Flexible Framework Technology in Visual Simulation System of Decoy

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Abstract
In order to fit diversified military simulation requirement, we propose a common visual simulation framework based on flexible architecture, which includes hierarchical structure design, model combined theory and decoy modeling method. Firstly, flexible architecture is given about framework design method, flexible interface design rule, modeling standards, library manage standards. Secondly, model is divided into base library, combined model library, application model library. The base modeling method of decoys is discussed, which 3D model is built by Creator, mathematical model of movement is built by stress analysis, special effects of interference is simulated with particle system. Then making chaff as an example, the modeling process is discussed in details. Finally an entire visual simulation demo system of decoy is implemented. The result shows that output image is realistic and good real-time, and proves flexible framework technology and modeling method could improve model utilization and system versatility.
Key words: FLEXIBLE FRAMEWORK, VISUAL SIMULATION, MODEL TECHNOLOGY, PARTICLE SYSTEM

1. Introduction

Nowadays all kinds of decoy become an important method in modern complex war, visual simulation of different interference appears usual in confrontation simulation. For current popular visual software development tools include simple special effects without professional toolkit of decoy[1]. Usually researchers use OpenGL and Vega to develop the decoy visual simulation in direction, but the system is limited in respective area lacking of general applicability [2-3]. Technically the framework of system needs a flexible architecture with which open hierarchy, function module and combined model, etc.

The flexible architecture and visualization method of decoy visual simulation system are applicable to different combat simulation system, which providing fast development service for

diversified scenario[4]. It adopts open framework and fast scheduling simulation, which is convenience to different simulation system and helpful to professional development and scientific management, apply in variety of environment models, decoy models and other 3D model.

2. The overall design of decoy visual simulation system

2.1 System component

The visual simulation system of decoy is researched in 3D visual technology, which is designed for combat progress in land, sea and air. It not only achieves complete period of passive decoy changing and active decoy interference, but also realizes 3D realistic simulation of combat environment and an entity model.

The visual simulation system contains: natural environment model, weapon entity model, decoy model, visual drive, element library schedule, viewpoint management, etc. shown in Figure1. Thereto, natural environment model means sea surface, underwater, sky and light model, weapon entity model means ship, aircraft and underwater vehicle 3D model, decoy model contains variety of passive and active interference, which passive interference contains multi-band chaff flares, infrared imaging decoy, broadband smoke flares, infrared stealth device flares, IR / MMW flares, glare confuse, passive radar, and active decoy includes acoustic interference, floating active communication, wake homing torpedo, drag active, communication jammer shells, rockets interference, radar active, etc.[5-6]

