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Enhancement of TV Tracking Effeciency Using Deterministic and Statistical Automatic Control Predictors

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ABSTRACT :

The tracking process is simply the continuous determination of the target coordinates. The tracking of moving objects in noisy conditions is very complex. The use of spatial band-pass filters (window) reduces the effect of all objects lying outside this window. The crossing object is a moving object flying across the window at the same time with intended target. So, the tracking system may be confused and become unable to recognize the correct target after separation. If the system is designed to have the ability to predict the new target center relative position, the window will be located at the predicted center, which is assumed to be very close to the real position. As a result, the system performance to track maneuvering targets will be improved. This paper introduces the use of different kinds of predictors to overcome the two main problems of tracking process (crossing moving targets and target maneuver).

Simulation results show that the use of statistical predictors gives useful performance in a large class of tracking problems, but it increases the system complexity due to the need to compute the mean and variance of the target pixels inside the window.

1. Introduction:

The recent development of the rader jamming electronic systems, reduces the effectiveness of rader systems. In the recent time, the large improvement in the optical systems (TV cameras & IR sensors) sensitivity and accuracy attract the attention towards employing these sensors for air target sensing and tracking. The development of the new TV camera with long range and high resolution makes the design of precise optical systems more feasible. The published conventional TV tracking systems have some problems on target/ambient-ground separation that degrades the tracking system performance. An advanced target/ambient-ground separation algorithm is proposed by Bahgat et al [1] to slove this problem. In addition, it had been found that the location

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of the spatial band-pass filter (window) at the measured target center makes many restrictions on the window size and tracking performance against the maneuvering target. Several solutions have been suggested to overcome this problem. The most effective solution is the use of advanced window by locating the window around the predicted target position. Investigation and solutions using different kinds of predictors for solving this problems are proposed.

The predictor is simply a mathematical algorithm for estimating the next states using the history of some sequence of the system states. The performance of the predictor based on the minimum mean square error is mainly described by its ability to estimate the values of the target center and to overcome the main problems of the tracking process (crossing moving objects and target maneuvering).

The use of spatial band-pass filters (windows) reduces the effect of all objects lying outside this window. Fig.1. shows the flowchart of the conventional TV tracking systems using a lead window located at the last measured target center. The size of the window is a very important parameter which affects the accuracy of the target measured parameters. The narrow window reduces the effect of the outside ambient-ground objects. However, it reduces the system accuracy due to the possibility of existence of target pixels outside the window, which increases the probability of missing maneuvering targets. On the other hand, the wide window increases the processing time and the effect of ambient-ground pixels.

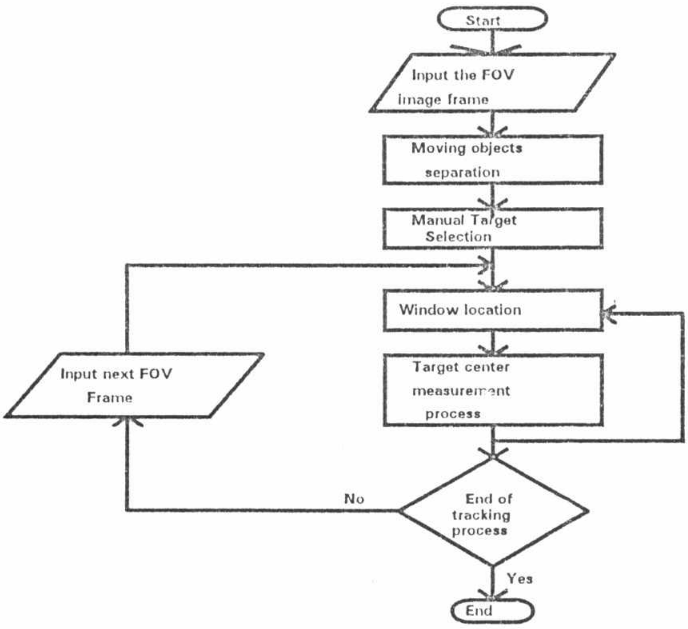

Fig.1. Flowchart of the conventional TV tracking system.

The crossing object is a target flying across the window at the same instant of time with intended target. So, the conventional TV tracking system may be confused and become unable to recognize the correct target after separation.

The crossing and maneuvering targets are the main tracking process problems. Fig.2. and Fig.3. represent two non-successful tracking processes due to crossing and maneuvering targets without predictor respectively.

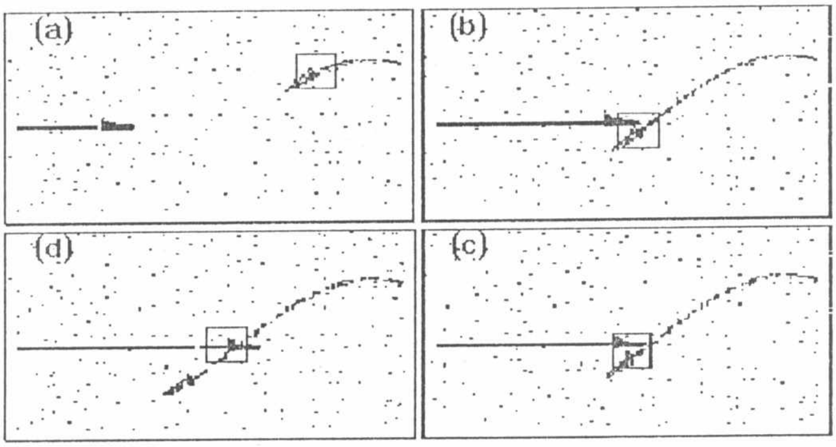

Fig.2. A non-successful tracking process due to crossing object without predictor
(Window size (W_s)= 14 pixel, target velocity (V_t)= 4 pixel/fram, target max. acceleration $a_{t\ max}$ = 0.17777 pixel/fram^2)

