A Render Data Optimized Organization Strategy Based on Kalman Prediction

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***Abstract*—Large scale scene rendering is essential to Visualization Navigation, and needs optimized organization strategy. Combining Kalman prediction and equal interval organization measure, a render data optimized organization strategy was proposed. Kalman prediction was adopt to estimate scheduling region, which optimizes rendering data organization. Organization data amount is decreased and visualization effect is meliorated.**

***Index Terms*—kalman prediction, optimized organization, equal interval, OSG Earth**

I. INTRODUCTION

One of the methods in the visual navigation technology is based on the fundamental of topographic database. Computers will generate graphics which can guide the pilots to fly according to the correct route [1]. Three-dimensional scene simulation provides the most efficient channel for navigation; it offers flight assistance to pilots under conditions of low-visibility. High resolution remote sensing image and digital elevation model (DEM) database retrieved from detective satellites and cartographic satellites are the basic conditions in order to create the real landscapes [2]. Currently, most of the helicopters' routes can reach about hundreds of kilometers, by using 32 meters resolution from DEM and one meter resolution from satellite image, the total volume will hit terabyte level. The current memory and hard-disk storage volume are limited and CPU efficiency is also low thus navigation will be terminated. The huge amount of database will definitely affect the efficiency of plotting the landscape as a result a further research is needed for the high resolution remote sensing image and DEM database efficient scheduling policy is particularly important. Supposing that, system required data can be determined in advance. And save the data into buffer cache. When plotting system demand the data, need only to call the data from buffer region directly. Thereby avoiding low plot speed due to the disk latency [3].

Kalman filter does well in maneuvering target tracking [4]. It is the best estimate and also good at recursive computation, thus state estimating only needs the measured value and the predicted value of previous sampling period [5], such as position, velocity. It is now widely used in aircraft, ships and other moving objects in the area of target tracking, state estimation and other aspects. Taking use of the advantage of the Kalman filter applied in track forecast, Kalman prediction can effectively improve the terrain rendering.

II. KALMAN FILTER

Kalman filter is a kind of filtering algorithm, which estimates the desired signal from extraction signal measurement values. It is an optimal estimator, so its state vector estimate is unbiased, whose variance is minimum [6]. Due to the velocity, acceleration, third-order vector Kalman predictor is adopted to predict the positions of the next viewpoint.

Vector Kalman predictor equations:

Prediction equation:

$$\hat{\boldsymbol{X}}(k+1/k) = \boldsymbol{A}\hat{\boldsymbol{X}}(k/k-1) + \boldsymbol{G}(k)[\boldsymbol{Z}(k) - \boldsymbol{C}\hat{\boldsymbol{X}}(k/k-1) \quad (1)$$

Prediction gain:

$$\boldsymbol{G}(k) = \boldsymbol{A}\boldsymbol{P}(k/k-1)\boldsymbol{C}^{T}[\boldsymbol{C}\boldsymbol{P}(k/k-1)\boldsymbol{C}^{T} + \boldsymbol{R}(k)]^{-1} = \boldsymbol{A}\boldsymbol{K}(k) \quad (2)$$

Prediction Mean Square Error (MSE):

$$\boldsymbol{P}(k+1/k) = [\boldsymbol{A} - \boldsymbol{G}(k)\boldsymbol{C}]\boldsymbol{P}(k/k-1)\boldsymbol{A}^{T} + \boldsymbol{Q}(k)\,. \quad (3)$$

The symbol '/' indicates the recursive value between the moment and its previous moment, standing for predicted values. $\boldsymbol{A}$ is the state transition matrix, $\boldsymbol{C}$ is the observation matrix, $\boldsymbol{Z}$ is the unknown observed value, $\boldsymbol{R}$ is the observation noise covariance matrix, $\boldsymbol{Q}$ is the single signal covariance matrix.