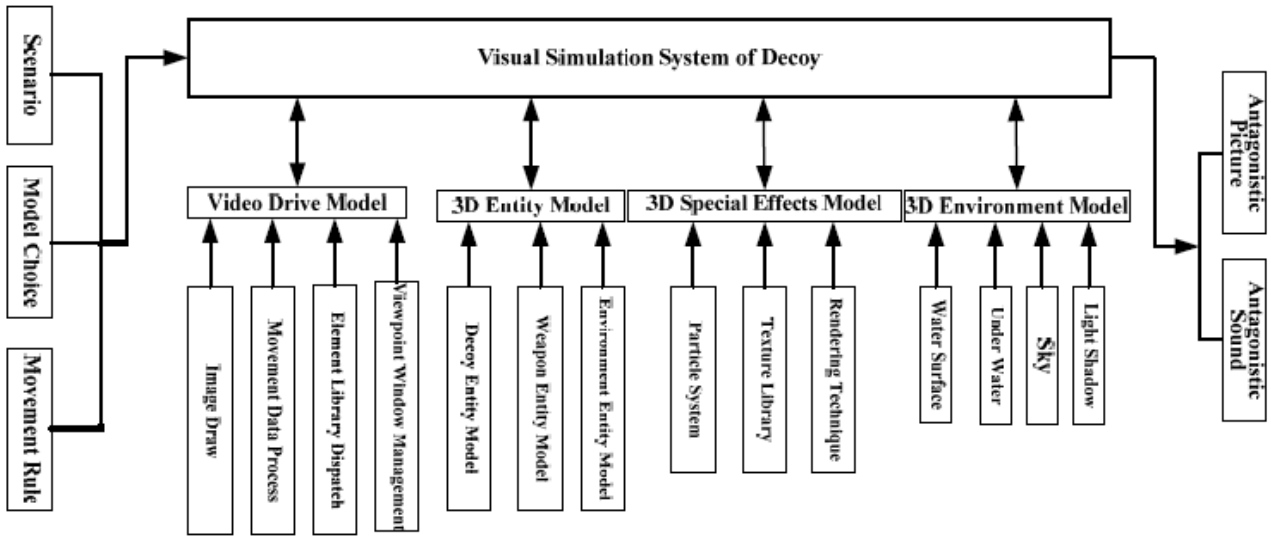


Figure 1. System component of decoy visual simulation

2.2 System framework

Visual simulation system of decoy contains video drive, 3D environment model, entity model, and decoy entity, special effect, input and output section, as shown in figure 2. Video drive contains against movement processing, 3D image drawing, element library dispatching, viewpoint and window managing. 3D environment model contains water surface, underwater, sky, light, shadow and terrain environment. Equipment entity model includes surface ship, aircraft and underwater vehicle 3D model. Decoy bomb model includes chaff, infrared, smoke ball, underwater decoy 3D model with unexploded. Special effect model includes the whole period affecting from transmitter, diffusion to demise of decoy, that related technologies involve particle system, texture library and rendering technique. Input section refers to combat scenario of red and blue, confrontation environment, weapons, movement planning initially. Output section refers to a realistic picture and sound finally.

