



**THE 26th CHINESE CONTROL AND
DECISION CONFERENCE**

Final Program and Book of Abstracts

Hunan Fenglin Hotel
Changsha, China
May 31–June 2, 2014

Organizers

Northeastern University, China
IEEE Industrial Electronics (IE) Chapter, Singapore
IEEE Harbin Section Control Systems Society Chapter, China
Hunan University of Technology, China
Central South University, China



2014 CCDC Technical Program Monday June 2, 2014

Track 1	Track 2	Track 3	Track 4	Track 5	Track 6	Track 7	Track 8	Track 9	Track 10	Track 11	Track 12
Room 11A 08:00-10:00 MonA01	Room 6A 08:00-10:00 MonA02	Room 7A 08:00-10:00 MonA03	Room 7B 08:00-10:00 MonA04	Room 8A 08:00-10:00 MonA05	Room 8B 08:00-10:00 MonA06	Room 9A 08:00-10:00 MonA07	Room 9B 08:00-10:00 MonA08	Room 10A 08:00-10:00 MonA09	Room 10B 08:00-10:00 MonA10	Room 11B 08:00-10:00 MonA11	The lobby of the 4th floor 08:00-10:00 MonA12-4B
Robust control-III(Chinese)	Optimal control and optimization-IV(Chinese)	Nonlinear systems-III(Chinese)	Hybrid systems	Delay systems (Chinese)	Fault diagnosis and fault-tolerant control-IV(Chinese)	Supply chain and logistics management	Instrumentation systems	Space and underwater robots	Renewable energies-III	Computer Games/Invited Session-I(Chinese)	Interactive Session MonA13-4B
10:20-12:20 MonB01	10:20-12:20 MonB02	10:20-12:20 MonB03	10:20-12:20 MonB04	10:20-12:20 MonB05	10:20-12:20 MonB06	10:20-12:20 MonB07	10:20-12:20 MonB08	10:20-12:20 MonB09	10:20-12:20 MonB10	10:20-12:20 MonB11	10:20-12:20 MonB12
Complex networks and systems-II	Co-operative control(Chinese)	Intelligent systems-II(Chinese)	Distributed parameter systems	Decision-making theory and method-IV(Chinese)	Fault diagnosis and fault-tolerant control-V(Chinese)	Control applications-IV	Mobile robotics (Chinese)	Modeling, control and simulations of biological systems-I	Traffic control	Computer Games/Invited Session-II(Chinese)	Interactive Session MonB13-4B
13:20-15:20 MonC01	13:20-15:20 MonC02	13:20-15:20 MonC03	13:20-15:20 MonC04	13:20-15:20 MonC05	13:20-15:20 MonC06	13:20-15:20 MonC07	13:20-15:20 MonC08	13:20-15:20 MonC09	13:20-15:20 MonC10	13:20-15:20 MonC11	13:20-15:20 MonC12
Complex networks and systems-III(Chinese)	Identification and estimation-III(Chinese)	Intelligent systems-III(Chinese)	Stochastic systems	Decision-making theory and method-V(Chinese)	Signal processing-II(Chinese)	Control applications-V(Chinese)	Planning, scheduling and coordination-III(Chinese)	Modeling, control and simulations of biological systems-II	Smart grids-II(Chinese)	Motion control -II(Chinese)	Interactive Session MonC13-4B
15:40-17:40 MonD01	15:40-17:40 MonD02	15:40-17:40 MonD03	15:40-17:40 MonD04	15:40-17:40 MonD05	15:40-17:40 MonD06	15:40-17:40 MonD07	15:40-17:40 MonD08	15:40-17:40 MonD09	15:40-17:40 MonD10	15:40-17:40 MonD11	15:40-17:40 MonD12
Complex networks and systems-IV(Chinese)	Sensor network systems-III(Chinese)	Decision supporting system and production planning and scheduling-I(Chinese)	Nonlinear systems-IV(Chinese)	Networked control systems-III(Chinese)	Data processing-II(Chinese)	Control applications-VI(Chinese)	Network-based systems (Chinese)	Multi-legged robot systems (Chinese)	Energy management systems (Chinese)	Fuzzy systems (Chinese)	Interactive Session MonD13-41

12:20-13:20 Lunch

18:00-20:00 Buffet

12:00-12:20
Revisiting singular Boolean networks
Min Meng
June Feng

Shandong Univ.
Shandong Univ.

