AUV Junior - Small Autonomous Underwater Vehicle from SEC FEFU for Robosub 2012 Competition

Vladislav Goy, Fedor Dubrovin, Andrey Kushnerik, Nikolay Sergeenko, Igor Tuphanov

***Abstract* - AUV Junior (fig. 1) was developed in 2012 in Scientific Educational Centre of Far Eastern Federal University /SEC FEFU/ for Robosub 2012 Competition. The AUV has weight of about 35 kg and size of L*W*H 1.1*0.5*0.4 m. It employs a modular 6 A-hr Lithium polymer battery. Navigation sensors include DVL Explorer (Teledyne RD Instruments), AHRS MTi (Xsens) and depth sensor DMP331. The vehicle structure and program control system performance are discussed in the paper.**

INTRODUCTION

The student team of Far Eastern Federal University /FEFU/ from Vladivostok in frame of Scientific Educational Centre /SEC/ of FEFU has developed the AUV Junior for Robosub 2012 Competition. The main number of AUV competition tasks are connected with images recognition and obstacles avoidance. So it was decided to produce small maneuverable frame autonomous underwater vehicle equipped with power computing network based on two industrial PC, advanced propulsion system, technical vision system, beacon localization system and precise on board navigation system. The technical vision system includes three fixed (up, down and forward looking) cameras and one industrial PC. Three receiving acoustical antennas with DSP compose the beacon location system.

This project started in December of 2011 from software designing. Motors and electronic components ordering was fulfilled in March of 2012. The electronic and mechanic subsystems were developed during April and May. The integration of subsystems

Fig. 1. AUV Junior.

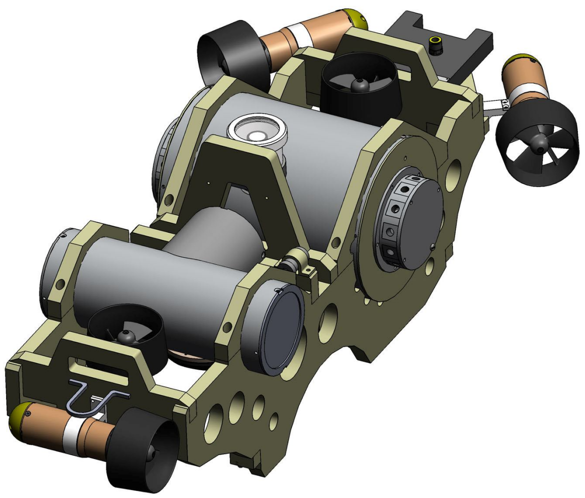

Fig. 2. 3D model of AUV Junior.

to the whole AUV was fulfilled in the first part of June.

There were three groups of students (7 persons) responsible for programming, electronic engineering and mechanics from FEFU School of Engineering and School of Natural Sciences. The ideas of AUV and its subsystems designing were received from [1-5, 7]. Some experience in underwater vehicle control system developing was received during small AUV MARK designing [6].

AUV DESIGN AND CONSTRUCTION

The vehicle construction consists of frame, five thrusters propulsion system, main pressure volume with digital control system and set of sensors and devices (fig.2) needed for competition mission execution. It includes three photo cameras (up, down and forward), DVL Explorer (Teledyne RD Instruments), depth sensor DMP331, shooting device for torpedoes and throwing device for markers. The AUV has weight of about 35 kg and size of L*W*H 1.04*0.45*0.30 m. AUV power management system employs a modular 6 A-hr Lithium polymer battery installed in the main pressure volume. All pressure volumes are made of anticorrosion aluminum alloy and frame is produced from plastic.