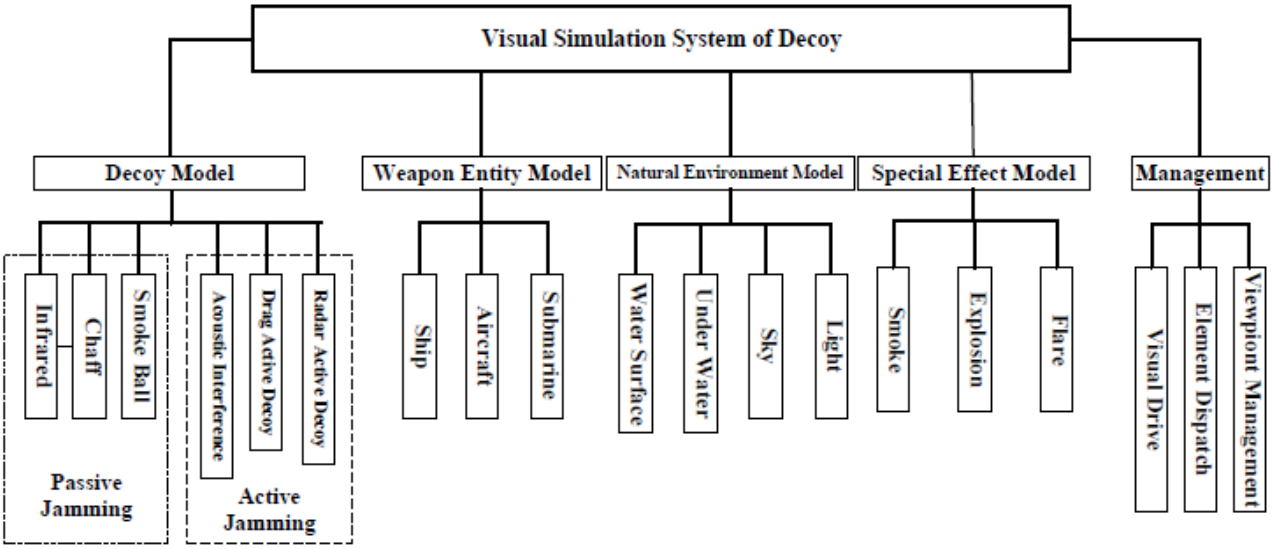


Figure 2. Framework of decoy visual simulation

3. Flexible framework design of visual simulation system

3.1 Flexible simulation framework

Flexible modeling method includes model structure, flexible interface, relationship between models, model hierarchy and component library management [7]. Simulation framework built by flexible configuration is not only to encapsulate new model from different modeling systems, which help to reuse and management, but also facilitate hierarchical development. The standard of flexibility design of decoy visual simulation system is as follows:

1) Framework of model structure is variable, that would compatible with isomeric structure, accommodate different types of model, and have high adaptation and scalability.

2) System has a hierarchical structure, each layer contains some models, model is reusability and composability, and model can be combined by interface, while layer can also be coupled through interface.

3) Interface of model is flexible, several models can be repackaged into a new derivative model, which is independence and reusability same as primary model.

4) Model component library is unified managing and scheduling all the models, which is helpful for hierarchical integration and secondary development of model.

The flexible framework of decoy visual simulation system is designed to hierarchical structure, system builders could be carried with top-down or bottom-up. According to the function, the model is divided into three categories: primary model, combined model and platform model, each model has a high degree of autocorrelation and weak coupled, model can related horizontal or vertical correlation interactively, as shown in figure 3. Framework includes primary model component library, combined model component library, platform specific model library, model instance library, simulation control management, model scheduling and management.