Ronglin Hu

Huaiyin Inst. of Tech.

MonB02
Co-operative control
Chair: Jianxiang Xi
CO-Chair: Zhiyong Geng

Room6A
10:20-12:20
High-Tech Institute of Xi'an
Peking Univ.

11:40-12:00
Video Abstraction via
Sonhao Zhu

Learning the Progress of Story
Nanjing Univ. of Post and Telecommunications,
Yangzhou Suan IOT Sensor Tech. Co., Ltd.
Nanjing Univ. of Post and Telecommunications,
Yangzhou Suan IOT Sensor Tech. Co., Ltd.,
Huaiyin Inst. of Tech.

MonB03-5

10:20-10:40
Finite Time Optimal Formation Control for Multiple Vehicles
Zhiyong Geng

MonB02-1
Peking Univ.

10:40-11:00
Coverage and Control of Diffusion Process based on Centroidal Voronoi Tessellations
KeCai Cao

MonB02-2

Nanjing Univ. of Posts and Telecommunications
Nanjing Univ. of Posts and Telecommunications
Nanjing Univ. of Posts and Telecommunications
Nanjing Univ. of Posts and Telecommunications

A novel approach for improving image annotation quality
Nanjing Univ. of Post and Telecommunications,
Yangzhou Suan IOT Sensor Tech. Co., Ltd.
Nanjing Univ. of Post and Telecommunications,
Yangzhou Suan IOT Sensor Tech. Co., Ltd.,
Huaiyin Inst. of Tech.

MonB03-6

MengJiao Lv
Xiang Gao
PingWei Fan

11:00-11:20
Formation Tracking Control for Multi-agent Systems with Nonlinear Dynamics via Impulsive Control
Meng Liu
Yanwu Wang
Jiangwen Xiao
Xiaokang Liu

MonB02-3

Huazhong Univ. of Scie. and Tech.
Huazhong Univ. of Scie. and Tech.
Huazhong Univ. of Scie. and Tech.
Huazhong Univ. of Scie. and Tech.

MonB04
Distributed parameter systems
Chair: Lu Lu
CO-Chair: Leping Bao

Beijing Institute of Tech.
Southeast Univ.

Room 6
10:20-12:20

10:20-10:40
An Architecture Model of Cloud Manufacturing Based on Multi-Agent Technology
Han Zhang

Shenyang Inst. of Computing Tech., Chinese Acad. of Scie.
Shenyang Inst. of Computing Tech., Chinese Acad. of Scie.;
National Engineering Research Center For High-End CNC
National Engineering Research Center For High-End CNC

MonB04-1

11:20-11:40
Observer-based Finite-time Tracking Control for Formations of Mobile Robots
Talren Sun
Xin Yu
Guohai Liu

MonB02-4

Jiangsu Univ.
Jiangsu Univ.
Jiangsu Univ.

10:40-11:00
Asymptotical stabilization of linear distributed parameter switched systems
Leping Bao

Key Lab. of Measurement and Control of Complex Sys. of Engineering, Ministry of Education;
Southeast Univ.
Key Lab. of Measurement and Control of Complex Sys. of Engineering, Ministry of Education;
Southeast Univ.

MonB04-2

11:40-12:00
Consensus-based Formation Control with Dynamic Role Assignment
Zhongqi Sun
Yuanqing Xia

MonB02-5

Beijing Institute of Tech.
Beijing Institute of Tech.

