# A Real-Time Intelligent Flight Meter Simulator

***Jian Zhang, Jigui Sun, Changsheng Zhang***

College of Computer Science and Technology, Jilin University, China
Key Laboratory of Symbolic Computation and Knowledge Engineering of Ministry of Education, Jilin University, China
No.2699 Qianjin Street, Changchun, China, 130012

**Abstract:** In order to improve the flight training level, a real-time flight meter simulator is developed. Based on all-purpose simulation math model, it can complete all the flight subjects. In the intelligent control model, by comparison with the actual flight data prepared in advance in the repository, it can automatically adjust the control input, which makes the system error decrease gradually. The model of gauge transposition is designed, which guarantees the harmony of operation and meter. The XML technology is imported, which can simulate all kinds of aircrafts. The experiment data shows that the simulator has high efficiency, veracity and real time. Through practice, it can satisfy with the requirement of flight meter simulation training.

**Key words:** Aerodynamics, Flight Simulator, Intelligent Control, XML

## 1. Introduction

Many countries in the world greatly attach importance to the development of real-time flight simulation training system. In the 1930s, USA first produced the *Linke Flight Simulator* which was used as pilot training. It made pilots know well the flight operations and emphasized on the flight mechanism operations. In the 1970s, the flight simulator was greatly ameliorated and the simulating computer was changed from analog computer to digital computer, which emphasized on the flight performance and aviation electron. In the 1990s, the simulator was extended to the direction of distributing. Now, the flight simulation training adopting simulator has become one of the important means of enhancing the air force campaign level in the world.

With the development of science and technology, the flight simulation has not only the corresponding math model, but also the actual circumstance [1]. In the flight simulation system, the meter simulation is very important. It is the display window of performance and navigation parameters. It provides the pilot with visual information of the cabin.

On the basis of resembling principle, control theory, computer technology, information technology and the corresponding application field technology, making use of the dynamic experiment research of the system model, a self-developed real-time intelligent flight meter simulator based on all-purpose math model——MMBFMS (Math Model Based Flight Meter Simulator) is expatiated on in detail. Its framework design is introduced and the all-purpose flight simulation math model is built. The intelligent control model which has the self-learning functions is built. Finally, the experiment data of this model is given. Furthermore, once all the parameters of the aircraft are given and configured, the flight meters of all kinds of aircrafts can be intelligently simulated.

## 2. The Framework of MMBFMS

MMBFMS is used to train the pilots. It adopts the computer graphic technology and creates digital graphic meters on the computer terminal. To the operations controlled by the pilots, it can provide the corresponding meter display on the computer terminal as the same as the actual aircraft.

The framework of MMBFMS is showed as Fig.1.

The servo and monitor model continuously call the data collection model to complete the data collection works from the hardware system. The data collection model realizes A/D conversion and gauge transposition, and then store data in the data queue model by the servo and monitor model. By a series of computing of the intelligent simulation math model, it outputs the meters

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display data and then stores them in the display queue model. Finally, the meter display model gets the data from the display queue model and shows the meters by graphics on the computer terminal.

MMBFMS includes the aircraft XML configuration file and specifies several types of flight control data. The configuration file makes it simple of creating a new type of aircraft, setting the initial position and designating the operation characteristics of the aircraft. At present, the standard of describing the simulation configuration file by XML is drafting [2].