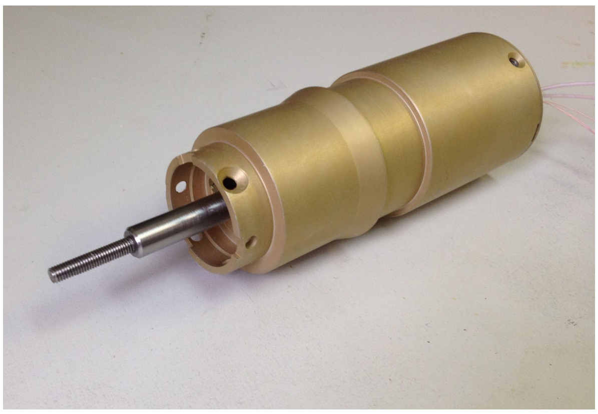

Fig. 3. Thruster for AUV Junior.

Bow part includes forward photo camera and device for torpedoes shooting. Two horizontal and one vertical thrusters are arranged in this part of AUV. The main pressure volume with digital control system, two photo cameras (up and down), DVL Explorer (Teledyne RD Instruments), depth sensor DMP331 and throwing device for markers are situated in the AUV central part. One horizontal and one vertical thrusters are arranged in stern part of AUV.

AUV propulsion system consists of three thrusters in horizontal plane and two thrusters in vertical plane. It allows controllable linear and rotational motion and heading in horizontal plane. In vertical plane the propulsion system allows controllable motion in depth and pitch. The vehicle is ballasted so that its roll is about zero. The AUV propulsion system allows speed from 0 to 1.5 m/s. All parts of the vehicle frame are free flooding. We use thrusters designed in the SEC FEFU (fig.3). The thrusters utilize the Faulhaber 4490 H 024BS-K312 24 volts brushless motors.

AUV CONTROL SYSTEM STRUCTURE

The base of AUV Junior on-board digital control system is a local network including two PC compatible computers and set of microcontrollers (fig. 4). One computer is intended for program control system and navigation, other – for technical vision system. The local Junior network includes Ethernet, USB, CAN and RS-232 several serial channels. Serial channels are used for on-board devices