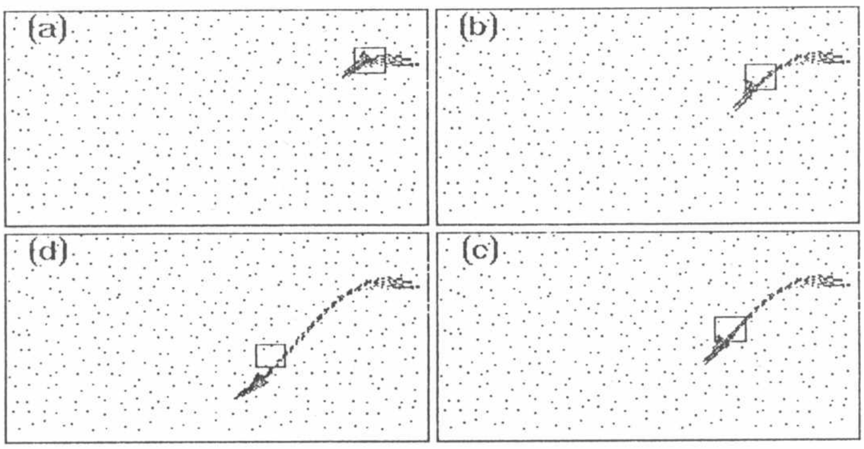

Fig.3. A non-successful tracking process due to maneuvering target without predictor
(Ws = 14 pixel, Vt = 4 pixel/frame, $a_{t\ max.}$ = 0.1777 pixel/frame^2)

If the system is designed to have the ability to predict the new target center relative position, the window will be located at the predicted center, which is supposed to be very close to the real one. This assignment, minimizes the probability of target pixels existing outside the window. As a result, the system performance to track maneuvering targets will be improved.

The flowchart of the proposed system using predictors is shown in Fig.4.

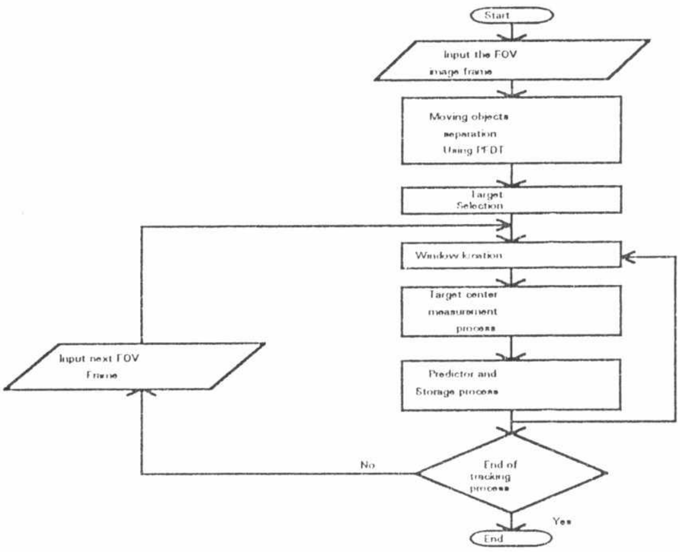

Fig. 4. The flowchart of the proposed TV tracking using predictors.

A simulated target flying with lateral acceleration with other moving objects which may cross the target window are used to determine the predictor performance, using the simulated algorithm, observing the target-window relative center error, and analyzing the performance of the tracking process (successful or non-successful).

2. Polynomial interpolators:

Several simple predictors are defined and the best estimate (in G.M. Flachs opinion [2], [3], [4]) of the predictors is used to define the control signals for the next frame. Since the form of the estimator equations is similar for the azimuth, elevation and image rotation variables, the following notation is used in the development.

n .... frame index,
j .... type of predictor index,
$\theta(n)$ .... variable to be predicted (azimuth or elevation angle),
$\theta_m(n)$ .... measured value of $\theta(n)$,
$\theta(n)$ .... estimated value of $\theta(n)$,
$\theta_j(n+1/n)$ .... predicted value of $\theta(n+1)$ using measurements through n frames and j index type of predictor, finally
$\theta(n+1/n)$ .... predicted value of $\theta(n+1)$ using combination of set of predictors.

G. M. Flachs [2] derived two types of polynomial predictors, the linear and the quadratic polynomial predictors. The N point linear predictor which minimizes the mean square error (MSE) is as follows:

$$MSE = \sum_{n=0}^{N-1} (\theta_j(n/n-1) - a_0 - a_1 t_n)^2 \qquad (1)$$

where N.......... is the number of measured points used in the prediction evaluation .

The 2-point linear predictor is simply, a linear predictor with N=2, $t_n=n$ and minimizes (1). So, the 2-point linear predictor [5] is given by:

$$\theta_j(n+1/n) = 2\,\theta_m(n) - \theta_m(n-1) \qquad (2)$$

This allows the system to estimate the next target center by only two measured points. Mainly, the 2-point linear predictor keeps the target flying with the same measured relative velocity (the difference between two sequential target center measures).

The time interval between measurments is considered as an important parameter, which controls the linear predictor accuracy. Suitable time interval improves the performance of the linear predictor which improves the performance of the tracking system because the location of the spatial band-pass filter (window) in advanced position close to the real target center, minimizes the error, which improves the system accuracy and, the system ability to track maneuvering targets.