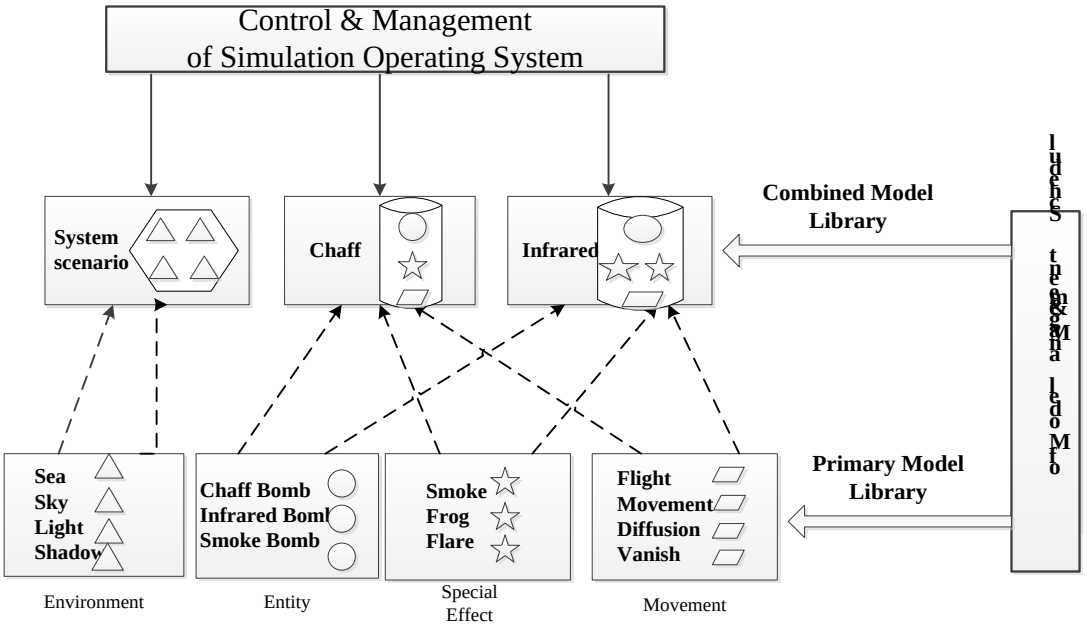


Figure 3. Flexible framework of decoy visual simulation system

The primary model means that the original model established by basic concepts, which is the basic elements composed system model. Based on particle system and rendering technique, the special effect model is like particle effects model of chaff slim, fire model of infrared, smoke model of smoke ball. Base on physical characteristics of the movement objects, mathematical model is established, such as random diffusion movement model of chaff slim in the air, trajectory model of infrared air-launched, diffusion motion model of smoke ball. Environment model established for realistic, such as water surface, underwater, land, light, sky and so on. 3D model is build by modeling tools, as chaff, smoke, infrared and other ball. These primary models can be combined to different decoy complete model, carry on variety equipments and apply in different conditions [8]. When the primary model need to re-dispatch, it just needs to schedule flexible interface and put into application parameters, then it can achieve special effect model of chaff slim being called by different bomb.

Combined model refers to the new model derived by some primary models and compound models. It is packaged as one model designed with flexible interface, which can be controlled and managed directly. For example, a complete chaff model requires ball entity model, chaff slim special effect model, movement physical models and other primary model, that are unified managed and called, encapsulated to a new compound model with flexible interface[9-10]. When the simulation system calls a chaff model, it is only need to enter some parameters as position, height, launch initial velocity, pitch angle, yaw angle and so on, then there would be obtained the complete simulation process from the chaff launch, diffusion to demise. Platform model means a certain setting for particular system, which is closely related to a particular system, such as initialization and scenario.

3.2 Model library management

3D model library requires scalability, so it should obey a uniform standard to build model on nomenclature, original position, orientation, scale units, LOD levels and other aspects, etc. By unified modeling, it can achieve the functions of rank of detail, polygon cut, drawing priority. At the same time, the proportion size of 3D model should be consistence with the actual, and have same detail level and same real-time capabilities. Thus the observation effect would met, the system running burden would minimize also.

Rules of unified modeling are:

1) unity of the original entity size;
unity of the LOD hierarchical standard;

2) unity of the coordinate system, all the models are established by the right-hand system, that the original coordinate is the geometric center of the model, x axis points to width direction, y axis points to head direction, z axis points to height direction;

3) unity of the model resolution.

According to unified administration, the unified standards for the model library are:

1) unity of naming rules, the name of model file is composed by letters and numbers;

2) unity of texture format, model image is processed by image software to convert Creator

texture format and make appropriate adjustments.

3.3 Database library management

In the decoy entity model library, 3D model library, component library and texture library are stored as files to be called with open architecture design, these files in the database are set up information field of name, storage path, creation date and others. When it is called by system, the data source is matched with the field. The field operation by database mainly includes: query, delete, increase and other movements, while the data source operation by database mainly includes: queries, load, store, add, delete and other movements.

3D model library database can be designed to model library, element library and textures library, etc., which the libraries have open architecture and dynamic changes, so it can ford add, delete and modify, the functions are as the following [11]:

1) Model library: the model library is responsible for storage information related model, which includes name, size, content, creation date of the model.

2) Component library: the component library is responsible for storage information related component, which includes name, size, attribute, whether have texture or not, texture number of the component.

3) Texture library: the texture library is responsible for storage information related texture, which includes type, size and attribute of the texture.

For flexible simulation database is the precondition of setting up flexible simulation framework, it's be required 3D model library standardized. Thus it should follow unified standard to build the model library, component library and texture library. The rule is as the following:

1) Name: follow the unified standard to name the model, component and texture files, and the name is in the same size composed by letters and numbers.

2) Hierarchy: 3D model adopts unified LOD classification standard, and makes the same simplification degree in layer and hierarchy.

3) Size: the models and components in 3D model library are uniform with the actual, the proportion is 1:1, when the model is managed or called in different systems, which can be used directly without considering size match.

4) Coordinate system: adopt right-handed coordinate system when constructing of 3D models and element models, that means center and origin are coinciding, x axis points to width direction, y axis points to warheads, z axis points to the height direction.

5) Resolution: after LOD classification the same level detail needs unified resolution in model resolution, component resolution and the texture resolution, so that the system would show harmonious visual effects as whole.