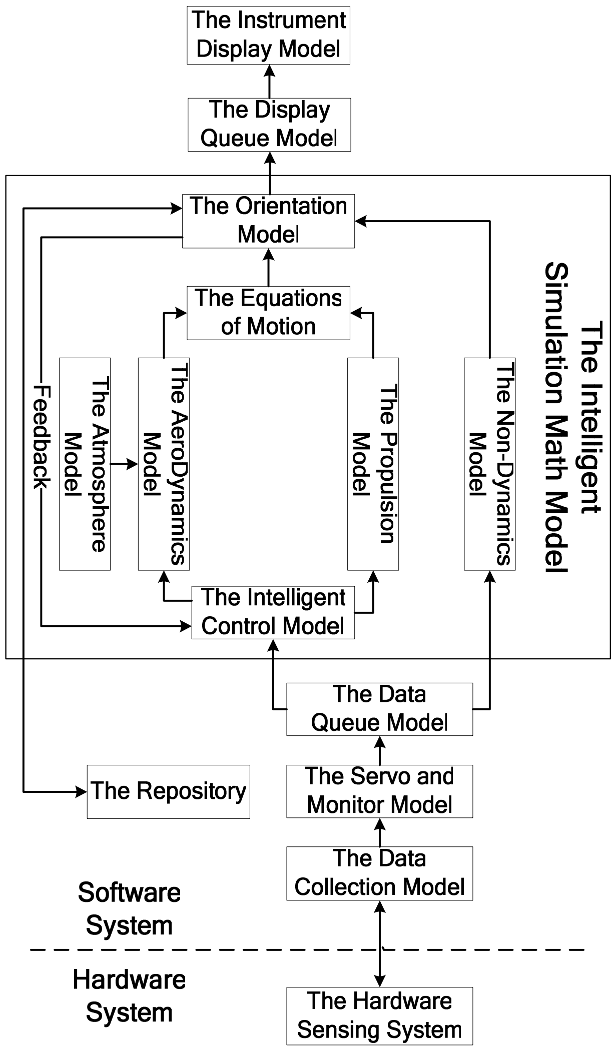


Fig.1 The Framework of MMBFMS

## 3. The Hardware System

The hardware system of MMBFMS is composed of several types of operation equipments, position sensors, PCI-7422 data collection card and micro personal computer [3]. The hardware sensing system is showed as Fig.2.

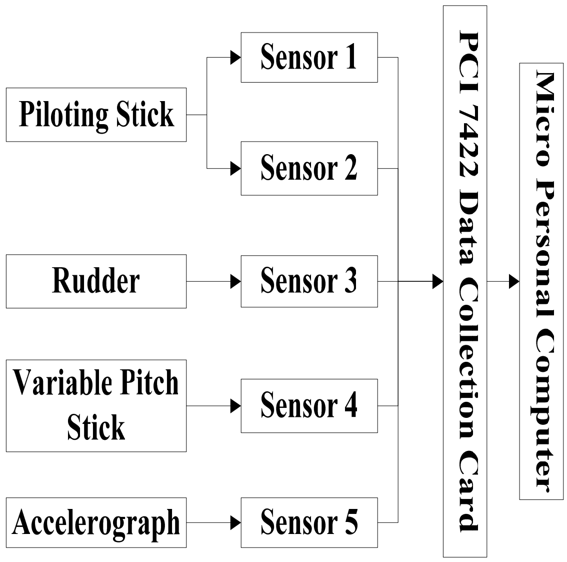


Fig.2 The Hardware Sensing System of MMBFMS

The hardware system includes the equipments of piloting stick, rudder, accelerograph and variable pitch stick. The displacement values of these equipments need to be converted into voltage analog values, and then convert them into digital values by PCI-7422 card.

MMBFMS collects five routes of analog values: angles of piloting stick (two routes, denoting front and back, left and right), angle of rudder, mete of accelerograph and angle of variable pitch stick. One end of sensor 1 used as measuring the angles of piloting stick is connected to the back of piloting stick bottom. One end of sensor 2 is connected to the left of piloting stick bottom. Another end of the sensors is fixed to one point and can rotate around the point. The output values of the five sensors are inputted into the data collection model. All sensors are straight type with 2K resistance and 0~5V output, which are plugged in PCI-7422 by D-connector plugs and converted into digital values by A/D.

## 4. The Software System

The software system is composed of the following six models.

### 4.1 The Data Collection Model

The data collection model realizes the A/D conversion and gauge transposition [3].

The mete of accelerograph, angle of rudder and angle of variable pitch stick are linear. So their gauge transposition formula is showed as follows.

$$A_x = A_0 + (A_m - A_0)\frac{N_x - N_0}{N_m - N_0} \quad (1)$$

In Eq. 1, $A_0$ denotes the lower input of the sensor and $A_m$ denotes the upper input of the sensor. $A_x$ denotes the value of requirement $N_0$ denotes the lower digital value of the sensor and $N_m$ denotes the upper digital value of the sensor. $N_x$ denotes the digital value of actual measuring.

For example, the angle of rudder is denoted by the number between -1 and 1, that is, $A_0 = -1$, $A_m = 1$. When the right rudder is at the limit, by measuring, $N_0$=03F9H= 1017; When the left rudder is at the limit, $N_m$=0A42H=2626.

