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DEVELOPMENT OF LOW-COST VIRTUAL REALITY SYSTEMS BASED ON REAL SITES AND OBJECTS 3D MODELS

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ABSTRACT

Perspective direction of development in the area of information and training systems is virtual reality (VR) – multimedia human-computer interface, which allows transmission of visual, audio and other data components to user in natural way. In VR systems 3D environment is created due to use of specially equipped computer running VR application. As the result of our VR application development and testing we found out that use of 3D models based on real data provides several significant advantages. Developed approach uses various sources of raw and preprocessed data for VR environment creation and is oriented at use of low-cost hardware. Developed method was applied in various commercial projects and R&D works.

1. INTRODUCTION

Traditionally specializations of our institute were mathematical modeling, data processing, automatic control systems and test-bed design in the field of aviation. Newest computer technologies such as virtual reality enable us to implement knowledge and experience in the new sphere – simulation trainers, human-computer interfaces and other commercial VR applications. For the last several years we developed a whole series of VR-related projects. Among them are:

- distributed flight simulator;
- driving simulator for urban transport;
- decision-making support system in the area of maintenance and reconstruction management;
- simulation trainers for shoulder-mounted rocket-launcher;
- 3D human-computer interfaces.

Distinctive feature of all our projects is orientation towards low-cost hardware platforms and preferred usage of real data for landscapes and objects 3D models.

1.1 Why low-cost?

We consider that progress in the field of hardware and software (CPUs, graphic accelerators, graphical APIs and SDKs) provides VR system developers with sufficient and affordable tools for their work. On the other hand cost is crucial for commercial VR-based product. According to our marketing analysis low-cost VR system is preferable to high-cost one even if it's performance specifications differ from maximum possible level of high-end systems (for example, graphics runs in lower screen resolution, lower color depth, lack of some visual effects). Also developed method utilizes various input data sources so we can choose the most appropriate data acquisition method in accordance to cost-efficiency criterion.

1.2 Why use real data?

The main objective of VR system design is to reach immersion effect and interactive feedback when VR is controlled by user behavior. Information field formed during VR simulation is intended for concentration of user attention at subject of his work while blocking out annoying and abstractive factors. Immersion concept is very complex and ambiguous. On the one hand VR world created for user must be as real as possible in order not to cause user's distrust. On the other hand excessive detail must be avoided in order to prevent undesirable users distraction. Basing on our experience in VR system development we consider VR world realism to be trade-off between image likelihood and frame rate. Thus the main task is to increase image likelihood taking minimum permissible frame rate as a limit (about 30 frames per second). We presume that real data use serves this purpose. Also as the result of our VR application development and testing we found out that use of 3D models based on real data provides following advantages:

- in training simulators it enables not only training for specific actions but also for actions in specific environment (for example, driving simulator based on real city 3D model teaches trainee not only driving skills but also city street layout);
- ability to evaluate result of decision made in the field of reconstruction and landscape planning by means of fly by and walkthrough;
- intuitive 3D interface for water and power supply lines construction/reconstruction planning systems;
- additional feature of visual target recognition training for various types of gunnery simulation trainers.

2. REAL DATA EXSTRACTION AND IMPLEMENTATION TECHNOLOGY

There are lots of real data sources (both raw and preprocess) on landscapes, natural and human-made objects. As a source of raw data we commonly use air/space photos and radiometric measurements. Photogrammetric data processing is accomplished by one of our institute divisions. And as for preprocessed data sources we apply digital elevation maps, GIS data, architectural blue prints and technical drawings. While being able to use data from any GIS we mostly apply data from domestic GIS software package "Panorama". Because it's very complex to elaborate one unified approach to real data processing and application we customize our method to meet requirements of specific task and available input data. It'll be explained taking our certain projects as examples.