4. Modeling method of decoy

Decoy module is composed of chaff, infrared, smoke ball, and other passive interference active decoy. Building decoy module not only contains 3D entity model, but also includes delivery mode, trajectory, and interference process and interference effects.

4.1 3D entity model of decoy

3D entity model building can use OpenGL or other professional tools. Decoy visual simulation system chooses polygon modeling tools with real-time visual simulation, called MultiGen-Creator, which can achieve the equal details, polygon cut, drawing priority and other advanced real-time capabilities. It's introduce development progress of incremental model when using Creator to establish 3D entity model, and to seek an optimized modeling method, so that established model is balanced between real-time simulation, realism, and accuracy, in order to meet the demand of real-time distributed interactive visual simulation system.

4.2 Mathematic modeling of decoy movement

Mathematic model of decoy movement contains chaff, infrared and smokescreen. Taking chaff bomb as an example, according to interference mechanism and motion characteristics, the progress can be divided to transmitter, expansion, cloud formation, until scattered. And the whole progress is classified into three phases: ball phase, cloud cluster phase, cloud ceiling phase. It's made motion analysis and built motion model on each stage respectively. The trajectories of chaff are shown in figure 4.

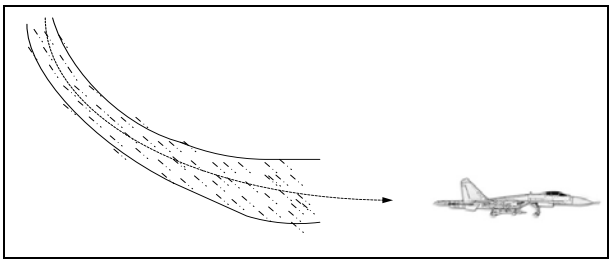


Figure 4. Movement principle of chaff interference

The first phase is the stage of bomb, that bomb is fired, launched, blasted. The motion model is shown in equation 1-5. The second stage is cloud

cluster phase, that chaff bomb explores, rapid expansion, during the phase RCS reaches maximum. The motion model is shown in Equation 6-7. The third stage is cloud ceiling, it continues to spread, falling gradually, and disappeared finally. The density distribution model is shown in equation 8-9. Within each state, ball and slim are subjected to all kinds of forces in direction and magnitude. Based on the knowledge of fluid mechanics and low speed aerodynamics, it's built a physical model, and simplified as the math model which is easy to implement [5].

Initial velocity of chaff bomb is V_{BO}, pitch angle is θ_{BO}, yaw angle is ϕ_{BO}, the components in three axes are:

$$\left.\begin{aligned} &= V_{BXO}\,\mathrm{Cos}\,\theta_{BO}\cos\emptyset_{BO} \\ V_{BYO} &= V_{BO}\,\mathrm{Sin}\,\theta_{BO} \\ V_{BZO} &= V_{BO}\,\mathrm{Cos}\,\theta_{BO}\sin\emptyset_{BO} \end{aligned}\right\} \quad (1)$$

Air resistance is:

$$F_B = C_d\rho S_B\frac{V_B^2}{2} \quad (2)$$

Components decomposition of F_B in three axes are :

$$\left.\begin{aligned} F_{BX} &= C_d\rho S_X\frac{V_{BX}^2}{2} \\ F_{BY} &= C_d\rho S_Y\frac{V_{BY}^2}{2} \\ F_{BZ} &= C_d\rho S_Z\frac{V_{BZ}^2}{2} \end{aligned}\right\} \quad (3)$$

Velocity of chaff bomb in three axes are:

$$\left.\begin{aligned} V_{BX} &= \frac{d_{XB}}{d_t} = V_{fx} - \frac{F_{BX}}{m}t + V_{BXO} + V_{MXO} \\ V_{BY} &= \frac{d_{YB}}{d_t} = -gt - \frac{F_{BY}}{m}t + \frac{F_f}{m}t + V_{BYO} + V_{MYO} \\ V_{BZ} &= \frac{d_{ZB}}{d_t} = V_{fz} - \frac{F_{BZ}}{m}t + V_{BZO} + V_{MZO} \end{aligned}\right\} \quad (4)$$