To the piloting stick, the two sensors connected with it are used to measure the displacement of its bottom end to two directions: front and back, and left and right. The angles of the piloting stick are not linear with the output of the sensors. So a math model needs to be built so as to expressing the relation of the angles of the piloting stick and the two displacements. We adopt the following method to build the planar coordinates. The connection point of the bottom end of the piloting stick and the sensors is regarded as the origin *O* in the coordinates. The front and back direction of sensor 1 is regarded as *x* axis (front as positive). The left and right direction of sensor 2 is regarded as *y* axis (left as positive). The bottom end of the piloting stick is supposed as $S(x, y)$ in the coordinates. If getting *x* and *y* of *S*, we can get the angles of the piloting stick departing the middle position.

According to the sphere coordinates, the following equations can be built.

$$\begin{cases} x^2 + (y + k_1)^2 = |SA|^2 \\ (x + k_2)^2 + y^2 = |SB|^2 \end{cases} \quad (2)$$

In Eq. 2, $k_1$ and $k_2$ can be directly measured. The length of the sensor is *L*. The distance between the rotate axis of the piloting stick and *O* is *M*. Using Eq. 1 to sensor 2, we can get $A_{x2}$ according to the output digital $N_{x2}$ of sensor 2, thus $|SB| = L + A_{x2}$; in the same way, we can also get $|SA|$. Thus, we can get *x* and *y*. Therefore, the angle of departing the middle position in *x* direction is: $\alpha = -arctg\frac{x}{M}$ , and the angle in *y* direction is: $\beta = -arctg\frac{y}{M}$.

### 4.2 The Servo and Monitor Model

The servo and monitor model is realized by the computer multi-thread technology. In order to enhance the real time of MMBFMS, the servo and monitor model continuous calls the data collection model to complete the data collection works from the hardware system. The timeslice of collecting data can be configured. The default timeslice is 500ms. Once the servo thread exits because of some suddenness, will the monitor thread restart the servo thread in time, which ensures the data collection works. The sketch map is showed as Fig.3.

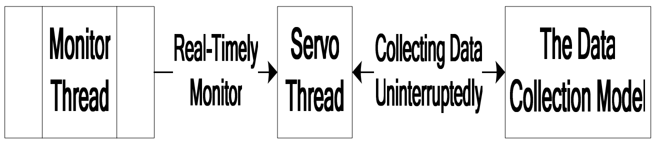


Fig.3 The Sketch Map of the Servo and Monitor Model

The servo thread reads data from the interface of the data collection model and adds them into the data queue, which is provided to the intelligent control model for use.

### 4.3 The Data Queue Model

The data queue model answers for storing data from the data collection equipments. The queue adopts the data structure of doubly linked list, whose size can be configured according to the practice. The default size is 10. The doubly linked list structure is showed as Fig.4.

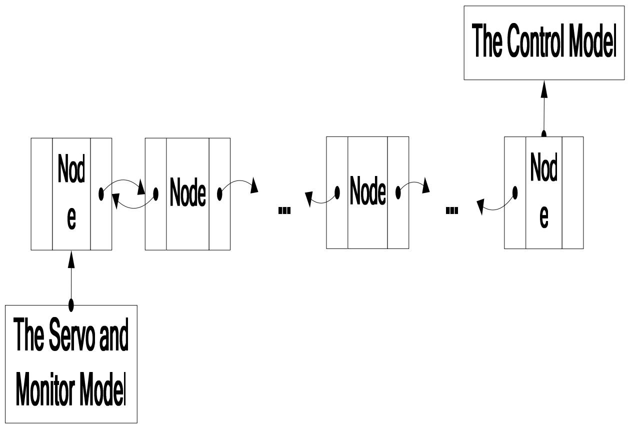


Fig.4 The Sketch Map of the Data Queue

The structure of the data queue is showed as follows.

```
typedef struct DATAQUEUE {
    int nDataLen ;              //Length of Data Buffer
   char * pszData ;             //Data Buffer
   DATAQUEUE * pstPrv ;         //Pointer of Pre-Node
   DATAQUEUE * pstNext          //Pointer of Post-Node
}
```

The data queue is the quickest method between two asynchronous tasks in the process of communication. By adopting the data queue, the system running speed is improved, because the data need not be directly fetched from the hardware interface.

### 4.4 The Intelligent Simulation Math Model

The building of simulation model is the base of MMBFMS and is the key element to the lifelike extent of the simulation system. The principle of model building firstly will stratify with the subject and object; secondly the math model will also reflect and express the impersonal object [1].

The intelligent simulation model of MMBFMS is mainly composed of the intelligent control model, the aerodynamics model, the propulsion model, the non-dynamics model, the equations of motion, the orientation model and the atmosphere model.