12:00-12:20
Second-order Consensus of Discrete-time Multi-agent Systems via One-step Delayed data
Guanghui Xu
Jishi Zhang

MonB02-6

Huazhong Univ. of Scie. and Tech.
Huazhong Univ. of Scie. and Tech.
Henan Univ.
Yangtze Univ.
Yangtze Univ.
Huazhong Univ. of Scie. and Tech.

11:00-11:20
Mobile sensor networks for sampled-data control of a class of distributed parameter systems
Xueming Qian
Baotong Cui

Jiangnan Univ.
Jiangnan Univ.

MonB04-3

MonB03
Intelligent systems (II)
Chair: Zhifu Li
CO-Chair: Hexu Sun

Room7A
10:20-12:20

South China Univ. of Tech.
Hebei Univ. of Tech.

11:20-11:40
Exponential Stability for Linearized Korteweg-de Vries-ODE system
Lu Lu
Dong-Xia Zhao
Lin-Hong Yao

Beijing Institute of Tech.
North Univ. of China
North Univ. of China

MonB04-4

10:20-10:40
Monotonically convergent feedback-forward iterative learning control for linear discrete-time systems
Zhifu Li
Yueming Hu

MonB03-1

South China Univ. of Tech.
South China Univ. of Tech.

11:40-12:00
Stabilization for boundary controlled cascaded heat-ODE system with time-dependent coefficient
Zhongcheng Zhou

Southwest Univ.

MonB04-5

10:40-11:00
Improved Differential Evolution Algorithm and its Application in Complex Function Optimization
XiaoGang Dong
Yan Liu
ChangShou Deng

MonB03-2

Jiujiang Univ.
Jiujiang Univ.
Jiujiang Univ.

MonB05
Decision-making theory and method (IV)
Chair: Dalzhan Cheng
CO-Chair: Renzi Yang

Shandong Univ.
Southeast Univ.

Room 6
10:20-12:20

11:00-11:20
Predictive Image Based Visual Servoing of Manipulators with Multiple Constraints
welpeng Liu
Halyong Chen
Hexu Sun
Guansheng Xing

MonB03-3

Hebei Univ. of Tech.
Hebei Univ. of Tech.
Hebei Univ. of Tech.
Hebei Univ. of Tech.

10:20-10:40
Convergence of Potential Networked Evolutionary Games
Yuanhua Wang
Ting Liu
Daizhan Cheng

Shandong Univ.
Chinese Academy of Scie.
Shandong Univ.
Chinese Academy of Scie.

MonB05-1

11:20-11:40
A Novel Method For Face Recognition
Sonhao Zhu

MonB03-4

Nanjing Univ. of Post and Telecommunications;

10:40-11:00
Integer Programming Based Optimal Side Jets Ignition Combination for Advanced Missile Attitude Control
Zhenchao Wang
Lingyu Yang
Jing Zhang

Beijing Univ. of Aeronautics and Astronautics
Beijing Univ. of Aeronautics and Astronautics
Beijing Univ. of Aeronautics and Astronautics

MonB05-2

Integer Programming Based Optimal Side Jets Ignition Combination for Advanced Missile Attitude Control

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Abstract: The ignition logic of Reaction Control System (RCS) is one of the core issues of the precision and blended control combined aerodynamic force and reaction force of the advanced guided weapons. Firstly, a side-jet model based on the American Patriot Advanced Capability-3(PAC-3) missile was established, and a calculation method based on the equivalent forces, which convert the positional deviation of the thrusters to the deviation of the equivalent forces, was proposed. Considering the side-jets constraint, the ignition logic is transformed into a mathematical problem based on 0-1 integer programming. To deal with the high complexity of traditional algorithms for 0-1 integer programming model, restrictions of the thruster efficiency, was introduced to reduce the complexity of the algorithm and the computation time. Finally, simulation results indicate that this algorithm can satisfy the requirement and find out a better solution.