Location components of chaff bomb in three axes are

$$\left.\begin{aligned} X_B &= \frac{1}{2}t(V_{BX} + V_{BXO}) \\ Y_B &= \frac{1}{2}t(V_{BY} + V_{BYO}) \\ Z_B &= \frac{1}{2}t(V_{BZ} + V_{BZO}) \end{aligned}\right\} \quad (5)$$

Velocity components of chaff slim in three axes on geodetic coordinate system are:

$$\left.\begin{aligned} V_{bx} &= V_{fx} - \frac{F_{bx}}{m_b}t \\ V_{by} &= -gt + \frac{F_f}{m_b}t - \frac{F_{bf}}{m_b}t \\ V_{bz} &= V_{fz} - \frac{F_{bz}}{m_b}t \end{aligned}\right\} \quad (6)$$

Location components of chaff slim in three axes are:

$$\left.\begin{aligned} X_b &= \frac{1}{2}t(V_{bx} + V_{BX}) \\ Y_b &= \frac{1}{2}t(V_{by} + V_{BY}) \\ Z_b &= \frac{1}{2}t(V_{bz} + V_{BZ}) \end{aligned}\right\} \quad (7)$$

Fluctuating velocity of chaff slim is follow normal distribution:

$$\overrightarrow{F_f} = m_b\frac{d\overrightarrow{V_f}}{dt} \quad (8)$$

Distribution of cloud ceiling in earth axis is:

$$\left.\begin{aligned} f(x) &= \frac{1}{\sqrt{2\pi}\delta_x}\exp\left[-\frac{(x-\bar{x})^2}{2\delta_x^2}\right] \\ f(y) &= \frac{1}{\sqrt{2\pi}\delta_Y}\exp\left[-\frac{(y-\bar{y})^2}{2\delta_y^2}\right] \\ f(z) &= \frac{1}{\sqrt{2\pi}\delta_Z}\exp\left[-\frac{(z-\bar{z})^2}{2\delta_z^2}\right] \end{aligned}\right\} \quad (9)$$

4.3 Special effects model of decoy

Special effects of decoy use particle system to express, which can simulate irregular and blurred movement patterns and rules. It uses a lot of simple geometric shapes micro particles to construct complex transformation, such as clouds, smoke, frog and fire. Thus, it can simulate special effects, which have no fixed geometry, and external contour changes all the time, such as chaff corridors, infrared fireworks, smokescreen, etc.

The basic idea of configuration effects model with particle system [6] is: for the irregular movement objects it can't build model by modeling tool, such as clouds, smoke, frog and fire, we use a large amount of particles with life cycle and attributes to simulate, by controlling the particles property and location at different times we can get the overall effect of particle swarm. Particle shape is generally drawn as simple geometric shape, such as spherical, cubic, etc. Particle property includes shape, size, color, transparency, life cycle, velocity and motion direction, etc. Particle life cycle is from generation, movement to die. The particle motions in accordance with the system planned trajectory model, coupled with the random motion control, in this way a large number of particles show a regular shape but uncertain shapes of change on the whole. For particle system, to describe interference effects is as shown in figure5:

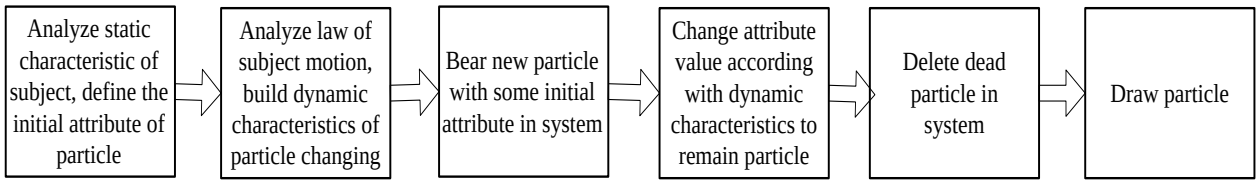


Figure 5. Draw steps of special effect in particle system

Interference effect of mass chaff slim in the air is suitable for particle systems to simulate the realistic effects, so the erratic chaff corridor in the air can be defined that the thousands of irregular, randomly distributed particles, each particle has a certain life cycle, they constantly change shape, motion, and show the movement regular and interference effects as whole.