2.1 Distributed flight simulator

The main objective of this project was to create distributed flight simulator containing several pilot trainers, flight control center simulator, several simulation trainers with simplified control for beginners and live participants (real aircrafts with special equipment). Because live and simulated participants have to operate in common mission environment landscape model for trainers must correspond to real relief of flight zone. Originally it was supposed to use results of photogrammetric processing of air photos but subcontractor failed to provide sufficient quality air photos. So we were forced to use alternative data source such as digital elevation maps from GIS "Panorama". In order to automate development process and thus make it more effective we created special plug-in module for 3D modeling and editing software we use (3DStudio MAX R2). It utilizes modified Delaunay triangulation algorithm to convert elevation data stored in internal GIS format MTW to 3D models in 3DS format. Developed plug-in provides generation of levels of detail (LODs) by means of varying elevation matrix processing step with appropriate height drop approximation. As a substitution of lacking photo textures we applied self-developed texture generation method. It consists of following steps:

- extraction of terrain features (forests, rivers, roads and etc.) contours from GIS data;
- selection of terrain feature textures (ortho-photos of water, forest, pavement and etc. surface fragments) from our photo texture database;
- texture fragment filling to corresponding feature contours;
- whole image filtering for edge smoothing.

Under the circumstances this method is the only one to provide photo realistic texture map for surface model. Also it simplifies texture map creation for LODs with distinctive feature preservation (because terrain feature description is stored and processed in vector format which can be scaled without distortions unlike raster ortho-photo).

At lowest level of detail natural and human-made objects are represented by texture. 3D models built by shape extrusion represent them at higher level of detail. For these shapes we use vectorized objects outlines obtained from GIS and architectural drafts, which are needed for airfield model. Objects, critical for visual navigation during low and medium altitude flight (for example, rivers, lakes, rail roads, towns and etc.), are represented by 3D models with more levels of detail than surface model. This approach provides correct image generation and smooth LOD switching. As a quality test for resulting virtual environment we invited expert pilot with significant experience of flight in this zone. He verified realism and likelihood of image generated by our flight simulator (figure 1).

Figure 1. Image, generated by our flight simulator.

2.2 Urban modeling for driving simulator

Driving simulator being developed on demand of Moscow city administration is aimed at urban transport driver training. In huge city such as Moscow urban transport driver must have not only high professional skills but also possess intimate knowledge of city street layout. Therefore image generated by simulation trainer visualization system must depict real city with high level of realism. Thus our urban modeling is based on real data. Our institute division dealing with mapmaking provides us with preprocessed data - detail city plan in electronic format (specifically, multi-layer CAD vector format - DWG). Each layer contains its own data, for example layer one contains data on buildings sizes and placements, level two – roads and pavements geometry, level three – large trees and lawns placements and so on. Because we were to create scene 3D model for driving simulator we modeled only those urban objects, which can be seen from streets. In order to create texture maps for buildings models we used two methods: texture generation similar to previously described and direct photo texturing. First method is applied for models of typical buildings, which are common to new districts of Moscow. Second method is preferable for buildings with rare and unique architecture. Often it is very difficult to take a photograph of desired building in ortho-projection due to narrow and curve streets and various blocking objects such as advertisement hoardings, people, cars, trees and etc. So we applied several image processing methods such as perspective correction, noise reduction, undesired fragment removal and image reconstruction. Most of texture preparation and mapping procedures are executed manually with the help of common graphics editors such as Adobe PhotoShop, Corel PhotoPaint and 3DStudio MAX. But currently we are working on their automation by means special scripts and plug-ins for graphics editors we use.

2.3 Buildings models with interiors and communications.

One of our internal projects was development of decision-making support system in the area of maintenance and reconstruction management of our institute buildings. Our institute is allocated in more than three dozens of buildings, which were built non-simultaneously during the period of fifty years. Many buildings are connected with each other by passages. As the result of this communication infrastructure (power supply lines, sanitation, heating, phone and network cables) became very complex. In order to facilitate maintenance and reconstruction management it was necessary to create information system containing all data concerning this matter (architectural blueprints, technical drawings, power lines layouts and etc.). Effectiveness of such a system greatly depends on user-friendly interface. As the result of our research in the field of human-computer interfaces we carried out that 3D immersive interface based on buildings

models is one of most suitable for such kind of information system. Such kind of interface provides much more information on the display screen for user than traditional 2D methods.