Key Words: Integer Programming , Blended Control ,Reaction Control System (RCS), Ignition Logic

1 INTRODUCTION

The new generation of ballistic missiles and near-space weapons carries out the attacks through aerial invasion, high Mach number speed reentry and mobile penetration. Those targets fly at rarefied atmosphere airspace, leading to that the aerodynamic effects on traditional intercept weapons are poor in mobility and the overload response time is too long. Thus the success rates of interception drop. For this reason, the paper introduces the blended control combined aerodynamic force and reaction force, which needs to apply the RCS thrusters or divert and attitude control system in the missile body controlled by an array of single shot, high thrust, short duration and solid propellant rocket thrusters [1, 2], such as the missile of American Patriot Advanced Capability-3(PAC-3) consisting of 10 rings of 18 RCS thrusters.

The control of reaction force is actually a combination of all thrusters, which is influenced by the thruster efficiency, control accuracy and other factors. The difficulty lies in that the current RCS thrusters mostly are not adjustable and it is difficult to adjust the side jet forces continuously. Besides each one of the RCS thrusters cannot work twice because of its single shot. Then how to combine the RCS thrusters is one of the key issues on the blended control combined aerodynamic force and reaction force.

Reference [3] gives out a symmetric ignition algorithm. In the direction of side jet force on the demand, the selected

RCS thrusters are symmetrically fired. Its advantage is that it is convenient to solve the solution and the symmetry ignition can greatly reduce the effects of side jet interference. However, in the process of the continuous ignition, if one of thrusters has been used, the other one in the symmetrical position will not be available. It will reduce the efficiency of the thrusters. In Reference [4], the algorithm model is simplified that the force of side jets and the desired force are all integer. Thus the algorithm is difficult to meet the demand of engineering practices with large complexity. Reference [5] provides the process of ignition conditions and ignition logic. However, it only proves the correctness of the algorithm, and it is not optimized of its ignition internal algorithm logic.

Considering the characteristics of the RCS thrusters, the paper uses the method based on the equivalent forces and 0-1 integer programming model to solve the ignition logic. Besides, since the complexity of traditional algorithms for 0-1 integer programming model is very large, the paper adds restrictions on the thruster efficiency to reduce the amount of data related to the RCS thrusters and reduce the complexity of the algorithm under the premise of ensuring the results meet the requirements. Finally, we take the PAC-3 missile for example. The paper builds a simulation model about the ignition logic of the RCS thrusters based on 0-1 integer programming algorithm, and gives out the simulation results and conclusions.

This work is supported by Aviation Science Foundation of China.

2 PLACEMENT OF RCS THRUSTERS

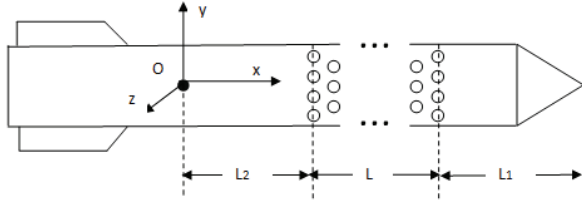


Fig 1. Schematic of PAC-3 missile

Figure 1 is the schematic of PAC-3 missile in the body coordinates system (Oxyz). The RCS thrusters are consisted of $2N$ rings of M thrusters. Thus the number of the RCS thrusters is $2N \times M$. L represents the width of RCS, L_1 represents the distance from the area of RCS to the warheads and L_2 represents the distance from the area of RCS to the barycenter in the X-axis direction.