1) Static properties of chaff slim

The static property of chaff slim includes: shape, size, particle color and transparency, light transmission, reflection and scattering. While the shape of slim use a two-dimensional circle, instead of spherical shape as common. We define slim as two-dimensional shape and map texture with billboard methods to determine the shape of the slim. When viewpoint rotates to non-opposite two-dimensional plane, in order to solve the one-dimensional shape problem all the shape planes should rotate with viewpoint rotating. Thus two-dimensional plane is always perpendicular to sight, slim would show the status of two-dimensional always in the line of sight observation. This approach solves the problem of slow calculating, drawing delayed and other phenomenon in three-dimensional drawing. Therefore, two-dimensional particle method can effectively enhance drawing speed and improve real-time, reducing the limits of scale.

2) Dynamic properties of chaff slim

The dynamic properties of chaff slim includes: distribution density of particle swarm and dynamic characteristic. The produce of slim particles is controlled by a random process. We control the number of particles at time interval, by which this value would directly affect the density distribution. When the bomb is in explore phase, we increase new particles born rapidly without dead. When cloud cluster is in diffusion stage, we increase the number of new particles slowly, while increase particles to die slowly. When the chaff erratic is in scatter, we reduce the number of new particles born with accelerate dead. Meanwhile, when each slim would random motion independently in 3D space, while the general situation follow the movement of chaff corridor.

5. System implementation

The operation system is Windows XP, the development programming language is C ++, build environment is Microsoft Visual Studio.NET 2003 MFC7.1 above, visual simulation software is Vega Prime 2.2, modeling tool is Multigen Creator 3.0. The hardware configuration of workstation are CPU is Intel E5-2690 2.90G * 2 8-core, memory is DDR3 ECC 4G * 8, graphics is NVIDIA NVS 450 512M, hard is SAS hard disk 600G, display is 24-inch LCD monitor.

The development steps of decoy visual simulation system are as figure 6

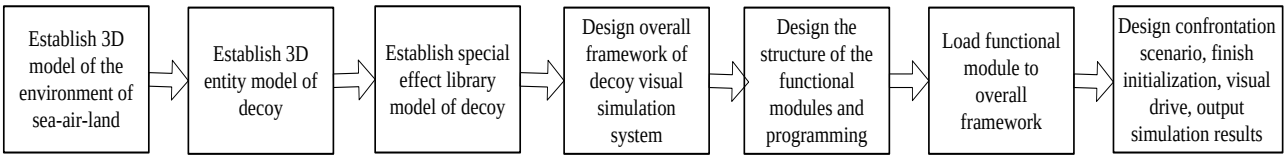
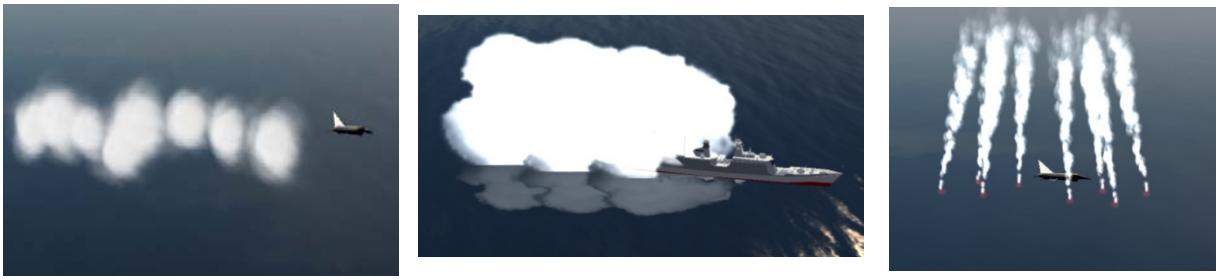