As it was said before base of 3D interface for decision-making support system in the area of maintenance and reconstruction management has to be formed by 3D models of our institute buildings with all needed infrastructure. All input data for modeling process was represented by set of architectural drawings and blueprints in hard copies (on paper). There were no data in CAD or other electronic format contrary to the situation with driving simulator project. So whole process of 3D modeling was fulfilled in following consequent steps:

- drawings and blueprints scanning and filtering of resulting images;
- vectorization and correction of images;
- creation of wireframe models;
- texture generation based on photo texture libraries;
- texture mapping;
- optimization of resulting models.

All power supply lines, sanitation, heating, phone and network cables are stored in internal database as 3D graphs and graphically are represented as colored 3D lines with corresponding thickness and geometry.

User can navigate 3D scene by means of various devices: head-mounted display, stereo glasses or ordinary hi-resolution display with help of 3D isometric controller (Logitech Magellan), sensor glove (5DT Glove), joystick and mouse or just standard mouse and keyboard. Such a variety in display and controller options provides flexibility of interface customization in order to meet end-user requirements. Also it simplifies access for users with common workstations through local network. User can switch between several types of navigation (free flight, axis rotation, walkthrough) and view modes (textured, wireframe, communication lines exposed) (figure 2).
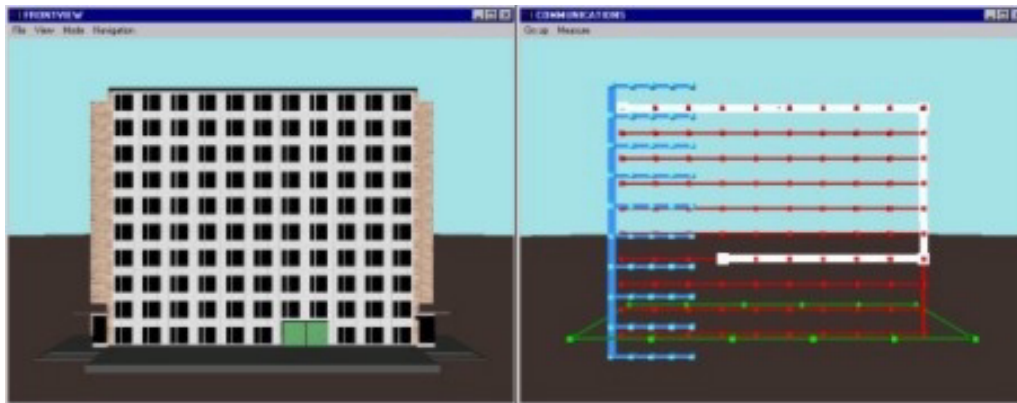

Figure 2. Different view modes: external (left) and communication lines exposed (right).

Most of elements of 3d model are interactive and provide some specific data when selected. User can measure distances, floorspaces, areas, communication line lengths and etc., also user can access some building specific data such as date of construction, dates of all reconstruction and repairs, construction materials and etc. Also in order to facilitate decision making in the field of new communication lines construction our software package incorporates several optimization algorithms: "the shortest route", "minimum construction costs", "minimum reconstruction of building needed".

Created 3D model of institute buildings was also applied in application, which help in external security surveillance cameras placement planning. User can create virtual camera and customize it position, orientation, optical characteristics and movement trajectory (if needed). After that he can view image, which will be produced by such camera (figure 3).

Figure 3. Screenshots from security surveillance cameras placement program.