Vector Kalman predictor structure is shown in Fig. 1, which z^{-1} stands for the delayer, due to z^{-1}, $\hat{\boldsymbol{X}}(k+1/k)$ transfer to $\hat{\boldsymbol{X}}(k/k-1)$.

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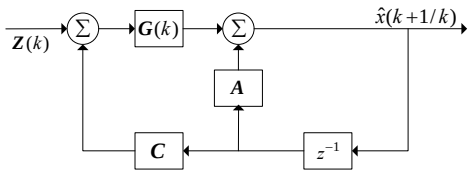

Figure 1. Vector Kalman filter structure.

According to the viewpoint motion state and current observation viewpoint position, it is possible to predict the viewpoint position, organize and schedule rendering data. The proposed algorithm can be shown in Fig. 2.

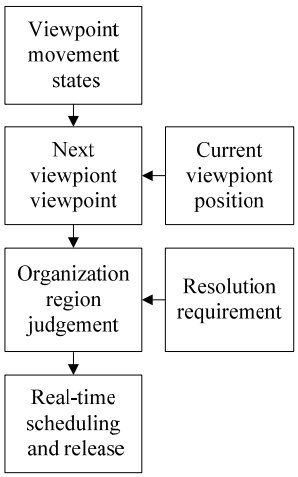

Figure 2. Algorithm processes.

The next viewpoint position is determined by the current position and the current viewpoint motion state; the current viewpoint position is obtained by the aircraft equipment, and the motion state can be calculated from history records; then it can predict the next viewpoint position, and estimate scheduling region. The level of detail is chose according to the screen resolution, and real time loading and release are carried out at last.

III. Viewpoint Prediction Modeling

Considering viewpoint velocity and acceleration impact position prediction, the viewpoint movement states at time are denoted as O_x, O_y, O_z, v_x, v_y, v_z, a_x, a_y, a_z, represented by vector ***X(k)*** ,which show the viewpoint position, velocity, and acceleration, etc. In three-dimensional scene, three parameters describe one parameter. ***Z(k)*** represents the measured position at time *k*. There are the following equations,

$$\begin{cases} O_x(k) = O_x(k-1) + v_x(k-1)t + \frac{1}{2}a_x(k-1)t^2 + \omega_1(k-1) \\ \cdots \\ v_x(k) = v_x(k-1) + a_x(k-1)t + \omega_4(k-1) \\ \cdots \\ a_x(k) = a_x(k-1) + \omega_7(k-1) \\ \cdots \\ z_x(k) = O_x(k) + \upsilon_x(k) \\ \cdots \end{cases} \tag{4}$$

Thus,

$$\begin{cases} \boldsymbol{X}(k) = \boldsymbol{A}\boldsymbol{X}(k-1) + \boldsymbol{W}(k) \\ \boldsymbol{Z}(k) = \boldsymbol{C}\boldsymbol{X}(k) + \boldsymbol{V}(k) \end{cases}. \tag{5}$$

and

$$\begin{cases} \boldsymbol{R}(k) = E\left[\boldsymbol{V}(k)\boldsymbol{V}^T(k)\right] \\ \boldsymbol{Q}(k) = E\left[\boldsymbol{W}(k)\boldsymbol{W}^T(k)\right] \end{cases} \tag{6}$$

A and ***C*** can be calculated by the formula (4), ***W*** and ***V*** respectively stands for the system noise and observation noise, which are impacted by the viewpoint position and movement state. ***A*** is a 9 × 9 order matrix, and ***C*** is a 3 × 9 order matrix.

According to current viewpoint position measure values and equations (1) (2) (3), next moment predicted values $\hat{\boldsymbol{X}}(k+1/k)$ can be calculate, and. the prediction MSE is $\boldsymbol{P}(k+1/k)$. $\hat{\boldsymbol{X}}(k+1/k)$ contains the viewpoint position and direction information next time.