Figure 6. Development steps

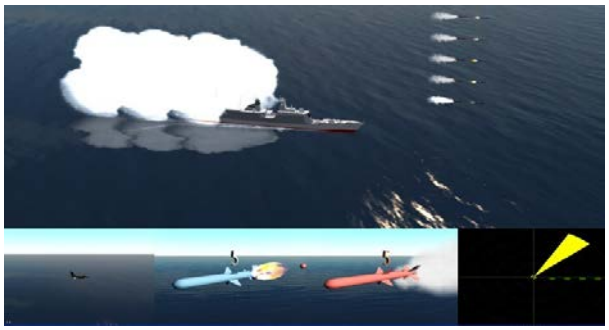
The special effect result of decoy is shown in figure 7. In (a), a jet fighter and chaff cluster are drawn, cluster spread, slim inside motions in random, ensemble follows normal distribution, which obeys the physical model of 4.2. In (b), a ship and smoke ball is drew, the special effect of smoke screen is simulated by particle system, the shadow and light is expressed clearly. In (c), several infrared decoys and a jet fighter are drew, special effect is combined by flare model, smoke model and physical model.



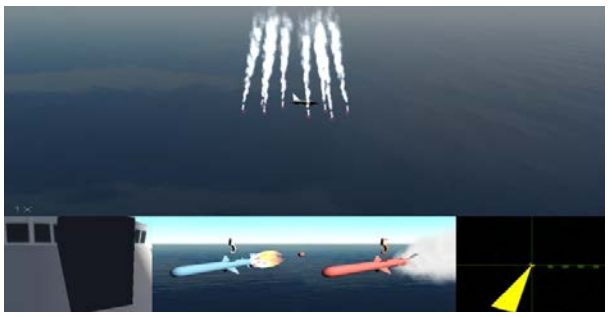
(a) Chaff (b) Smoke ball (c) Infrared

Figure 7. Combined model of decoy

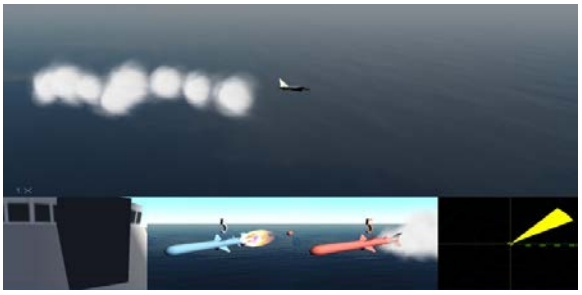
The system framework of visual simulation is shown in figure 8. It shows the overall system result, that we can see entity model, surrounding model, effect model. Among them, entity model includes ship, aircraft, submarine and bomb etc. Surrounding model includes sky, water surface, wave, sun, light, shadow, etc. Special effect includes smoke screen, infrared, chaff corridor, flare, etc. Further there are five windows with a main window and other four assistant windows. Main window displays the overall combat procedure, while assistant windows display radar detection, rockets fly, ship surrounding, jet fighter motion and other details. By compared (a), (b) and (c), it shows that view point can be changed freely either in main window or in assistant window, and the viewpoint tracks object motion.



(a) Multi model management and schedule



(b) Multi viewpoint management



(c) Multi window management

Figure 8. Visual simulation system of decoy

6. Conclusions

The paper completes a design of flexible visual architecture, entity modeling and special effects modeling, developed a complete decoy visual simulation demonstration system finally. The system achieves good simulation results with realistic and better real-time, which up to 30 frames/sec. This flexible framework and modeling method are applicable to sorts of military demonstration simulation systems.

Acknowledgements

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