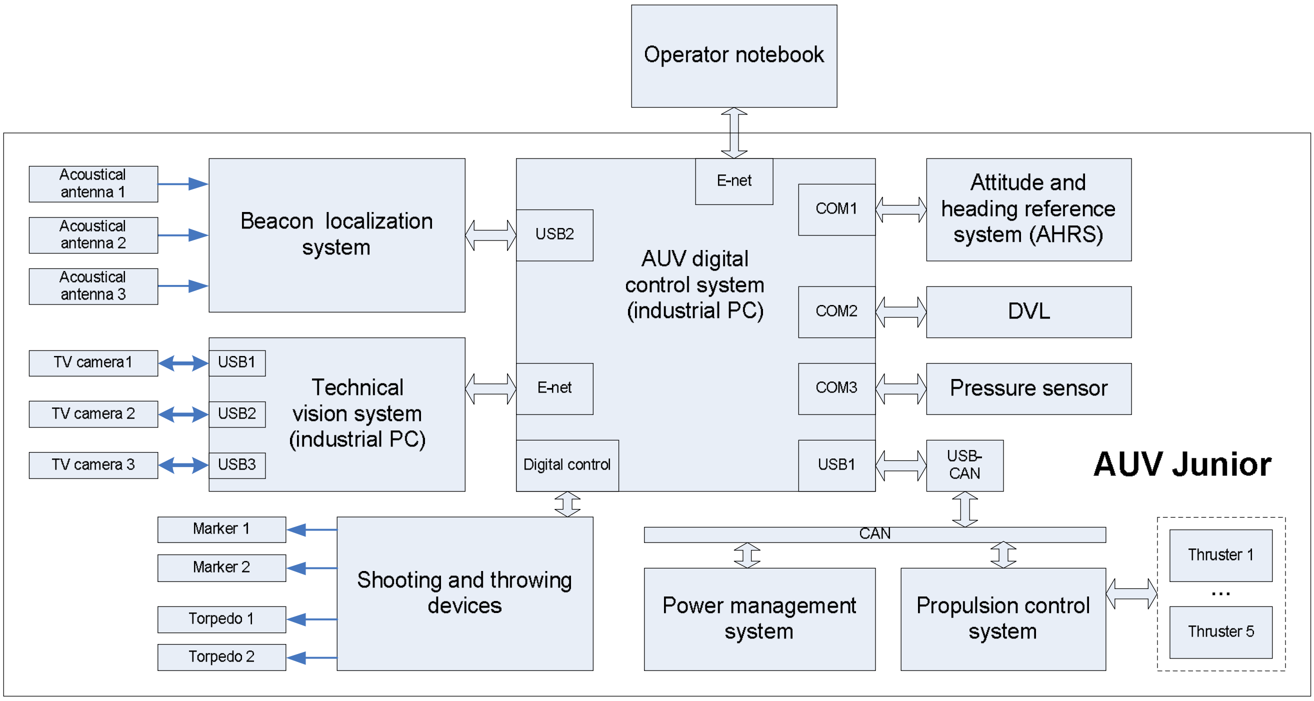

Fig. 4. AUV Junior control architecture

control by built-in microcontrollers. Microcontrollers are intended for device self testing, communication and data preprocessing. Ethernet channel is used for sizeable volume data transmission and for Junior on-board computers communication. When AUV on the land the operator computer is connected by electrical cable to the local AUV network and Ethernet channel is used for operator and AUV computers communication. The network operates under the OS Linux.

AUV Junior trajectory calculation is executed by on-board autonomous navigation system /BANS/. It processes the AHRS MTi measurements of heading, roll, pitch, angle rate, horizontal velocity projections from DVL and depth meter DMP331 data. The Junior underwater position is calculated relatively to the start point near the launch platform.

PROGRAM CONTROL SYSTEM

The Program Control System of our vehicle consists of several executable modules communicating via CMU IPC. This is publish/subscribe mechanism, based on network sockets. So, for the integrity of the system it's not important which computer runs each module.

The structure of Junior Program Control System is depicted on Fig. 5, illustrating three-layer architecture. Modules in lower level are device drivers. Middle layer consists of computational modules which are motion control, navigation program and video processing module. These modules use low-level sensor data from drivers to produce high-level data for upper level. The only upper-level module encapsulates all decision-making.

All modules, except for video processing are running on one computer, while video processing runs on the other. This is because video module is the hardest in computational sense. Video module and mission are two modules, which are developed specifically for the RoboSub competition. All other modules are suitable for general-purpose AUVs. The major development language is C++.

In our control system each module produces a text log. Each line of log file is whether a text message or a list of numbers, which can be visualized as a chart afterwards by log viewer