2.4 Shoulder mounted rocket launcher training simulators

Research and development for this project at first stage was sponsored, in part, by office of training of Russian Federation Land Forces. Originally objective was to create simulation trainer for single-shot grenade launcher with incendiary charge. High cost of charge and specific technique of use call forth importance of creation of simulation trainer suitable for training soldiers to high level of skills without need of use of real launchers for shooting practice.

Prototype of simulation trainer was created basing on VR technologies and utilizing high-resolution head mounted display with precise tracking system and real size launcher dummy. Later research and development were carried out as an internal project. It resulted in creation of simulation trainer for shoulder launched air-defense missile system.

Both simulation trainers have import scene feature, which provides ability to train weapon operator to act in specific environment. For example it is possible to train for ambush at specific locality or to protect specific object from enemy helicopters and aircrafts.

Distinctive features of our simulation trainer:

- Skill level obtained by use of our simulation trainer permits to reject real launches from training process and use them only for tests and exams.
- Training for all phases of weapon use (arming, searching for target, aiming and launch).
- Still and moving targets, realistic appearance and maneuvers.
- Various environment conditions (time of the day, lightning, weather effects and fog).

In order to provide 3D models of landscape together with buildings, trees and etc. we apply technologies similar to one of described above. In case of grenade launcher simulator it is very important to have precise relief model with buildings and trees with realistic ratio because all distance measurements are by done weapon operator by means of visual perspective distortion estimation. Thus high resolution air photos or preprocessed GIS data are preferable as input data for 3D modeling.

Figure 4. Samples of images generated in shoulder launched air-defense missile system simulation trainer (countryside and urban scenes).

3. OTHER VR RELATED PROJECTS AND RESEARCH

3.1 Human-computer interfaces

Our current research in the field of human-computer interfaces utilizes newest computer graphics technologies and bases on considerable experience in the field of automatic control systems. Among others we emphasize following projects:

- 3D interface for data retrieval system;
- test-bed for research of new 3D human-computer interfaces;
- real-time human face 3D animation .

We consider interface for data retrieval system to be one of the main applications of 3D graphics based interface. In comparison with traditional 2D representation, based on lists, 3D interface is able to display much more information in a single image. We are currently working on interface prototype based on representation of found documents as 3D objects. Each object's position, size, shape, color, pattern of movement (still, spin, pulsate and etc.) corresponds to different document characteristic such as type, size, date of creation, how many times keywords were met and etc. Also cross references and interdependences or even timeline can be shown by means of colored 3D lines, connecting document corresponding objects. User can navigate virtual 3D space, filled with document-corresponding objects using 3D isometric controller or just standard mouse to rotate, zoom and reorganize (user can control sorting, filtering and representation processes). Each 3D object when selected provides in floating text window extensive data on corresponding document.   We are planning to apply this interface in different data retrieval systems from Internet to electronic document archives.

Another application of 3D interface is remote control systems for manipulators, robots, space station docking systems and etc. In order to evaluate impact of various control methods and image representation technologies on control effectiveness and accuracy we created computer-based test-bed.   It simulates control process of several dynamic objects, moving in 3D space. It is possible to simulate various trajectories and types of movement for target objects and various transfer and control functions for operated object. Main task for operator is to merge controlled object with moving target object. Operator can use various input devices such as 6DOF isometric controllers, 6DOF isotonic tracking systems, several types of joysticks and control pads, common mouse and keyboard. Also various display options are supported: head mounted display, stereo shatter glasses, stereo red/blue glasses and common monitor in various resolution/frequency modes. Test-bed has its own database where all test results are stored for subsequent statistical analysis.

Our latest initiative in the field of 3D interfaces was real-time human face 3D animation project (figure 5). It's a part of system, which is based on automatic real-time human face expression and orientation recognition. User of this system can communicate in real time using animated 3D avatar to represent him in virtual environment. It has many potential applications from Internet 3D based chats and WEB TV to distant learning and multiplayer computer games.

