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AN ADAPTIVE PREDICTION OF AIRCRAFT MOTION WITH THE ELEMENTS OF VIRTUAL REALITY

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Abstract—*The problem of adaptive method for predicting the aircraft state, which, by the dynamics control of the object, allows to reduce the load on the distributed network of virtual reality (with data consistency), while improving the accuracy of prediction the objects state, has been considered. The high-level protocol interaction approach let to organize interprocess communication network at a higher logical level, with less network loading, by supporting variable-length messaging and built-in mechanism the data replication control based on the principle "the election of consistency". Method develops to reach better the prediction of the object rotation and trajectory motion correction of the aircraft*

Index Terms—Graphics processing unit; multi-threaded; object state; adaptive motion control; wavelet analysis; replication, parallel computing.

I. INTRODUCTION

Taking into account the existing views on armed struggle in the world and the main ways of resolving armed conflicts, it is quite logical to conclude that the rate is on aviation, which is the main bearer of the military potential of the armed forces, and hence the unmanned aircraft that performs reconnaissance, shock, fighter, target, transport, repeater and many other functions without the risk of loss of flight composition.

One of the problematic issues for creating an operational tactical reconnaissance unmanned aerial vehicle (UAV) is to develop a rational architecture for its navigation system. Existing navigation complexes have properties that do not provide the possibility of operative change the flight tasks and they don't allow to provide group application. Therefore, it is actual scientific task to create an adaptive intellectual method for predicting the aircraft state for complex navigation equipment, which required for objects of this class.

The leading companies in the production of inertial navigation system (INS) of various types in the world are Sperry Marine, Litton Industries Inc., Honeywell, Zinger (USA), Sagem (France), Marconi-Elliott (UK), Litef (Germany), Ramenske Instrument Design Bureau (RPKB), Moscow Institute of Electromechanics and Automation (MIEA) and others [1].

These firms are engaged in the creation of the INS, mainly in three main directions: on three-step float gyroscopes (TFGs), on dynamically tuned gyroscopes (DTGs), and free-form INS – on laser gyroscopes (LG), fiber-optic gyroscopes (FOG) and solid-state vibrational gyroscopes (SVGs) [2].

Typical representatives of free-form inertial navigation system (FINS) are modular navigation systems MAPS, developed by American firms Honeywell and Zinger. These systems are used to determine the location and spatial orientation of various objects. The FINS MAPS includes an inertial-measuring block, a control and display unit. In addition to the aforementioned equipment, FINS MAPS of Zinger Company includes the equipment of consumers of satellite navigation systems, which significantly increases the accuracy of FINS. The basis of the inertial-measuring block consists of three identical RLGs and three accelerometers. The FINS inertia-measuring unit provides two modes of operation: self-orientation of the system and automatic determination of the current coordinates and spatial orientation of the object.

However, distributed virtual reality systems (DVRS), as a new step in the development of interactive 3D graphical applications, are allowing geographically distant users to interact in a three-dimensional virtual environment that they share in the same way as if they were in the same room.

Realism of the virtual world, which is obtained in such systems, depends on the quality of visualization, and on the established mechanisms of network interaction. These mechanisms should ensure consistent mapping of all virtual reality objects, helping to overcome the physical constraints of a particular network. At the present time, the architecture and mechanisms for ensuring the consistency of data in DVRS are developed and justified, which allow to reduce the influence of hardware network restrictions and the total load on the network due to flexible ways of control network traffic, taking into account the dynamics of objects motion.

II. Problem Statement

Taking into account limited possibilities of the existing navigation systems, where inertial navigation systems are widely used, due to their autonomy and satisfactory accuracy properties at limited time intervals, as well as the possibility of obtaining a complete vector of navigation parameters for solving control problems of aircraft, the use of which is associated with the disadvantages arising from the principle of their operation: the integration of measurements the accelerometers and gyroscopes for getting speed and coordinates of the aircraft due to the accumulation of errors defined navigation parameters.

It causes the use the non-inertial navigation equipment for correction accumulated errors and to develop the combined adaptive navigation system UAV, which will enable to improve the accuracy of determining the current coordinates of the location the UAV.