Small time intervals minimize the target relative displacement, thus minimizing the target-window error. The adapted narrow window will decrease the needed processing time and the effect of the ambient-ground object will be minimized. Also, the effect of the crossing objects will be decayed especially for objects having large velocity compared to the tracked one. The linear predictor succeeded to decay the effect of crossing target and failed to increase the performance of tracking maneuvering target. For this reason, Flash [3] proposed a linear predictor with increased order which increases the window ability to decay the crossing objects effect, but reduces the system ability to track maneuvering targets. For N=3, the predictor will be expressed [2] as follows:

$$\theta(n+1) = \theta(n) + [\,\theta(n) + \theta(n-1) - 2\,\theta(n-2)\,]\,/3 \qquad (3)$$

The design of the linear predictor is very simple and it can be easily manipulated using digital systems, but it does not give the needed performance due to the contradiction between the way for improving the system ability to track maneuvering targets and the way for improving its ability to track crossing targets. For a large class of maneuvering targets and crossing objects, the linear predictor fails to track the assigned target, especially if the crossing objects fly with a velocity close to the target velocity.

Accordingly, a more powerful predictor is required to accomplish better accuracy in the tracking of maneuvering targets. The N-point quadratic polynomial predictor which uses N previous measures to estimate the new filter position, such that the mean square error is minimized;

$$MSE = \sum_{n=0}^{N-1} (\,\theta_j(n/n-1) - a_0 - a_1\,t_n - a_2\,t_n^2)^2 \qquad (4)$$

the estimated parameter will be:

$$\theta(\,n+1\,) = a_0 + N\,a_1 + N^2 \qquad (5)$$

The 5-point quadratic polynomial predictor [2] is expressed as follows:

$$\theta(n+1) = \theta(n) + [\,4\,\theta(n) - 4\,\theta(n-2) - 3\,\theta(n-3) + 3\,\theta(n-4)\,]/5 \qquad (6)$$

It is mentioned that, the quadratic polynomial predictor is more sensitive to the target motion , so it gives better performance in the tracking of maneuvering targets than the linear predictor. But, the linear predictor relates the window with the target previous motion , so it gives better performance in the tracking process in case of crossing object than the quadratic polynomial predictor. Fig.5. shows a successful tracking due to maneuvering target using 5-point quadratic predictor. Fig.6. shows a non-successful tracking due to crossing target using 5-point quadratic predictor.

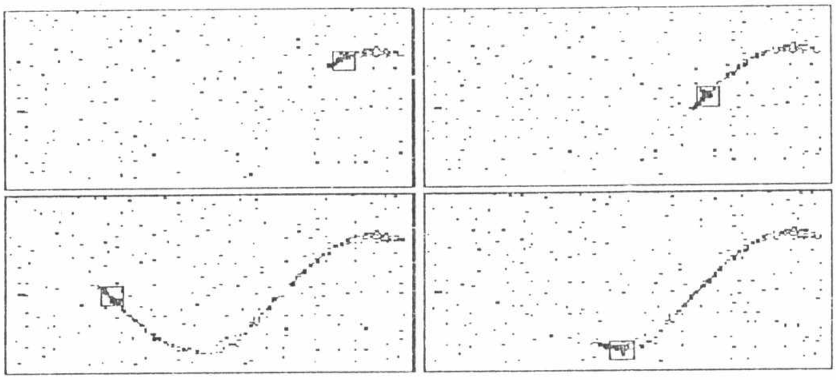

Fig.5. A successful tracking process due to maneuvering target using 5-point quadratic predictor (Ws=14 pixel, Vt=4 pixel/frame, $a_{t\ max.}$=0.1777 pixel/frame^2)

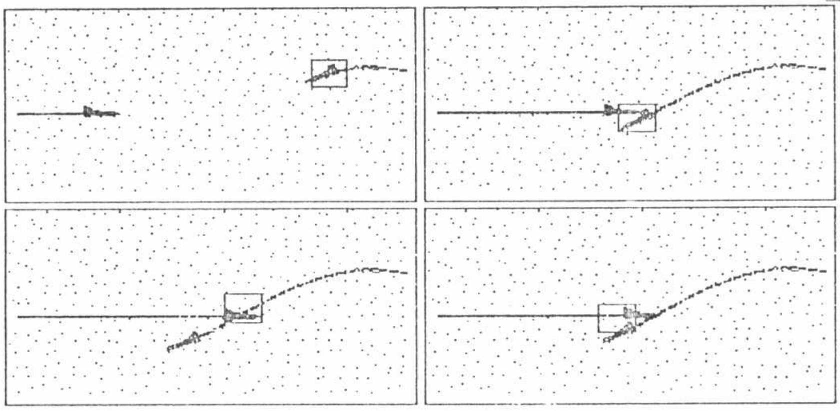

Fig.6. A non-successful tracking process for crossing object using 5-point quadratic predictor (Ws=19 pixel, Vt=5.0442 pixel/frame, $a_{t\ max.}$=0.07407 pixel/frame^2)

It is clear that, the adaptation of polynomial predictors to achieve better performance is very poor due to the contradiction between the used tools to improve the ability to track maneuvering targets and those used to overcome the effect of crossing objects.

3. The Automatic Control Predictor [6]:

The automatic control predictor is proposed for predicting the physical target measured parameters like position, velocity, acceleration, and rate of acceleration [7]. Then, it is necessary to study the predictor stability, step response, and its effect on the simulated tracking problem to acquire the maximum benefits from the desired predictor.

In this paper, 2-types of predictors are proposed. The first type is an optimum automatic control predictor with constant coefficients called "deterministic automatic control predictor". The second type has adaptive variable coefficients, and called "statistical automatic control predictor".

3.1 Deterministic Automatic Control predictor:

The target motion can be considered as a completely random unknown input to the TV tracking system. However, this motion is constrained by the limited maneuverability (maximum normal acceleration), the bounded velocity, and the body inertia. These constraints prevent the target from introducing sudden changes in its motion. Accordingly, the next target motion parameters depend on its previous motion.