X(k) dimensions is not fixed, and it can be determined by actual situation. If the viewpoint movement maneuverability became strong, it may be appropriate to increase the number of dimensions of the ***X(k)***, that is, considering the jerk impact, and so on. Otherwise, considering the velocity is enough, which reducing the viewpoint prediction calculation amount. To get the next viewpoint position, a Kalman prediction experiments is carried out, its result is show in Fig. 3,

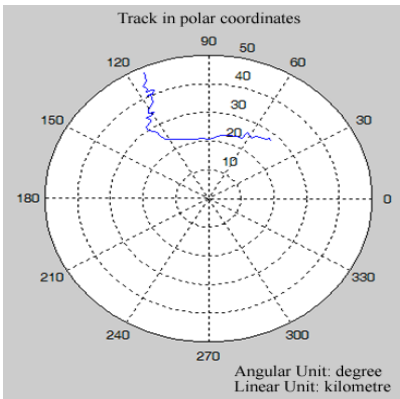

Figure 3. The flight track formed by positioning equipment.

Due to the limited accuracy of positioning equipments, the track cannot completely show the real aircraft flight track or position, and observed values jitter with real track-centered. So the viewpoints from positioning equipment are not the desired results; meanwhile aircraft position observed values jitter, which generate jittery visualization, and it is not suit for pilots.

The blue solid line in Fig. 4 is generated from aircraft positions track forecasted by Kalman prediction, and the red points stands for observed position. It is clear that predicted position is located in the center of the positioning observed value, which is consistent with statistical law. Compare with observed values, the predicted positions conform to real aircraft's actual flight track better. If organize data based on current viewpoint positions, disk I/O delay and aircraft high speed

movement, or high dynamic, will lead Visualization Navigation to render the scene what has already been flown past; and strict real-time requirement will cause frame dropping out. On the contrary, good prediction and organization next viewpoints render data can reduce or avoid above disadvantages.

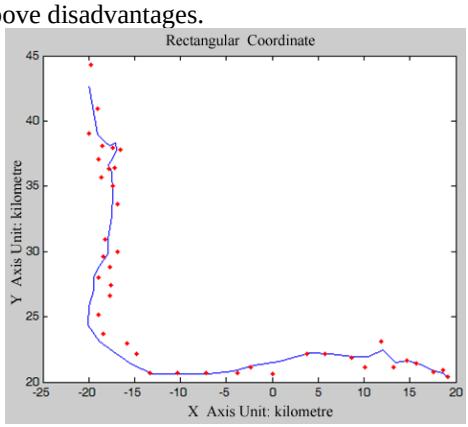

Figure 4. Predicted and observed positions contrast.

Experimental results showed in Fig. 4 illustrate that Kalman prediction can forecast aircraft next position well; due to the aircraft broad view, the predicted position can replace the real viewpoint position.

IV. Rendering Data Optimized Organization Strategy

A. Equal Interval Orgnization Strategy

After calculating next viewpoint position, good terrain data organization strategy is needed. An equal interval strategy is adopted, what schedules rendering data at set interval [7], is time interval between the two image frames. As shown in Fig. 5, at the moment, is viewpoint position, and next predicted position is. is the data set, at the moment, the data system desired is no more than . Organizing the data which are not in the cache, then at time all the required data have been transferred to the memory. Determining the new set of data based on current viewpoint and organizing rendering data are in the same way. Actually, it only needs to organize parts of data. Compared with traditional frame interval-based organization strategy, the new strategy is more stable and not easily impacted by other computing. There are several advantage, such as it can reduce page fault ratio in real-time rendering effectively, and be more easily combined with Kalman prediction.