III. The Adaptive Prediction Method

At the present time, there are many different prediction methods [1] – [3]. The most promising are adaptive prediction methods, that dynamically vary the frequency of sending update messages in accordance with any criteria. For example, W. Cai et al. [1] suggest using as a criteria the distance between objects (the further objects are located from each other, the less often it is necessary to transfer data between them).

To increase network capacity, and to reduce the influence of latency on consistency of data in the network in all existing the DVRS applies various methods for predicting the state of objects [4]. Although the methods used make it possible to achieve good results, a more in-depth analysis shows that many questions still remain unresolved. So, the question of what is the optimal frequency sending data that not only reduces network traffic, but also to maintain the required consistency between users of the distributed system virtual reality. If the sending frequency is low, users will not be have reliable data on each other's actions. And, conversely, if too high frequency, some updates may turn out to be redundant, and bandwidth of the network will be used inefficiently.

Most the current methods used to predict the state of the objects are applies fixed parcel frequency. For example, as described in [5] multiplayer source game uses a fixed parcel frequency data set in the limit of 20–30 messages/s. In the developed adaptive method of replication and prediction of the state the object (Fig. 1) the frequency of the sending of update messages is used – messages are sent only as needed. For this method adjusts the frequency sending updates messages to the current parameters of the object's dynamics.

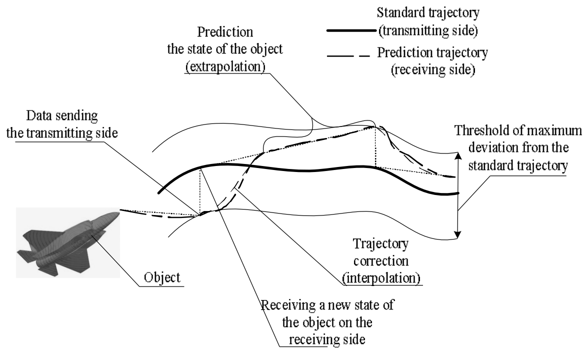

Fig. 1. Adaptive method of object replication and prediction

To determine the time when it is necessary to send another message an update is suggested to keep the prediction of the state of the object not only on the receiving side (to calculate the states of remote objects), but also on the transmitter (for the current client's own object). Change messages the status of a particular user object is sent only when the difference between the real and extrapolated states of the object on the transmitter side will exceed a certain predetermined value that can be called the threshold of maximum deviation.

The application of the adaptive approach is expected should give a more accurate account of the dynamics of motion object when reducing data exchanges between clients and saving the required accuracy of the prediction of the states of the objects corresponding to them.

The threshold of the maximum deviation, in the simplest case, can be given as the maximum distance between the predicted $r'(t)$ and real $r(t)$ trajectories of the Δs_{max} object motion. The distance between the trajectories Δs in an arbitrary the time instant t can be estimated as:

$$\Delta s = \max\left(\left|x'(t) - x(t)\right|, \left|y'(t) - y(t)\right|, \left|z'(t) - z(t)\right|\right). \quad (1)$$

In this approach the original trajectory of the object on the transmitting side and calculated at the receiver do not divide by a distance greater than the threshold set.

Even more reducing the frequency of sending an update message can be achieved by setting as the threshold for maximum deviation limiting the acceleration of the object on the transmitting side of $\Delta a_{\max}$. Change acceleration is calculated as:

$$\Delta a = \max\left(\left|a'_x(t) - a_x(t)\right|, \left|a'_y(t) - a_y(t)\right|, \left|a'_z(t) - a_z(t)\right|\right). \quad (2)$$

If the object moves with constant acceleration, messages updates are not transmitted at all, and quadratic extrapolation at the receiving side allows you to accurately predict the state of the object. Messages updates are only transmitted with changes in acceleration exceeding rejection threshold.

The maximum acceleration threshold is one key features of the developed adaptive prediction method. It is assumed, that, having selected a certain value of the threshold, it will be possible to achieve a reduction average frequency of sending data compared to the method with a fixed frequency parcels while maintaining the same accuracy (consistency)[4], [5].

When using the maximum acceleration threshold, consider that when the acceleration of an object does not change for a long time, it can accumulate significant prediction error, because there always exists a non- a large difference between the real accelerations $a(t)$ and the predicted $a^*(t)$.