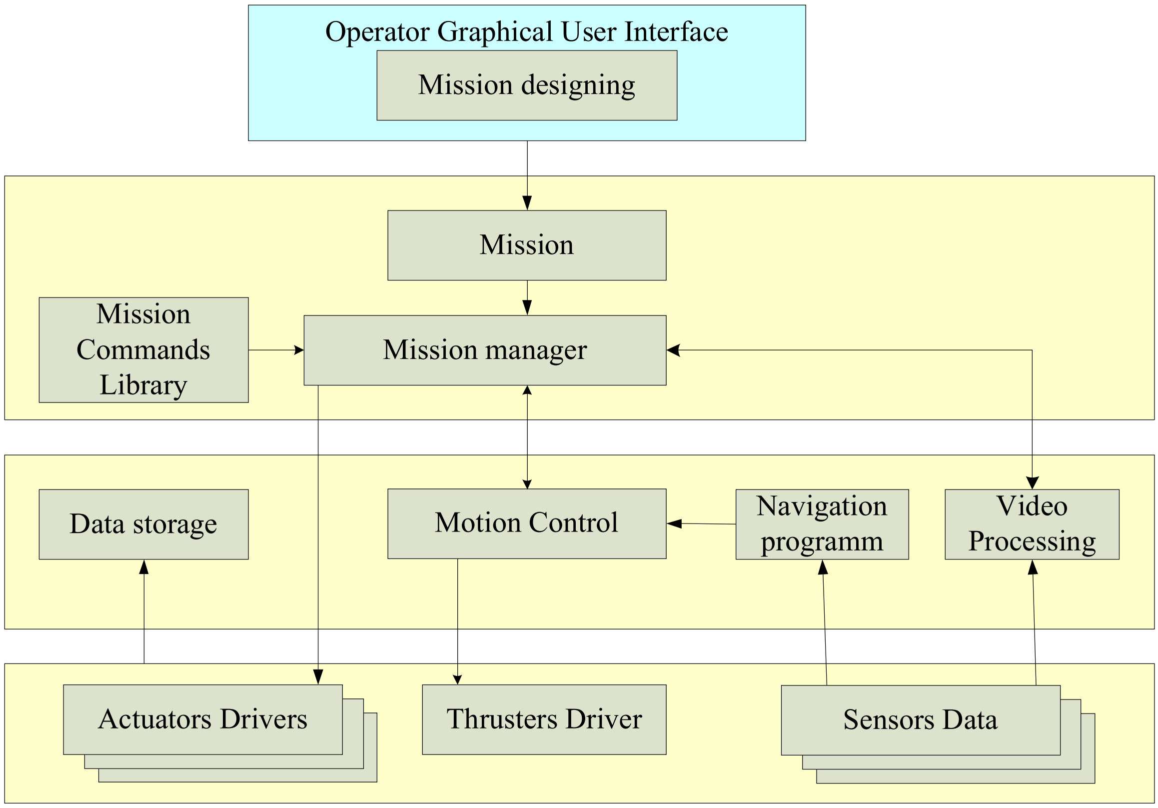

Fig. 5. Program Control System structure.

program. Each line of log file is supplied by timestamp in order to match log files for different modules. Furthermore, video module saves each frame in two versions: the original and the one with debug markup.

MISSION STRUCTURE

AUV Mission consists of tasks. Each task has a scene object associated to it (task object). In each moment of time the vehicle is either searching for task object or performing a task. These assumptions are the base for our mission structure.

Searching for object demands some search area. Search area is usually a sector. Task object is considered to be found if it was observed several times (usually not less then 3). In order to estimate task object position, the mission module solves geometry problem and filters object position and orientation throw all its observations. We use simple median filtering to avoid outliers.

To specify the order of tasks we use a mission tree. Each task, except for the gate task, has its parent. A task can be searched and executed only after its parent task execution. In fact, parent task object position gives us search sector coordinates for the next task. The base mission algorithm is shown on fig. 6.

AUV MISSION DEVELOPMENT AND MANAGEMENT

Junior operator has possibility for solution of the next tasks:
- mission designing;
- mission verification and loading into AUV;
- received data unloading, visualization and fast analysis;
- AUV subsystems maintenance;
- AUV remote control by electrical cable link.

Graphical user interface /GUI/ is a multi windows system. It allows Junior subsystem testing before launching, mission simulation in

