.08
2.361	2.488	3.34
3.382	4.009	6.15
4.091	4.118	3.98

Table 2. The test data of the middle section dynamic state.

Theory desired angle (°)	Measured angle reading (°)	Speed error (%)
20.812	20.997	4.87
24.677	24.566	4.78
30.756	30.908	5.49
35.871	36.083	5.37
38.070	38.573	3.81
40.237	41.244	2.76
41.240	41.889	3.16

Table 3. The test data of close to the end of the segment state.

Theory desired angle (°)	Measured angle reading (°)	Speed error (%)
59.461	59.608	5.74
60.608	60.573	3.88
65.543	64.998	3.63
68.803	68.089	4.89
70.341	70.945	3.45
72.306	72.017	4.85
74.087	74.334	2.98

Table 4, Table 5 and Table 6 is the part of data measured in another particular experiment and the results based on the analysis of data and images. Tracking platform rotation angle controlling unit time is set to 0.5 s, based upon the initial segment, middle segment and end segment of each point's tracking status data analysis, Table 4 shows the data of the initial dynamic state, Table 5 shows the data of the middle section dynamic state and Table 6 shows the data of close to the end of the segment state, speed error of each point position is the difference between the theoretical and measured speed.

Table 4. The test data of the initial dynamic state.

Theory desired angle (°)	Measured angle reading (°)	Speed error (%)
1.381	1.407	2.55
1.455	1.568	2.78
2.744	2.808	3.16
2.766	3.076	2.85
3.672	4.099	3.62

Table 5. The test data of the middle section dynamic state.

Theory desired angle (°)	Measured angle reading (°)	Speed error (%)
45.232	46.008	3.22
46.897	47.043	2.29
50.902	49.917	3.56
51.937	52.011	2.57
53.228	55.402	3.71

Table 6. The test data of close to the end of the segment state.

Theory desired angle (°)	Measured angle reading (°)	Speed error (%)
80.823	81.887	3.04
82.728	82.831	5.26
84.605	85.184	3.35
86.767	87.581	3.73
87.941	88.509	2.45

It can be shown from the data analysis of Table 1 to Table 6 that the tracking system has more error in the initial state because of the rotating platform's jitter and other effects, and has less error and it 's tracking is more stable in the middle section state.

According to the tracking geometric algorithms of tracking turntable, it is need to find the location angle θ_i of each point between object and tracking turntable center and the changes of object images' center pixel location in the unit time Δt , Table 7 and Table 8 show the position change of object in the imaging in two different intervals section image processing, it can be seen from the change results of imaging pixel position that the center position has a clear float in the horizontal direction, while the center position has small changes in the vertical direction. Reflected in a uniform unit time, the tracking system has the structural design errors and control errors, so that the object center is not in a fixed area but has floating around with the different distance from object to the optical tracking system, but in the entire tracking system, the center locked point of the image tracking is in the effective field of view.

Table 7. The location data of angle variable and object image center pixel.

Angle θ_i (°)	Horizontal x (pixel)	Vertical y (pixel)
11.027	348	588
11.891	362	527
12.825	719	602
12.991	944	571
13.074	467	528

Table 8. The location data of angle variable and object image center pixel.

Angle θ_i (°)	Horizontal x (pixel)	Vertical y (pixel)
56.755	102	476
57.089	116	587
57.725	562	483
58.293	898	497
60.842	794	588

7. Conclusion

According to the needs of the tracking object, based on the orbital tracking platform, and the optical imaging and reserve trajectory, object tracking trajectory is deduced and the high-speed moving object is tracked according to segment; combining Mean Shift tracking method, using improved Mean Shift tracking algorithm to track the object in real-time, this method overcomes the phenomenon that the traditional Mean Shift tracking method is ineffective under the low contrast of object. Meanwhile, the system through accurately angle measurement devices and image analysis processing, can be used to verify the velocity parameters of high speed object. According to the experimental data, the tracking measure which is used in the paper is feasible, the system provides a theoretical basis for remote object tracking.

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