To overcome the shortage in the method is set the maximum time between sending update messages, equal to 1 sec. If the update message is not is sent within a second, then a compulsory sending is made. Such approach should not greatly increase the generated traffic, and at the same time should will improve the accuracy of the method.

In current methods, little attention is paid to the question of how to predict the rotation of an object. The rotational motion is no less important than the translatory one. Errors in the translatory motion, the user can still not notice, but cutting turns object will precisely "cut the eye" and cause a feeling of discomfort (especially such turns are noticeable on the roll angle).

The maximum threshold proposed above acceleration deviation allows to remove errors of the translatory motion. Therefore, the method introduced one more threshold for the maximum deviation – limit change in the orientation angles of the object $\Delta R_{\max}$. Orientation setting objects are usually carried out using three angles: course (yaw), pitch ($pitch$) and roll ($roll$), also called the Euler angles. Changing the rotation angles is calculated as:

$$\Delta R = \max\begin{pmatrix} |yaw'(t) - yaw(t)|, |roll'(t) - roll(t)|, \\ |pitch'(t) - pitch(t)| \end{pmatrix} \quad (3)$$

A block diagram of the developed state prediction method is given in Figs 2 and 3. The algorithm of the developed method consists of two parts: transmitting side (used to determine when to send update messages) and receiving side (realizes itself prediction). Let's consider the work of the method in more detail.

On the transmitting side, before the method starts, the attributes of the object an explicit replication mechanism is introduced, assuming that serialization state will occur only if explicitly indicated. At each iteration of the work the client application calculates the real S and extrapolated S' state of the local object for the current time t. If the difference between these states exceeds a certain predetermined threshold of the maximum deviation $\Delta S_{\max}$ or has passed more than one second from the next sending of the data, the next update message is sent the server containing the real state of S at time t.

For simplicity, it is assumed that the condition $|S(t) - S'(t)| > \Delta S_{\max}$ includes itself as an examination of the excess of the maximum acceleration threshold, and the threshold for changing the angles of rotation. Then the time counter increases and the transition to the next cycle of modelling the local state object, on which everything repeats.

At the receiving side, at each iteration, it is checked whether the next update message from the server. If it is, the new state in beginning is recalculated taking into account the latency for the time instant $t_{send} + t_L$, after which is stored in a temporary buffer. Then the initial parameters correction step and its duration is set. Duration correction step is an important parameter and determines how quickly the error between the calculated and accepted states of the object is eliminated. If correction will be made too quickly, then the transition of the object from the old one to a new trajectory will be visible visually.

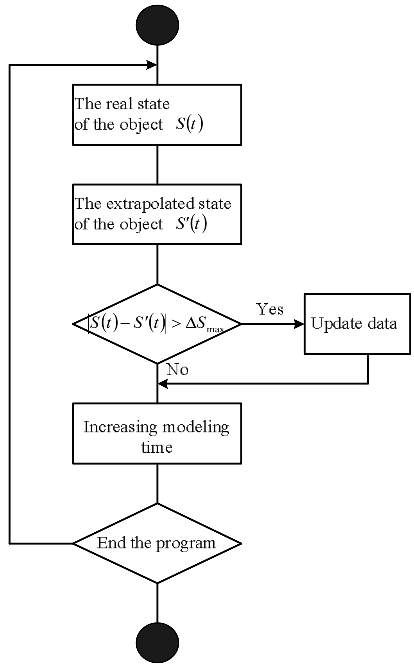

Fig. 2. The scheme of the developed adaptive method of prediction of the state of an object for the transmitting side