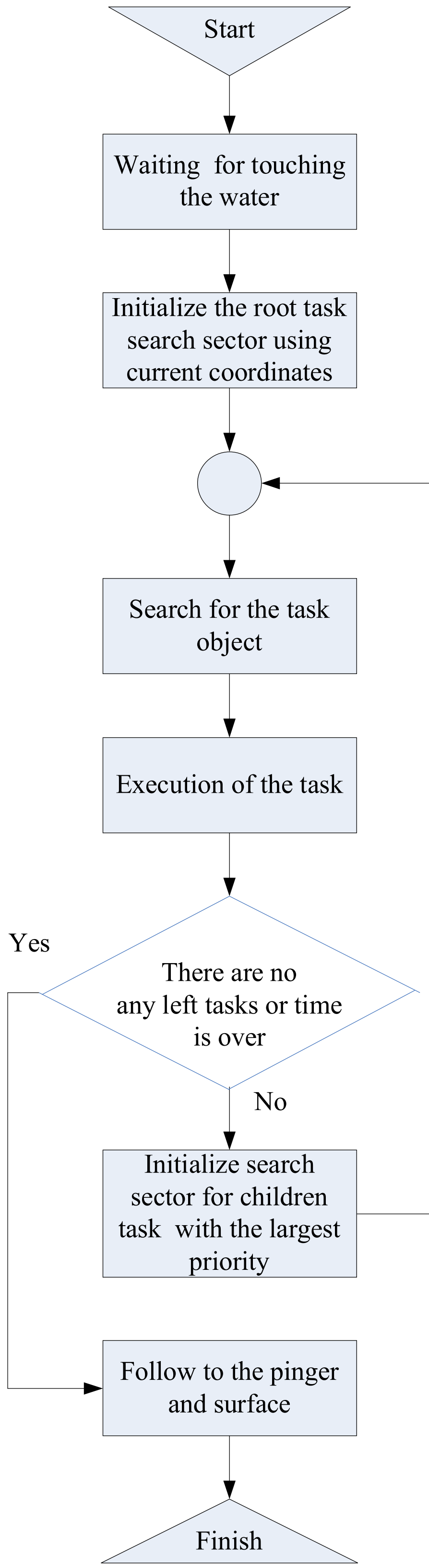

Fig. 6. Mission algorithm.

fast mode and real time graphical data visualization.

VIDEO RECOGNITION

All recognition algorithms are implemented in a single video module. It takes video frames from camera driver via v4l interface and processes it. If some of mission objects are recognized on a frame, the according IPC messages are published and received by the mission module. From the other side, mission module sends an IPC message telling which objects should be recognized at the moment. This is performed to reduce computation load of computer.

We use OpenCV library for image processing. Algorithms we use are mostly contour analysis algorithms combined with color analysis. We are using HSV color space. Consider an algorithm for blue "Cesar" detection. It should detect not only the blue board itself, but also two holes in it. The processing consists of the following steps:

1. Transform original image into black-and-white image A, where white corresponds to blue color.
2. Convert the original image to gray scale and apply Canny edge detection algorithm based on Sobel operator. This is black-and-white image B.
3. Construct image C, where $C = A \& \neg B$.
4. Find contours on image C, using Suzuki-Abe algorithm.
5. Among contours from step 4 find those, which can be considered as quadrangles.
6. Among quadrangle contours from step 5 find those, which has two holes inside, and calculate its centers.

So, we analyze an image (C), which contains both color (A) and edges (B) information.

The mission module receives navigation IPC packages as well as packages from video module. It also uses cameras relative position and angles information from a configuration file. All this data together with scene object sizes is used to calculate absolute coordinates of scene objects and their orientation.

We solve a single geometry problem for gate, obstacle course, paths and “Cesar”. This is due to the fact, that all these objects are plane fragments of known size. They have only four degrees of freedom: three for position and one for rotation angle.

More formally, consider a plane object with n key points $(x_1, y_1), (x_2, y_2),\dots,(x_n, y_n)$ in its local coordinate system (n is usually four as for corners of a rectangle). Consider this plane object located vertically in 3D-space in position $\mathbf{q}$ with rotation angle α. Let camera position is $\mathbf{p}$ and unit vectors to observed object key points are $\mathbf{c_1},\dots,\mathbf{c_n}$. We have the following vector equation for i-th keypoint:

$$\mathbf{p} + \mathbf{c_i}\rho_i = \mathbf{q} + (x_i\cos\alpha,\ x_i\sin\alpha,\ y_i)^T,$$

where ρ_i stands for the distance between camera and i-th keypoint. The unknowns are ρ_i, $\mathbf{q}$, and α. Note that if α is fixed, these equations for each i would give us an overdetermined linear system. So, we solve this system for different α, iterated with some small step and remember the one, which gives the smallest discrepancy.