The deterministic automatic control predictor, estimates the next position using the previous position and feedback's of the previous measured parameters with certain gains. The predictor response has to be with moderate rise time to track the maneuvering targets, and in the same time, it has to decay the effect of abrupt changes due to noise or crossing objects.

The deterministic predictor uses the linear predictor as a base predictor with feedback. The proposed predictor uses the relative acceleration as a negative feedback by gain C_1, and the acceleration rate as a positive feedback with gain C_2 as follows:

$$\hat{\theta}(n+1/n) = \theta_m(n) + V_m(n) - C_1 A_m(n) + C_2 Z_m(n) \tag{7}$$

where: $V_m(n)$ is the target relative velocity
$A_m(n)$ is the target relative acceleration
$Z_m(n)$ is the target relative acceleration rate

A general block diagram for the automatic control predictor is introduced in Fig.7. The predictor consists of some storage stages and summation junctions, in addition to some multipliers so that it is easy to implement. This implementation will be very useful for large class of tracking process problems.

The negative feedback's will damp the effect of noise and crossing objects by maximizing the predictor rise time. The positive feedback's will support the system inertia response to improve its ability to track maneuvering targets.

Determination of C_1, and C_2 is a very hard problem due to the contradiction between the system ability to track maneuvering targets and its ability to overcome the crossing objects effect and there is no mathematical algorithm to measure the system performance. Because of the previous reasons, a system simulation algorithm close to reality is presented. By testing the simulated closed loop tracking system unit step response and showing the effects of coefficient variations, we can determine the suitable values of C_1 and C_2.

System performance is examined through the algorithm shown in Fig.8. which is designed to simulate :

(1) A target flying with constant velocity.

(2) Predictor in the steady state tracking process (i.e. the target center lies in the window center).
(3) Abrupt change in the target velocity (simulating a unit step input to the predictor).
(4) Prediction process (new window center prediction).
(5) The window velocity is traced as the predictor unit step response for different coefficients variations.
(6) The coefficient variation test is achieved by keeping C_2 fixed and tracing the unit step response for different C_1 values, then changing C_2, and the process continues.
(7) The computer program eliminates the coefficient combinations that give non-successful tracking process.
(8) Return to step 4 until the end of coefficients variations.

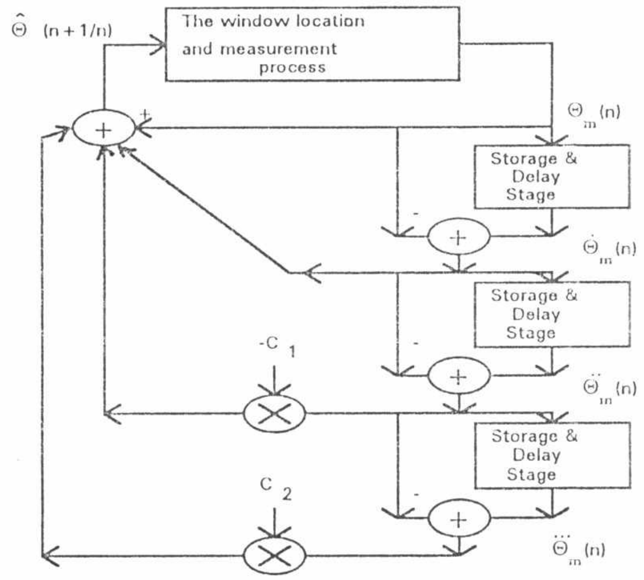

Fig.7. A general block diagram for automatic control predictor.

The obtained results reveal that the suitable ranges for C_1 and C_2 are (0.11 to 0.7) and (0.14 to 0.31) respectively. Actually the best ranges are (0.16 to 0.52) for C_1 and (0.16 to 0.21) for C_2 because the unit step response is more stable and smoother in this region. From the first look to the predictor unit step responses for different coefficients variation, it is clear that the values around 0.5 and 0.166 for C_1 and C_2 respectively, give large rise time (slow response) and minimum overshoot. This is very useful for overcoming the crossing objects effect, but it may decay the system ability to track maneuvering targets. This predictor will be called slow automatic control predictor. On the other hand, the values around 0.2 and 0.2 for C_1 and C_2 respectively give small rise time, and high overshoot. This is useful for the tracking of maneuvering targets, but it has some limitations in the tracking of the crossing objects. This predictor will be named as quick deterministic automatic control predictor.