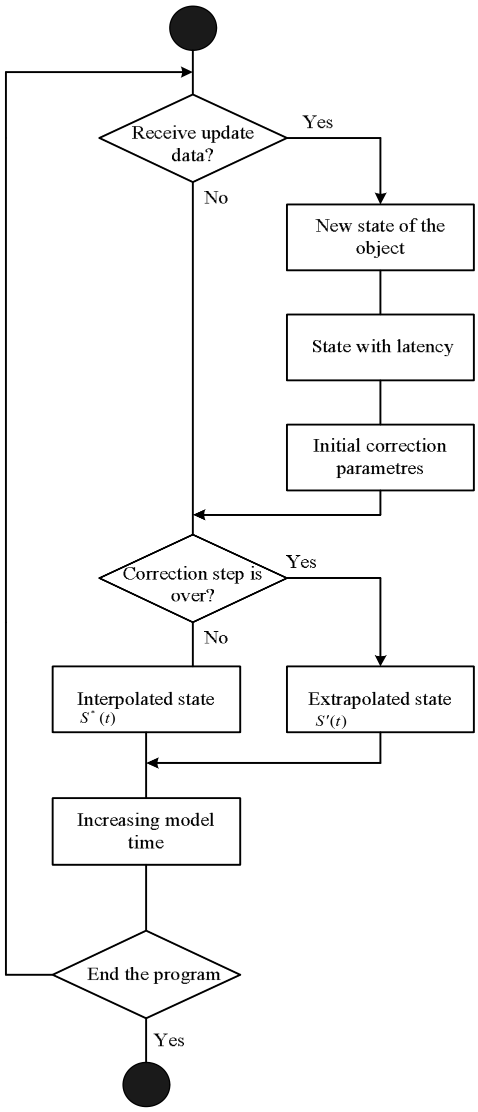

Fig. 3. The scheme of the developed adaptive method of prediction of the state of an object for the receiving side

In the current implementation, the correction time is set to $0.8T_{send}$, where T_{send} is the average data sending period for the last a few seconds (because the frequency of sending data varies). Time correction starts from the moment the data is received.

The next stage, regardless of whether the update message came, the new state of the object is calculated. If the time allotted for correction, has not yet expired, the state of the object is corrected from using one of the types of interpolation. Corrected as coordinates object (interpolation with the help of a cubic spline), as the angles of rotation (linear interpolation). If the correction time has already expired, the main step of the method is performed – the prediction of the state the object is performed on the basis of extrapolation (quadratic or linear). Then the time counter increases and a transition is made to the next iteration of the method, on which everything repeats at first.

IV. Estimation of Prediction Accuracy

The aim of the qualitative estimation the developed method was to establish the relationship between the level consistency of states the objects in various processes of the DVRS and the number of consumed network resources.

For numerical estimation of consistency, an average error was used in determining the distance between two objects ξ, and the average error in the determining the changes in the acceleration of the object δ.

As an estimate of the degree of consumption of network resources, the average bandwidth consumed by the object was used, which characterizes the average amount of network traffic generated per unit of time during replication state of the object. In this case, we took into account only useful traffic, those, the header of the packets of the downstream network layers (UDP, IP, etc.) in calculation were not accepted.

During the calculations was used [6], [7]:

– a replication mechanism with a fixed frequency, prediction of object states was disabled. It allows to define a pure relationship between the frequency of data replication and consistency (first line);

– the developed adaptive method of state prediction objects, and replication control was built into the method by the mechanism replication. It allows to estimate the effect of accounting dynamics and how the application of replication is affected by the condition (with variable frequency) on the consistency of interaction between two users (second line).

The technique of qualitative estimation of the developed mechanisms is as follows:

1) select two arbitrary objects, O_1 and O_2, which regulated by operator U_1 and U_2 respectively;

2) give the motion fixed trajectories of the two objects O_1 and O_2 (called reference trajectories);

3) select different sets of parameters, on which the experiment will be performed (for one line the set of frequencies for sending update messages is set, for other line, it varies the maximum acceleration threshold);

4) perform motion the objects O_1 and O_2 along the specified trajectories for each set of parameters of the selected line. In this case, the client application, that corresponds to the O_1 object, monitors and writes the trajectory of the object O_2, and the client application, that corresponding to the O_2, monitors and writes the trajectory of object O_1.

5) record on the server the average bandwidth transfer consumed by a single object;

6) estimate ξ and δ on the basis of the recorded and initial trajectories of the O_1 and O_2 objects and for each set of parameters the selected line;

7) build graphs of the dependence the estimating parameters ξ and δ on the total consumed two traffic objects;

8) repeat steps 4–7 for all the research lines;

9) made a conclusion about the expediency application of the line for a given bandwidth transfer.