Figure 5. Screenshots of different phases of face animation.

3.2 Distributed simulation and landscape 3D models for shared virtual environments

One of our main research areas in the field of virtual reality applications and training simulators is distributed simulation. As for architecture we currently apply High Level Architecture, but also we develop our own architecture, oriented mostly at human-in-loop training simulators. It will have HLA wrapper, so there are no compatibility problems. Our distributed simulation technology is suitable for simulators connected by local IP-networks and work faster than HLA. However performance advantage is considerable only if number of simulators does not exceed several dozens. Above this limit HLA is preferable.

Figure 6. Screenshots of networking simulators: helicopter simulator (top left), tank simulator (top right) and simulation manager (bottom).

Whenever we use HLA or our own architecture we encountered same problem – rapid distribution of landscape and dynamic object 3D models among distributed simulation participants. So we are currently working on special data base structure and file format to provide quick data extraction on centralized demand of simulation management program and delivery to all participants. We found out that traditional 3D formats and databases to be inefficient. Our idea is to use multi-level matrixes to store vertex coordinates and textures with mapping coordinates.

3.3 3D models simplification and optimization.

Real-time rendering itself requires optimization of 3D models in order to achieve satisfactory frame rate. Additional importance of optimization and simplification in our case is conditioned by hardware characteristics. In our projects we

orient at low-cost PC based platform, so there are   active constraints on polygon amount and texture memory size used.

We apply several methods, which can help to increase performance:

- various modified level-of-detail techniques;
- use of different models for image generation and calculations with different resolution;
- "feature by texture" and "texture by feature" techniques.

We developed several application-specific variations of traditional LOD technique. First is Flight Parameters Dependent LOD (FPD LOD). We apply this method in flight simulator for landscape model in order to achieve more realistic image generation. FPD LOD is based not only on measurement of distance between viewpoint and object, flight speed (for interim LOD nodes skipping) and altitude (for precise LOD switching timing) are also taken into account. In addition FPD LOD affects not only one region of landscape model but also all neighboring regions.

Another LOD technique modification we developed is LOD for fast moving dynamic objects (mainly we use it for aircraft and helicopter models, but also it is also applicable for car models in driving simulator). Main difference from traditional LOD is following. In traditional method when LOD switches whole model of aircraft is replaced by another. Our method is based on combination of invariable model distinctive features (shape of wing and empennage) supplemented by models of fuselage, cockpit and weapons with several LOD nodes. Such approach provides LOD switching without sudden changes in aircraft appearance with assured preservation of all distinctive features at all distances. Invited experts (air force pilots) verified image generated with our method to be more realistic than image generated with traditional whole model LOD scheme.

In addition to LOD nodes technique we use following method of multi-resolution representation of landscapes. 3D model which is used for image rendering has lower resolution than one used as input data for various algorithms such as simulations of range-finder, radar and so on. Same approach is used in driving simulator - for example tram-lines railing or block pavements are simulated by texture for image generation purposes and for car dynamics module they are represented as corresponding bump maps.

"Feature by texture" and "texture by feature" techniques come into play when we have to create application to be run on specific hardware platform.   Some graphics cards accelerate texture mapping and transformation better than geometry transformation, others on the contrary – handle geometry better than textures. Also one must take into account maximum texture memory size available. So we developed special techniques of 3D modeling which provides ability to represent object features by means of textures and vice versa without loss of realism. "Feature by texture" techniques are based on special prerendered shadowed textures (we use 3DStudio MAX to render highly detailed 3D models and then apply parts of resulting image as textures for low resolution models, used for real-time rendering).

4. CONCLUSION

Our vision of commercial VR application development based on our experience in this field is the following: low-cost solutions are suitable for most simulation and interface tasks and attractive for wide range of potential users especially by their affordability. Additional advantages for such VR applications can be provided by use of real data. So it is very important to develop techniques to process and apply various types of source data.