The road object gives us slightly different equations – it has other summand on the right side (because it’s not vertical but horizontal), but the algorithm remains the same.

BEACON LOCALIZATION SYSTEM

In order to execute the acoustic task, which consists in locating a beacon, our vehicle is equipped with an acoustic beacon localization system. In fact, it represents an acoustic direction finder, whose principle of operation is based on measuring the time differences in signal propagation to several hydrophones.

For the purpose we use three self-made hydrophones, which mounted at the bottom of vehicle’s hull. They are located as far as it possible in apexes of a right-angled triangle. The distances between each of them are greater than wavelength. The direct signal time-of-arrival measurements are used for determining of direction to the beacon. Since the hydrophone signal level is low, we use analog board for amplifying of them. Besides the preamplifiers, it includes bandpass filters also.

Then already amplified and filtered analog signals are routed to a digital signal processor (DSP). DSP executes signals sampling, analog-to-digital conversion and preprocessing, which consists in detection of acoustic pulses. We use the Danville’s dspstak™ 21369zx DSP with ADC/DAC c192k48 because it has allowable sampling frequency (192 kHz) and enough number of synchronous analog inputs, so we can make simultaneous processing of signals from all three channels.

After acoustic pulse detection, the short digital fragments (1024 samples per channel) of simultaneous-sampled signals are sent to the main computer via USB. Special program receives these fragments, analyzes them and determines the differences for times-of-arrival of acoustic signal to the each of hydrophones. This functional partitioning allows us to change algorithm of time difference calculating without DSP reprogramming.

Using determined time difference, the bearing angle to the source of sound can be calculated (fig. 7) :

$$\tan\theta \approx (a/b)(\Delta T_2/\Delta T_1),$$

$$\Delta T_1 = T_1 - T_0 = (R_1 - R_0)/c,$$
$$\Delta T_2 = T_2 - T_0 = (R_2 - R_0)/c,$$

where θ is a bearing angle to the beacon, a,b - distances L1(H1,H0) and L2(H2,H0) between hydrophones, ΔT1 and ΔT2 are differences of signals time-of-arrival, R_i is slant range between beacon and ith hydrophone (i = 0,1,2), and c is the sound speed in the water.

In order to determine the beacon coordinates, we supplement beacon direction information with current vehicle position, obtaining from autonomous board reckoning system. As a result, we have a collection of bearing angles to the beacon from different known positions. Combining these measurements allows to localize the beacon.

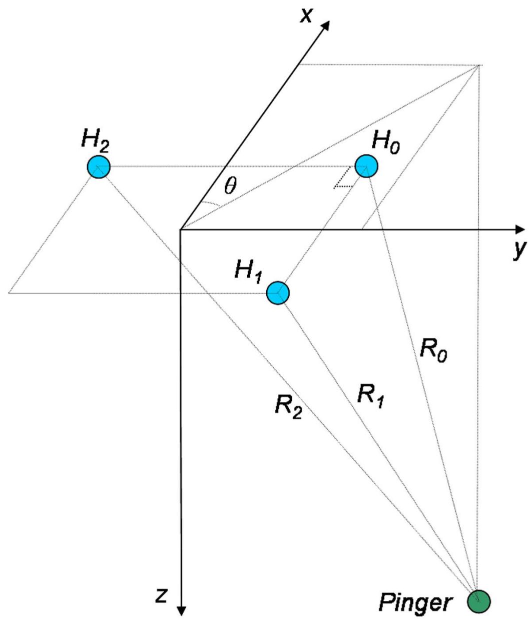

Fig. 7. Beacon position localization.

TEST AND DEBUG

Test and debug techniques are vitally important for complex technical system. In order to test mission logic, geometry solutions and basics of image processing we have been using a simulation.

In our simulation system we produce 3D environment model with tasks. Kinematics AUV motion is employed in this system. Based on 3D scene model and current AUV position and heading the simulation system generates camera images. It also has a GUI to visualize the scene. Screenshot of this GUI is shown on fig. 8.