As a result of the series the experiments performed for two lines (for different operating modes), the values of the estimates ξ, δ, μ are given in Tables I and II. The mode of operation in one line was determined by the period of sending messages update (in ms), and the mode of operation in other line was determined by the maximum threshold acceleration deviations (in internal units of virtual reality). The estimation of δ was calculated on the basis of the acceleration of the object O_1, and estimation of μ was calculated based on the acceleration of the object O_2.

TABLE I. ESTIMATION OF PREDICTION ACCURACY ξ, δ, μ (FIRST LINE)

The period of sending a message / update, ms	Required bandwidth transfer, KB/s	ξ, amount	δ, %	μ, %
95	1.9754	0.61587	0.66313	1.98476
135	1.0828	0.63292	0,95612	2.23407
190	0.8949	0.65771	2.2738	2.86688
290	0.6308	0.67531	2.86276	4.70206
310	0.6862	0.66786	4.43718	4.63425
400	0.4898	0.68192	4.76428	7.8287
440	0.5768	0.65962	7.12756	7.08085
560	0.2838	0.69239	8.22718	8.99112

TABLE II. ESTIMATION OF PREDICTION ACCURACY ξ, δ, μ (SECOND LINE)

Deviation by Acceleration, unit	Required bandwidth transfer, KB/s	ξ, amount	δ, %	μ, %
0.001	1.9114	0.64767	1.13869	1.71459
0.01	1.3156	0.6423	1.28341	1.93991
0.5	1.049	0.6575	1.15482	2.25645
0.7	0.7962	0.6244	1.31876	2.3868
1	0.6502	0.6418	2.0227	2.4579
4	0.2989	0.6597	2.82337	2.51786
7	0.2342	0.6934	5.78066	7.38516
12	0.1947	0.6855	8.2873	11.1137

In Fig. 4 shows the graph of the dependence the estimate of the object O_1 on the average consumed by a single object of bandwidth transfer. Adaptive method provides a smaller error with the incoming traffic 0.2 KB/s.

It confirm that taking into account the dynamics of the motion of the object allows to achieve greater consistency even for small values consumed by the object bandwidth transfer.

Due to the lack of a change tracking mechanism acceleration without adaptive prediction in Fig. 4 there is a characteristic shift in the graph acceleration on the object side O_2 relative to the original plot on the object side O_1, which, in the final analysis, can lead to a greater error in the calculation of the state object O_1. Adaptive method, by contrast, better tracks bursts of acceleration.