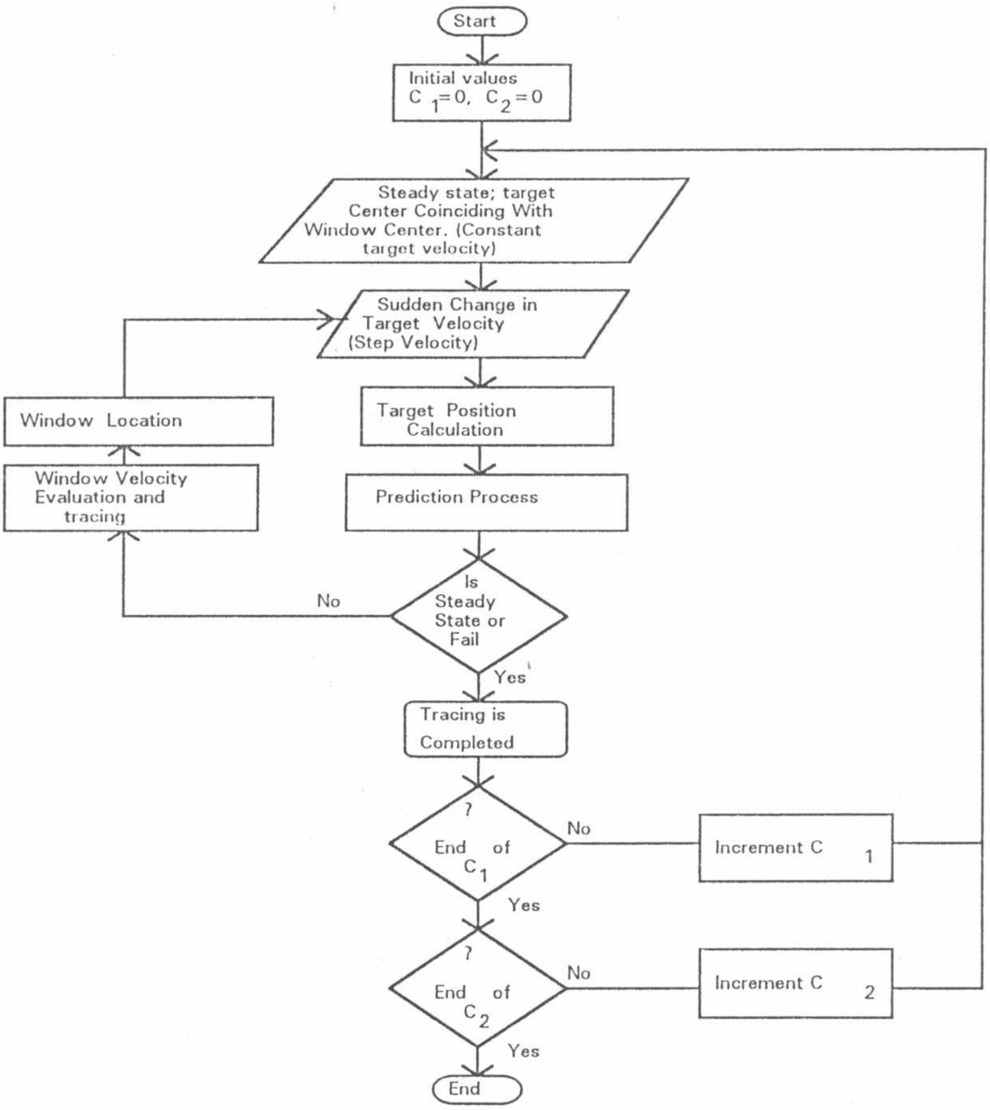

Fig.8. The predictor performance evaluation algorithm.

Fig.9. shows some responses due to choice of suitable and unsuitable values for the coefficients C_1 and C_2 .

However, the deterministic automatic control predictor, performs better than the linear & the quadratic polynomial interpolators. Fig.10. and Fig.11. show a successful tracking process for crossing target using deterministic slow and quick automatic control predictor with values of C_1 and C_2 equal to (0.5 & 0.16) and (0.2 & 0.2) respectivily.