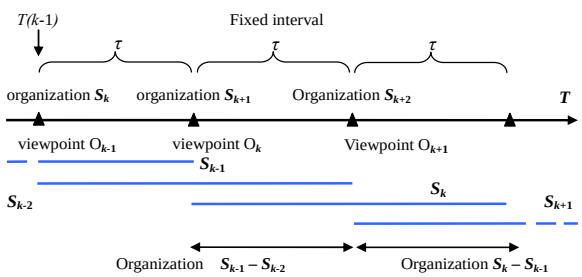

Figure 5. Equal Interval Organization Strategy

B. Scheduling Region Calculation

The observers are interest in viewpoint ambient terrains in Visualization Navigation, so the required organization rendering data should be a viewpoint-centered circle; organized data like a crescent as shown in Fig. 3, and the viewpoint position is calculated by the Kalman prediction. Scheduling region range can be calculated by the viewpoint height and sight angle. What is shown in Equation (7).

$$L = \tan\theta \cdot h \,. \tag{7}$$

In order to ensure that the organized data contains all required rendering data next moment, appropriate increasing prediction radius according to Kalman prediction MSE is enough. Organization radius ensures accuracy is around 98%.

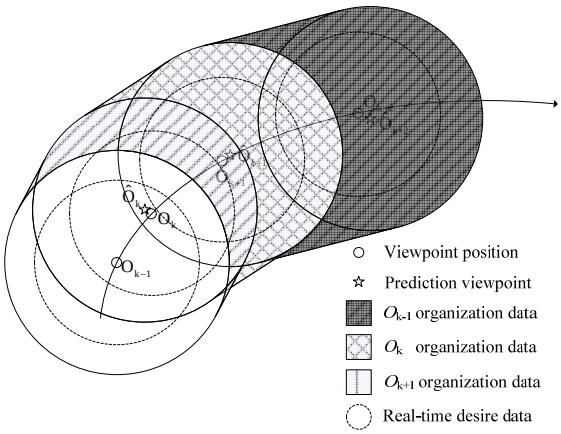

Figure 6. Data organization based on viewpoint prediction.

The maximum vision range is influenced by earth curvature and calculated by equation (8); what is the maximum organization data.

$$L_{max} = \sqrt{(r+h)^2 - r^2} \,. \tag{8}$$

L is the farthest visibility, r is the earth radius, h denotes viewpoint height, which can be calculated by Kalman prediction.

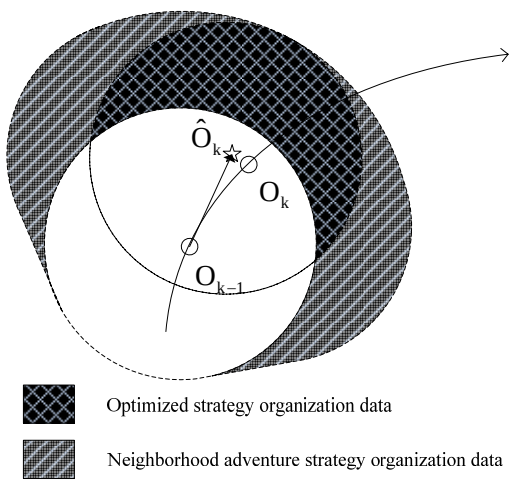

Figure 7. Data organization strategies compare.

Compared with neighborhood region adventure organization strategy, the optimize organization strategy based on Kalman prediction can forecast next viewpoint positions more exactly and reduce organization data amount. As shown in, the black shadow is optimized strategy organization data, and oblique line presents optimized data, which are not need to organize.

The above strategy determines next possible field of vision, nevertheless, it is impossible to watch the entire scene in organization circle. The front probability is maximum, both sides is the second, and the behind is minimum. Even in the same field of vision the interesting areas are also different: the areas near the viewpoint and the line of sight centerline are usually watched carefully; far and bias is on the contrary. So it is necessary to dynamically utilize the level of detail model (LOD).

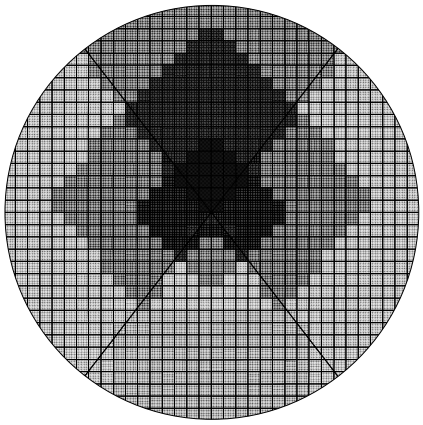

Figure 8. Block-stratification data organization.