The intelligent control model is mainly used to compute the corresponding controlled values according to several types of inputted data, such as the accelerograph, the angles of the piloting stick, and etc. In the MMBFMS system, it automatically adjusts the control input, by comparison with the actual flight data prepared in advance in the repository, which makes the system error decrease gradually. MMBFMS uses the PID (Proportion − Integral − Differential) feedback controller as the intelligent control instrument. It computes the output according to the proportion gain, integral and derivative of the error signal. PID controller commonly includes three types of elements: proportion element, integral element and differential element. The output of proportion element is in proportion with the error signal. It is a type of amplifier in substance. The time derivative of the output of the integral element is in proportion with the error signal. It is often used to solve the departure problems. The differential element is not separately used, which only acts in the transitional period. The sketch map of PID is showed as follows.

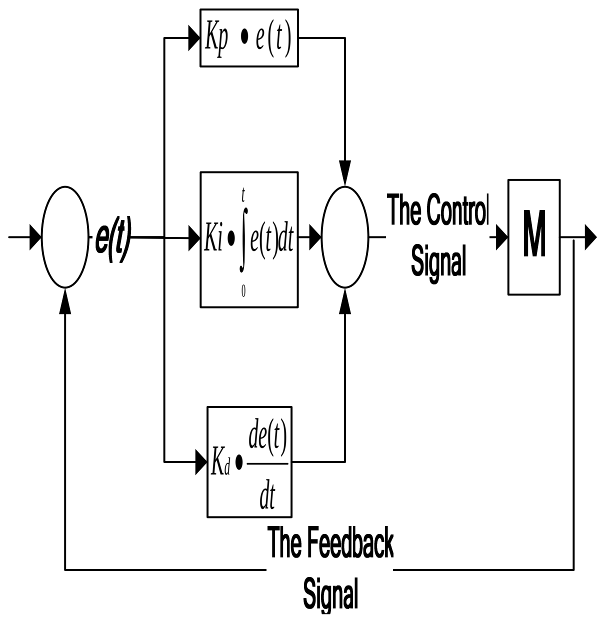


Fig.5 The PID Feedback Controller in the Intelligent Control Model

The error signal *e(t)* concurrently passes every element of PID feedback controller. It computes the output signal according to the following equation.

$$o = o_0 + K_p \bullet e(t) + K_i \bullet \int_0^t e(t)dt + K_d \bullet e^{'}(t) \qquad (3)$$

In Eq. 3, $o_0$ denotes the output offset, which corresponds to the action point of PID. When the error signal $e(t)$ is zero, the output $o$ is $o_0$. $K_p$ denotes the proportion element. $K_i \bullet \int_0^t e(t)dt$ denotes the integral element, which equals the multiplication of integral gain $K_i$ and the integral value of the error signal ranging from zero to current time. $K_d \bullet e^{'}(t)$ denotes the differential element, which equals the multiplication of differential gain $K_d$ and the time derivative of the error signal.

The aerodynamics model uses a coefficient build-up method for modeling the aerodynamic characteristics of aircraft. It is mainly used to update several types of forces and moments of force inflicted on the aircraft.

The propulsion model exists for the purpose of providing a realistic perception of the propulsion system from the point of view of a pilot, as well as providing accurate forces and moments on the aircraft.

The non-dynamics model also provides a group of speeds. But these speeds can be fetched by a pre-defined script, which is different from the aerodynamics model.

In the equations of motion model, the total resultant forces and moments inflicted on the aircraft are computed, and the full momentum equations of motion are solved. Thus several types of speeds of the aircraft are fetched. It supports aircraft motion over a rotating and spherical earth.

The orientation model is used to convert the speeds into the position and orientation in the inertia coordinates, and then solve the Euler angles of the aircraft, which is used to update the meter display values.

The computing of the equations of motion requires the atmosphere model, because the aerodynamics forces, moments and the engine propulsion all depend on the atmosphere [4]. In MMBFMS, the atmosphere model adopts NRLMSISE-00 [5].

The detailed building process of the intelligent simulation math model has been expatiated on in literature [6~8]. The readers may refer to these literatures.

### 4.5 The Display Queue Model

The display queue model answers for storing the data which is computed by the orientation model. The queue also adopts the data structure of doubly linked list, whose size can be configured according to the practice. The default size is 10. The structure and the merits of the queue are as the same as that in 4.3, which is not narrated in detail again.

By adopting the data queue, the system running speed is improved, because the data need not wait for the computing of the intelligent simulation math model. The interface displays more glibly and the simulation effect is more lifelike.