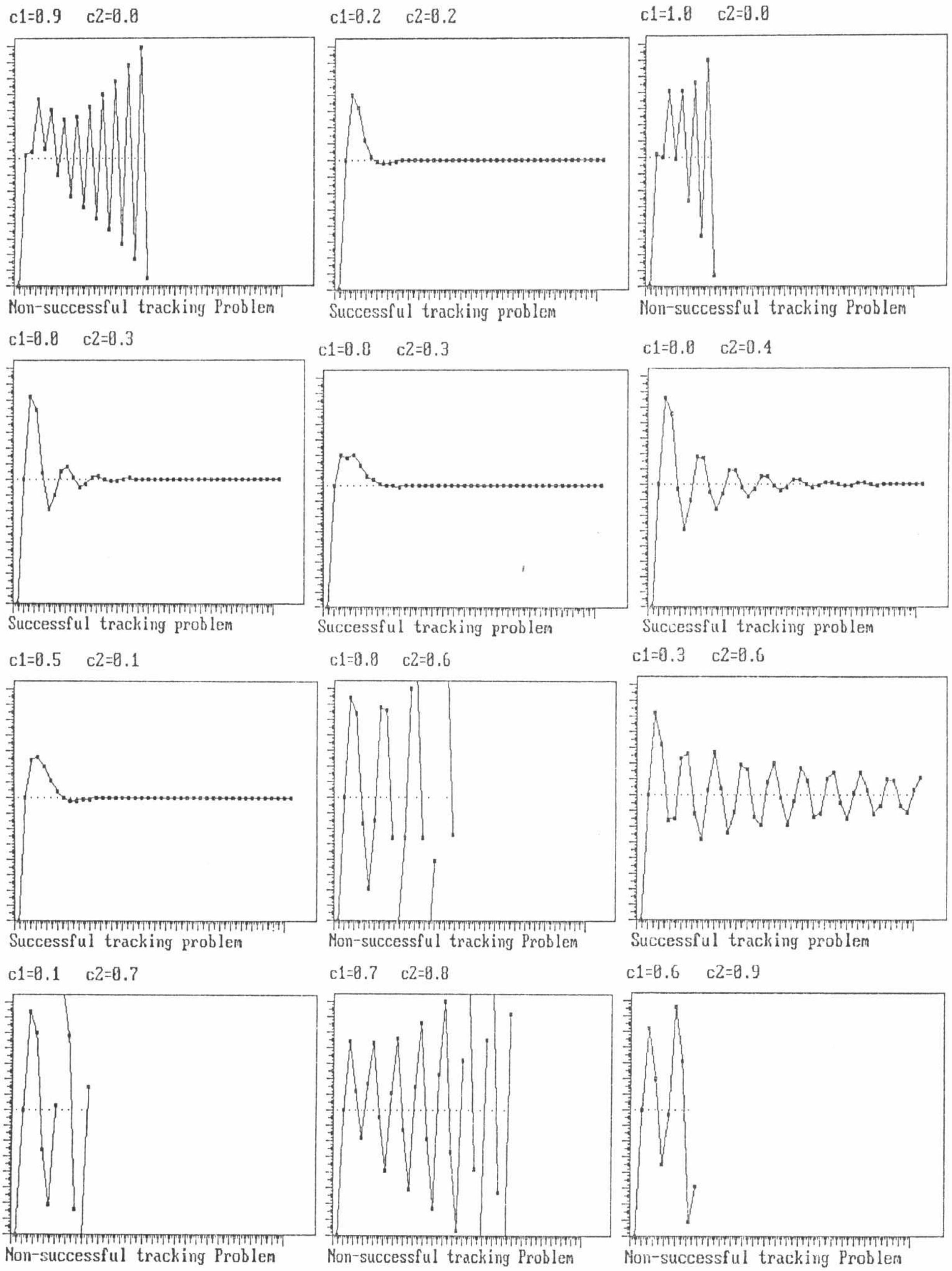

Fig.9. System responses for different values of the coefficients C_1 and C_2.

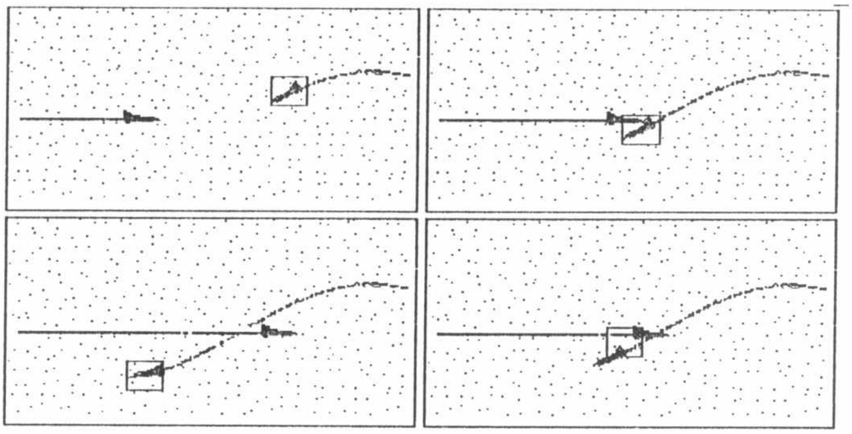

Fig.10. A successful tracking process for crossing target using deterministic slow automatic control predictor
(Ws=19 pixel, Vt=5.0442 pixel/frame, $a_{t\ max.}$=0.07407 pixel/frame^2)

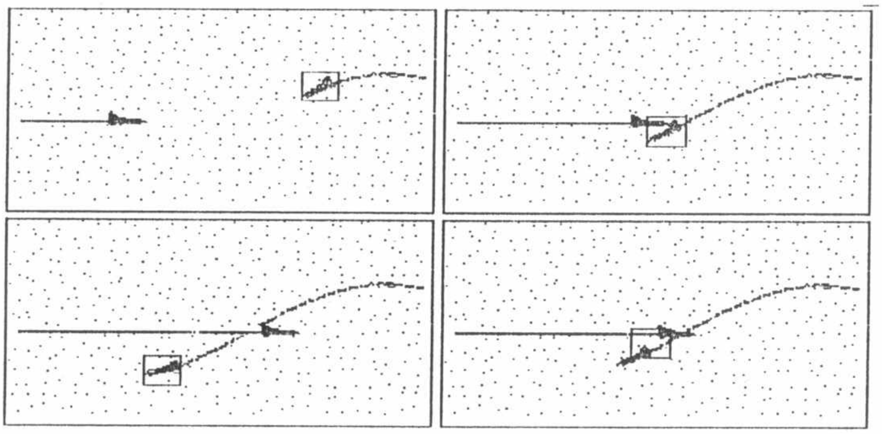

Fig.11. A successful tracking process for crossing target using deterministic quick automatic control predictor
(Ws=19 pixel, Vt=5.0442 pixel/frame, $a_{t\ max.}$=0.07407 pixel/frame^2)

3.2 The Statistical Automatic Control Predictor:

To get the benefits of the two deterministic predictors, the value of the coefficients C_1 (0.2 to 0.5) and C_2 (0.166 to 0.21) must be attached to the case under consideration. It was found out that, in the real case most of targets have a longitudinal shape, and the main target velocity has a close direction to the target longitudinal axis (axis of symmetry). The target direction change is achieved through fin deflection which produces an aerodynamic force perpendicular to the axis of symmetry and deviated from the center of gravity. This force produces a torque causing the target rotation around its CG.

As an example, if a target flies on the relative x direction in the FOV image plane, and if the longitudinal axis of the target coincides with the image relative x direction, then, the target pixels will be distributed along the x axis as in Fig.12. which maximizes the variance of the target pixels projection along the x direction. In the y direction the variance will be minimum (the target will have a narrow pixels projection distribution along the y direction). This phenomenon can be used to switch over between both couples of coefficients. In case of crossing object the variance will increase in the direction of the object correlation.

The key now is how to use the variance of the target and the window parameter (size) to vary the coefficients C_1, and C_2 to match a specific situation. Fixing C_1 and changing C_2 from (0.16 to 0.21) give a slight effect on the tracking problem, and accordingly, C_2 can be fixed about (0.2).