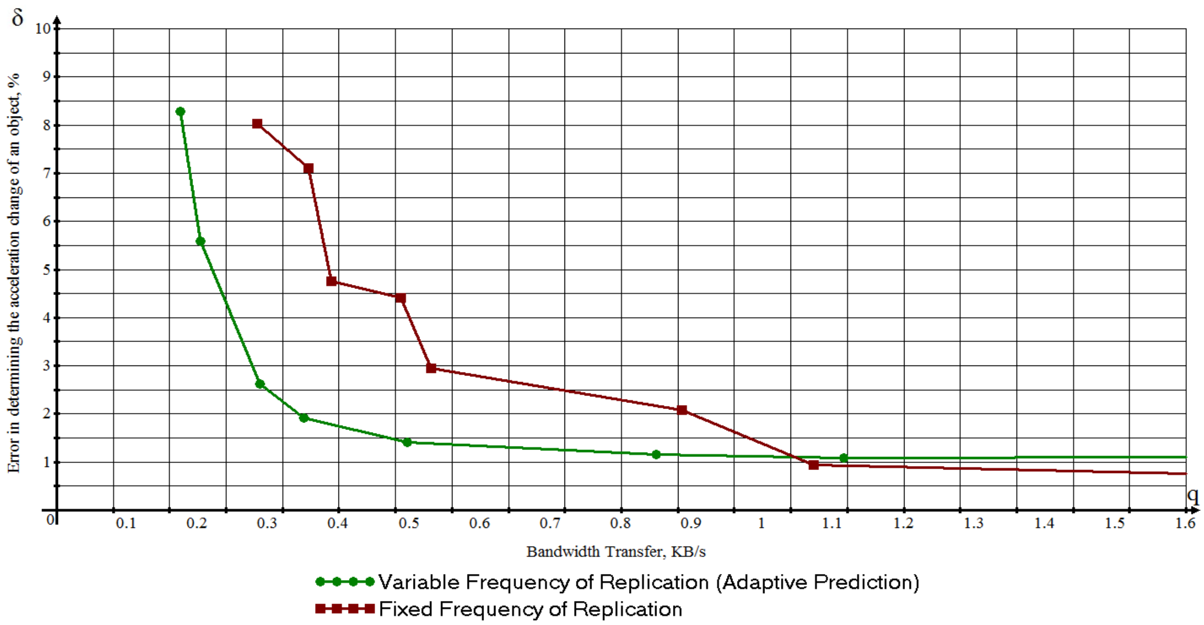

Fig. 4. The dependence estimation of the object motion

This fact confirms the effectiveness of the developed adaptive prediction method state of the object, and also shows the positive effect of accounting for the dynamics object motion during replication.

V. CONCLUSIONS

Mechanisms for ensuring data consistency in the DVRS have been developed and justified, in the case of adaptive method of prediction the state of the object, allowing due to the dynamics of the object motion, reduce the load on the network with a simultaneous increase in the accuracy of prediction the states of objects.

Thus, the developed adaptive method for predicting the aircraft has the following distinctive features:

– variation in the frequency of sending update messages and application as the criterion for sending update threshold messages by acceleration;

– prediction the object rotation using linear interpolation;

– use the second-order Taylor polynomial for prediction state of objects;

– correction the trajectory of the objects motion with the help of cubic splines.

A technique for qualitative estimation the network mechanisms was developed, allowing to establish the relationship between the consistency of states objects in various processes of the DVRS and the number of consumed network resources:

– the increase in the frequency of replication of object states, which conduce to decreases the error in the calculation of the states of remote objects, and to increase the consistency.

– the same consumption network traffic, accounting for the dynamics of the object motion during replication, with use of the developed adaptive prediction method, allows for greater consistency than with the use of standard mechanisms of replication with a fixed frequency.

– during the average traffic from one user equal to 1.1 KB/s while maintaining a sufficiently high level of consistency ($\xi = 0.6$ object cores and $\delta = 1\%$), up to 90 users can simultaneously connect to the system.

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С. С. Товкач, А. А. Романовська. Адаптивне прогнозування руху повітряного судна з елементами віртуальної реальності

Розглянуто адаптивний метод прогнозування стану повітряного судна, який за допомогою управління динамікою об'єкта дозволяє знизити навантаження на розподілену мережу віртуальної реальності (із узгодженням даних), одночасно підвищуючи точність прогнозування стану об'єктів. Підхід до високорівневої протокольної взаємодії

дозволив організувати міжпроцесорну комунікаційну мережу на більш високому логічному рівні з меншим навантаженням на мережу, підтримуючи обмін повідомленнями змінної довжини і вбудований механізм керування реплікацією даних на основі принципу «вибору узгодженості». Метод розвивається для досягнення кращого прогнозування повороту об'єкта і корекції траєкторії руху повітряного судна.
Ключові слова: графічний процесор; багатопоточність; стан об'єкта; адаптивна система управління рухом; вейвлет-аналіз; реплікація, паралельні обчислення.

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С. С. Товкач, А. А. Романовськая. Адаптивное прогнозирование движения воздушного судна с элементами виртуальной реальности

Рассмотрен адаптивный метод прогнозирования состояния воздушного судна, который посредством управления динамикой объекта позволяет снизить нагрузку на распределенную сеть виртуальной реальности (с согласованностью данных), одновременно повышая точность прогнозирования состояния объектов. Подход к высокоуровневому протокольному взаимодействию позволил организовать межпроцессорную коммуникационную сеть на более высоком логическом уровне с меньшей нагрузкой на сеть, поддерживая обмен сообщениями переменной длины и встроенный механизм управления репликацией данных на основе принципа «выбора согласованности». Метод развивается для достижения лучшего предсказания поворота объекта и коррекции траектории движения воздушного судна.
Ключевые слова: графический процессор; многопоточность; состояние объекта; адаптивное управление движением; вейвлет-анализ; репликация, параллельные вычисления.

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