### 4.6 The Meter Display Model

The meter display model adopts the OpenGL technology. OpenGL is a professional 3D program interface and graphic library. This model firstly initializes the corresponding graphics and sound resources. Secondly, it continuously fetches data from the display queue model and real-timely shows the current state on the computer terminal. The timeslice of fetching data can be configured by the program. The default timeslice is 500ms.

## 5. The Experiment Data

The experiment data was obtained in the process of simulating the training plane of type-VI in MMBFMS. Three basic actions were tested: ascending (Table 1), level and descending (Table 2); Two stunt actions: hovering (Table 3) and diving (Table 4). The experiment data is showed as the following tables.

Table 1: The Experiment Data of Ascending

| *Elevation (degree)* | *Gradient (m/s)* | *Speed (km/h)* | *Rotate Speed (revolution/min)* | *Intake Pressure (mercury)* |
|---|---|---|---|---|
| 14.89 | 9.87 | 110.08 | 2055.01 | 635.24 |
| 11.01 | 8.12 | 125.04 | 2022.40 | 650.06 |
| 9.12 | 5.50 | 138.20 | 1998.36 | 625.43 |
| 5.06 | 3.01 | 170.00 | 1895.44 | 615.10 |

Table 2: The Experiment Data of Level and Descending

| *Elevation (degree)* | *Gradient (m/s)* | *Speed (km/h)* | *Rotate Speed (revolution/min)* | *Intake Pressure (mercury)* |
|---|---|---|---|---|
| 3.05 | 0.23 | 181.06 | 2053.04 | 433.01 |
| 2.89 | 0.14 | 198.97 | 2076.19 | 498.84 |
| 3.03 | 0.07 | 273.02 | 2110.82 | 669.34 |
| 1.03 | -3.06 | 178.50 | 2051.36 | 303.11 |

Table 3: The Experiment Data of Hovering

| *Slope (degree)* | *Altitude (m)* | *Speed (km/h)* | *Intake Pressure (mercury)* | *Radius (m)* | *Time (s)* |
|---|---|---|---|---|---|
| 30.23 | 1311.03 | 205.05 | 546.01 | 450.11 | 50 |
| 45.06 | 1320.40 | 211.36 | 538.10 | 378.25 | 38 |
| 60.37 | 1314.86 | 200.53 | 535.04 | 210.13 | 22 |

Table 4: The Experiment Data of Diving

| *Altitude (m)* | *Angle of Depression (degree)* | *Starting Speed (km/h)* | *Ending Speed (km/h)* | *Intake Pressure (mercury)* | *Height of Descending (m)* |
|---|---|---|---|---|---|
| 1453.24 | -15.02 | 171.58 | 305.45 | 413.34 | 190.80 |
| 1461.33 | -30.31 | 173.12 | 311.25 | 415.00 | 277.54 |

Through tested by some senior pilots, it proves that the experiment data obtained in the test is very close to the actual flight data, which is in the effective error range. This indicates that the model is correct, effective and applied.

## 6. Conclusions and Future Works

This paper mainly introduces a flight meter simulation training system based on intelligent simulation math model. It is an effective real-time dynamic flight simulator. It shortens the flight training period, reduces the flight dangers and saves a great deal of funds. In the actual practice, MMBFMS receives users' praise.

On the whole, MMBFMS has the following characteristics.

Firstly, in the design, the intelligent control method and technology are adopted, which makes the system error decrease gradually. It considers the expansibility of the software and hardware. So the functions are convenient to be added in the future, such as weapon launching, aviation electron, and etc.

Secondly, in the realization, it fully considers the agility by importing the XML configuration file and can simulate all kinds of aircrafts.

The research of motion system and scene simulation is now under way. Some results have been obtained, which will be expatiated on in the posterior papers.

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**Jian Zhang** received the B.S. and M.S. degrees in Computer Application from the College of Computer Science and Technology, Jilin University of China, in 2000 and 2003, respectively. From 2000 to now, he stayed in the Key Laboratory of Symbolic Computation and Knowledge Engineering of Ministry of Education, Jilin University of China, to study the workflow technology, artificial intelligence, decision support system, and etc. Now he is a PHD student to continue the above mentioned study fields.

**Jigui Sun** is professor of Jilin University of China. The research fields include artificial intelligence, automated reasoning, constraint program design, decision supporting system, and etc.

**Changsheng Zhang** received the M.S. degree from the College of Computer Science and Technology, Jilin University of China, in 2006. Now he is a PHD student of Jilin University of China. The research fields include intelligent control, visual reality, and etc.