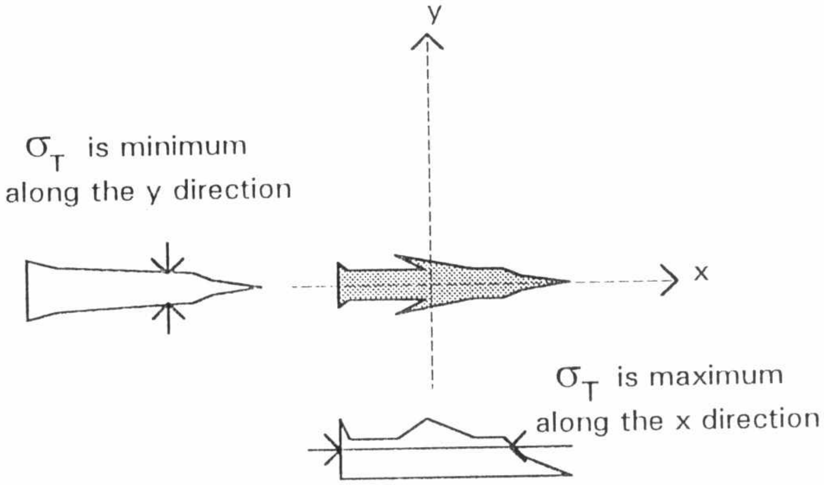

Fig.12. The (X,Y) target projection distribution

C_1, the main varying coefficient which controls the predictor response, is formulated as follows:

$$C_1 = \frac{\sigma_T}{\sigma_T + \sigma_A} = \frac{\sigma_T}{\sigma_W} \tag{8}$$

where σ_T is the variance of the target pixels in x or y direction.

σ_A is the ambient-ground variance in x or y direction.

σ_W is the window variance in x or y direction.

$\sigma_W = \frac{L_W}{\sqrt{12}}$ for uniform distribution

L_W is the window size (in pixels).

A general block diagram for the statistical automatic control predictor is shown in Fig.13. to declare the simplicity of the predictor implementation and the needed stages to achieve that implementation.

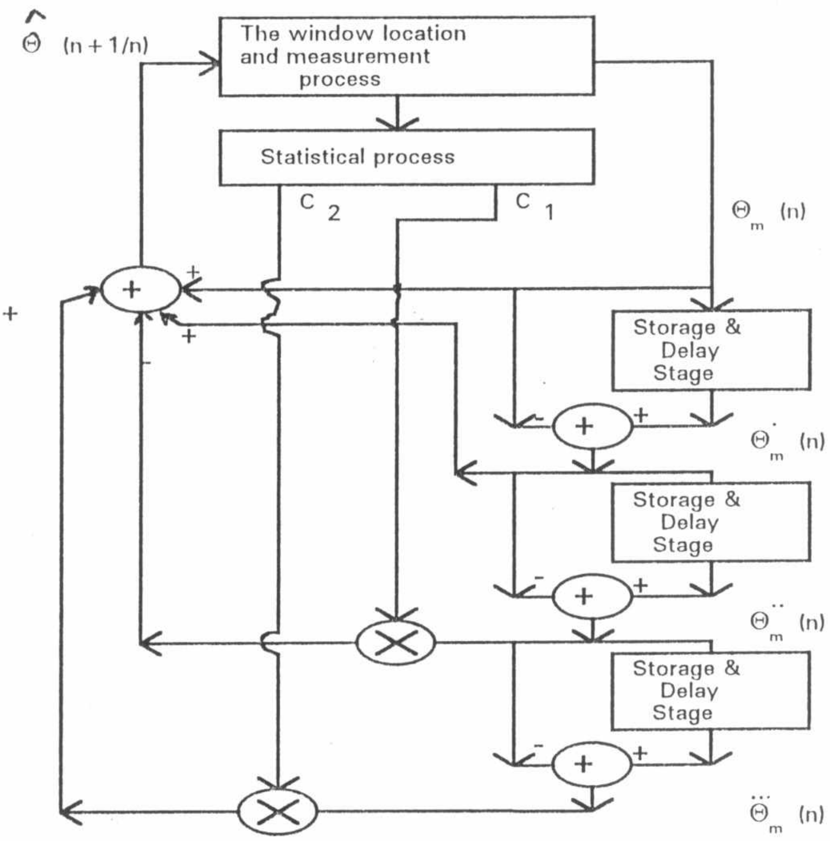

Fig.13. A block diagram for statistical automatic control predictor

Actually, the target will have minimum variance at lateral direction of the target motion (approximately the lateral of the target longitudinal axis). C_1 will be minimum in this lateral direction. This makes the predictor more adaptive to the target maneuver. The maximum variance will be at target velocity direction (approximately the target longitudinal axis). C_1 will be maximum in this direction. This ties the window motion with the target previous motion. When another object passes through the window (crossing object) the variance will increase in the direction of the crossing object which will affect C_1. C_1 will be increased which ties the window motion with the previous target motion. This strong tie improves the system ability to overcome the bad effects of the confused measure due to the crossing object. Fig.14. represents a non-successful tracking process due to maneuvering target using slow deterministic automatic control predictor C_1=0.5 (slow predictor), and Fig.15 represents a successful tracking for maneuvering target using the statistical automatic control predictor. Fig.16. represents a non-successful tracking for crossing target using the predictor with coefficient C_1=0.2 (quick one), and Fig.17. represents a successful tracking process for crossing target using the statistical automatic control predictor.