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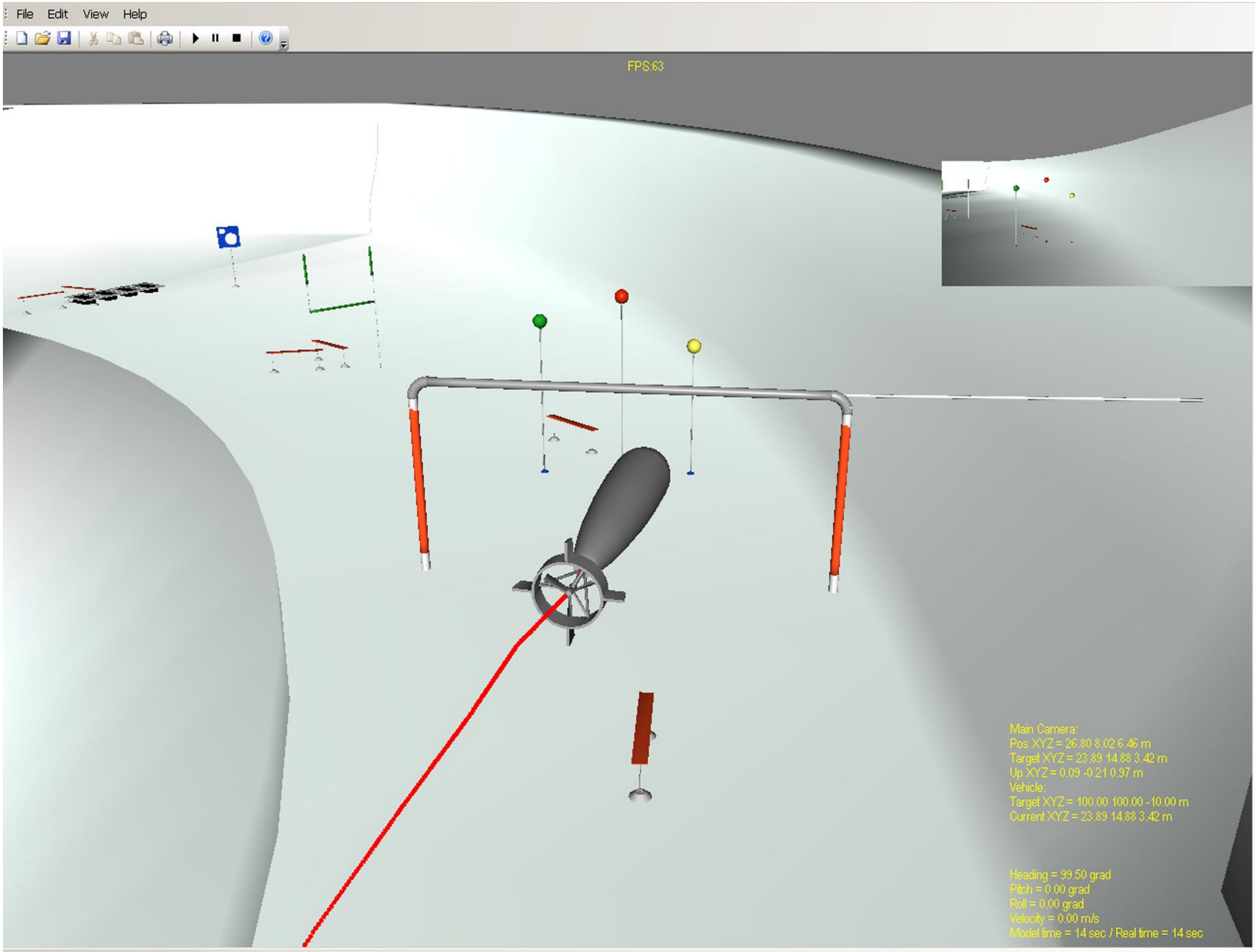

Fig. 8. Environment simulation model.