Based on above two points, a new organization strategy is proposed. As shown in Fig. 8, the center stands for viewpoint position. Side resolution and behind resolution is determined by observers head tilt and turn back probability. The scheduling region in Fig. 8 is constituted by four sight ranges. The four regions' visibility judgment and LOD selection method is the same, except that the LOD selection standards are different. The front visible blocks judgment and LOD selection is chosen to illustrate.

Visibility judgment is obtained by calculating the projection of terrain convex closure. Convex closure is the minimum convex polyhedron surrounding a terrain block. There are three relationships between convex closure projection and visible areas, thus out of, completely in, part in the visible areas. As shown in Figure X. Projection completely in the visible region; projection part in the visible region. As shown in Fig. 9.

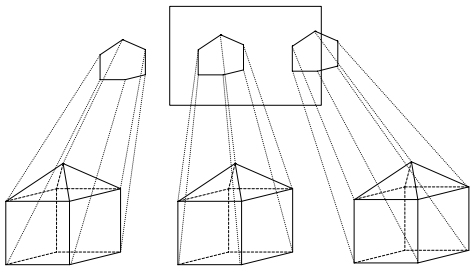

Figure 9. Terrain convex closure visible judgments.

Data blocks of first case are direct cast, and the latter two are visible nodes. By calculating projected area of visible node, the appropriate resolution LOD models into memory are closed to draw graphics. If the visible node projected area is greater than a certain set Smax, $\mathrm{Smax}_{\mathrm{front}} = 1/2\mathrm{Smax}_{\mathrm{sides}} = 1/4\mathrm{Smax}_{\mathrm{rear}}$, its son nodes are treated as visible nodes and added in a set as node, otherwise the noise nodes was added [8]. What will not only to convey vision determine different resolution terrain data display, but also satisfied the accuracy and speed requirements.

C. Data Organization Interval Calculation

Rendering data organization interval should meet requirements as followed,

- Organization data amount must not exceed the memory capacity limit.

The organization data amount is equal to the sum of each frame data in the interval. As the size and resolution of each frame terrain data are different, it is not convenient to calculate the data amount; screen resolution estimate is adopted here.

$$D = k \cdot t \cdot m \cdot n \cdot c\left(a + b \cdot \rho_{DOM} / \rho_{DEM}\right) < D_{\mathrm{limit}} . \tag{9}$$

m, n denote the screen resolution, ρ_{DOM} is the digital orthophoto resolution, ρ_{DEM} is the Digital Elevation Model (DEM) resolution, c is a correction coefficient, which indicates the amount ratio of organization region data to display data, t denotes the organization interval, D_{limit} denotes memory capacity limit. k denotes the frame number per second, a is the DOM data amount correspond with each pixel, b is the DOM data amount correspond with each elevation point.

- In the organization interval, the viewpoint should move over the minimum organized terrain block.

$$vt > l_{\min} \tag{10}$$

l denotes the minimum terrain block width which is independently organized.

- 3, the organization data amount is less than the product of the hard disk transmission speed and organization interval.

$$D = k \cdot m \cdot n \cdot c\left(a + b \cdot \rho_{DOM} / \rho_{DEM}\right) < T \tag{11}$$

T denotes the transmission speed of the hard disk to memory. The factor is always true in the current conditions of computer hardware, DEM or DOM resolution.

Then according to the factors above, appropriate organization radius and interval are determined.

D. Data Release

When the viewpoint moves past, to avoid the data amount exceeding memory capacity limit, data need to be released. An improved least recently used (LRU) algorithm is adopted to determine the data to be deleted [9] and priority is determined by formula (12).

$$p = f + ktl . \tag{12}$$

f is the frame number when the data block was scheduled at the last time; l is the LOD level number which schedules the terrain block, higher resolution smaller level number. t is scheduling time interval, k is the frame number per second, and the smaller p is, the higher priority it should be deleted. To improvement original method, taking into account the priority of different resolutions data to be deleted and multiplying by factor kt are adopted. Then the viewpoint moves past, its rearward retains parts of data, which high resolution is close to the viewpoint and low resolution is far away.