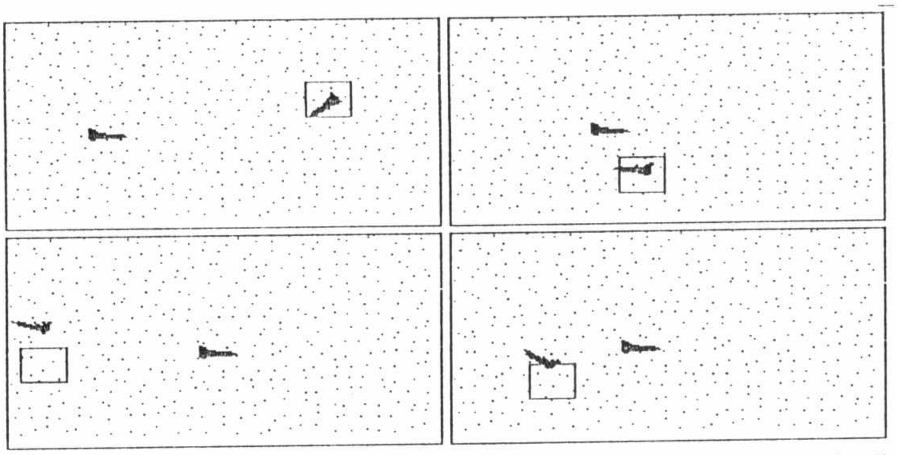

Fig.14. A non-successful tracking process for maneuver ing target using deterministic slow automatic control predictor
(Ws=23 pixel, Vt=5.0689 pixel/frame, $a_{t\ max.}$=0.13887 pixel/frame^2)

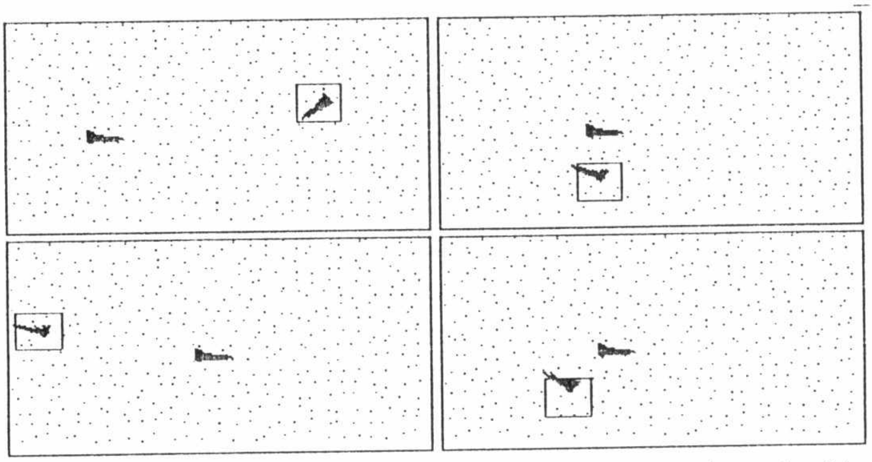

Fig.15. A successful tracking process for maneuvering target using statistical automatic control predictor
(Ws=23 pixel, Vt=5.0689 pixel/frame, $a_{t\ max.}$=0.13887 pixel/frame^2)

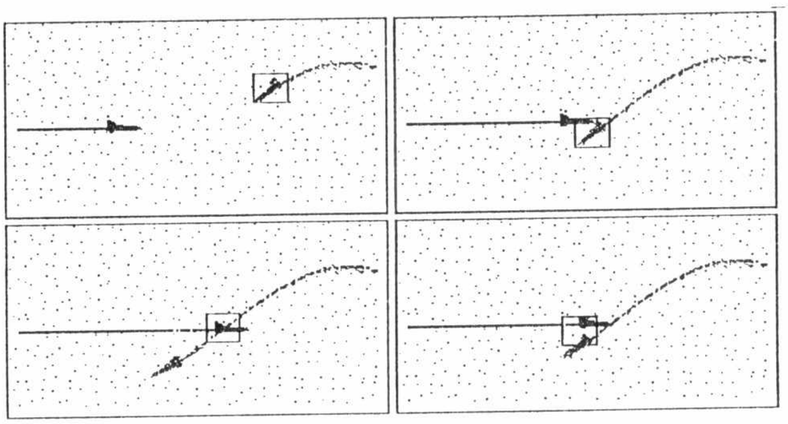

Fig.16. A non-successful tracking process due to crossing object using deterministic quick automatic control predictor
(Ws=19 pixel, Vt=4.7833 pixel/frame, $a_{t\ max.}$=0.0928 pixel/frame^2)

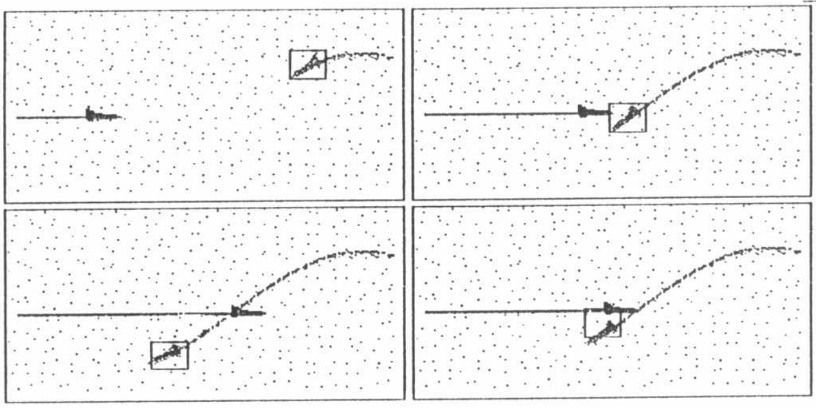

Fig.17. A successful tracking process for crossing target using statistical automatic control predictor (Ws=19 pixel, Vt=4.7833 pixel/frame, $a_{t\ max.}$=0.0928 pixel/frame^2)

It is clear that the use of statistical predictors gives acceptable performance in a large class of tracking problems.

Conclusion and Future Work:

The proposed tracking system decays the bad effects of the target maneuver and the crossing objects. The use of automatic control models (quick and slow ones) leads to improved performance. The use of these predictors in real time using real processors is the subject for future work.

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