V. EXPERIMENT RESULT

Experiment platform was OSGEarth [10]. Based on the class addTill, prediction function was realized. Two experiments were conducted.

A. Experiment I

A aircraft model was imported ,which traced at the speed of 300 m/s, scene was set to move with the aircraft, as shown in Fig. 10.

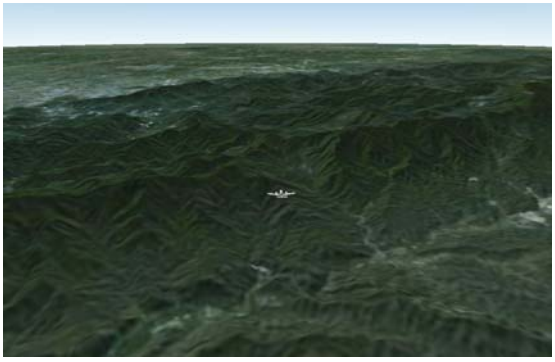

Figure 10. Simulation result

Experiments show that, [3] cannot predict the next viewpoint position accurately. It is needed to expand organization region so as to ensure the next required data is in organization range, which may lead to transfer much data from external memory to memory, exceed the hardware processing capability, and frames drop out. Kalman prediction is set up on state space, importing state variables, which describes the system dynamic information at a higher level. Our rendering data optimized organization strategy can accurately predict viewpoint, and effectively reduce the organized data amount. Theoretically, the reducing data amount can be calculated by the formula (13).

$$E = f(v \times c) . \tag{13}$$

As the case of 0.6 meters resolution terrain data and viewpoint movement speed 80m/s, it is able to save 18% resources. E is the saving ratio, v denotes viewpoint moving speed, and c is the organization data resolution.

B. Experiment II

Different redraw intervals were set and the impacts produced by data organization strategy were tested. The experiment results are shown in Table I,

TABLE I.

DIFFERENT STRATEGIES SIMULATION RESULTS

	Frame ratio (frame/second)	15	25	100
No optimized organization strategy	Task 1	Smooth	Relatively smooth	Frames drop out
	Task 2	Smooth	fluency	Relatively smooth
	Task 3	Smooth	Smooth	Relatively smooth
Adopt optimized organization strategy	Task 1	Smooth	Smooth	Relatively smooth
	Task 2	Smooth	Smooth	Smooth
	Task 3	Smooth	Smooth	Smooth

15 frames per second were adopted in experiments, which enabled users to feel the interaction and were the minimum display capability system required. 25 frames per second can achieve better real-time requirement, which were the scene rendering rate system required. Relatively smooth in Table Ⅰ means there were frames dropping out sometimes.

Task 1 showed viewpoint prediction and rendering data organization strategy made an obviously contribution to rendering efficiency. As high resolution terrain data was adopted, optimized organization strategy could meet the requirement of real-time smooth rendering, which is 25 frames per second.

Task 2 and task 3 were tracks in mountains, resolutions are 32 meter. Due to the low resolution, their data amounts were small and experiments visualized well; our strategy advantages could be shown at the ratio of 100 frames per second.

VI. SUMMARY

In the Visualization Navigation, the carrier position, such as aircraft, vehicles, is the viewpoint position, or there is a fixed function relationship. Therefore, the viewpoint positions can be obtained from the prediction of motion carrier tracks. Based on above considerations, the paper researched Kalman filter for track prediction, and applied it in rendering data organization. Experiments showed that the optimized organization strategy can improve rendering efficiency, especially at the high viewpoint movement speed. The proposed strategy can also be used in other relative areas, such as visual scene roaming.

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