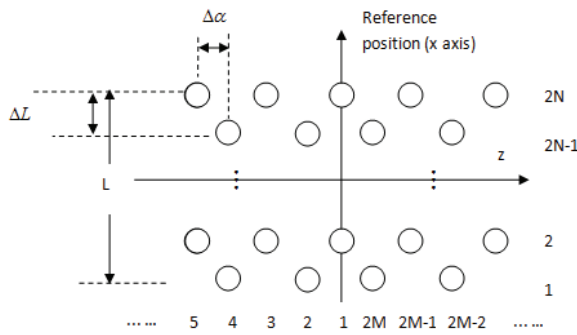


Fig 2. Placement schematic of RCS thrusters

Select a column of thrusters in the x-axis in the x-y plane as the reference position as shown. For the convenience of calculation and numbering, define the two adjacent rings of the thrusters as one layer. So there are N layers thrusters with $2M$ thrusters in each layer. As shown in Figure 2, starting from the reference position in the direction towards the warhead, the thrusters of the first ring are numbered counterclockwise as $1, 2, 3, \dots, 2M$. ΔL represents the distance between two adjacent rings of the thrusters in the X-axis direction and $\Delta \alpha$ represents the distance between two adjacent columns of the thrusters that the direction is perpendicular to the X-axis direction.

$$\Delta L = \frac{L}{N-1} \quad (1)$$

$$\Delta \alpha = \frac{2\pi}{2M} = \frac{\pi}{M} \quad (2)$$

Let the average jet force of a single thruster be F_p , then the moment of one thruster, whose index of the ring is 'i', relatively to the barycenter is

$$M_i = F_p [L_2 + \Delta L(i-1)], i \in [1, 2, \dots, 2N] \quad (3)$$

3 DESIGN OF IGNITION LOGIC

3.1 Equivalent forces of RCS

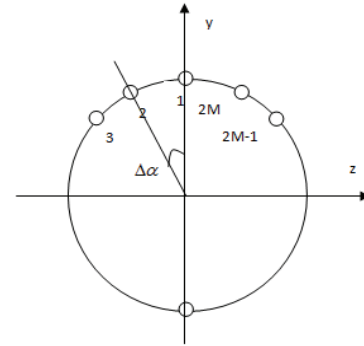


Fig 3. Schematic of longitudinal projection about RCS

All thrusters will be projected onto the same circumference, that the index of the layer is N , as shown in Figure 3 in the direction towards the warhead.

Taking the consumption of RCS thrusters into account, the barycenter of the missile is changing. When calculating the equivalent forces, the paper uses the warhead as the reference point instead of the barycenter.

Before the projection, the distances of the different rings of thrusters to the warhead are different, so the moments generated by the different rings of thrusters are different. And the distances of the different rings of thrusters to the warhead are same after the projection. Note the equivalent of forces as:

$$\tilde{F}_i = \frac{L_1 + \Delta L(i-1)}{L_1} F_p, i \in [1, 2, \dots, 2N], \quad (4)$$

where F_p is the average jet force of a single thruster, i the index of the thrusters. Then the equivalent forces matrix of thrusters can be defined as:

$$\tilde{\mathbf{F}}_J = \begin{bmatrix} \tilde{F}_{J,1}^1 & \tilde{F}_{J,2}^1 & \dots & \tilde{F}_{J,N-1}^1 & \tilde{F}_{J,N}^1 \\ \tilde{F}_{J,1}^2 & \tilde{F}_{J,2}^2 & \dots & \tilde{F}_{J,N-1}^2 & \tilde{F}_{J,N}^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{F}_{J,1}^{2M-1} & \tilde{F}_{J,2}^{2M-1} & \dots & \tilde{F}_{J,N-1}^{2M-1} & \tilde{F}_{J,N}^{2M-1} \\ \tilde{F}_{J,1}^{2M} & \tilde{F}_{J,2}^{2M} & \dots & \tilde{F}_{J,N-1}^{2M} & \tilde{F}_{J,N}^{2M} \end{bmatrix}_{2M \times N} \quad (5)$$

After the equivalent calculation, the changes of moments generated by the different positions of the RCS thrusters are regarded as the changes of the side jet forces. And the calculation process is also simplified.

3.2 Work area of RCS

For the convenience of analysis, the desired side jet force command $F_c \angle \theta_c$ is given out. As shown in Figure 4, F_c is the value of the desired side jet force and θ_c is the angle from the reference position to the desired command position of F_c in a counterclockwise direction.

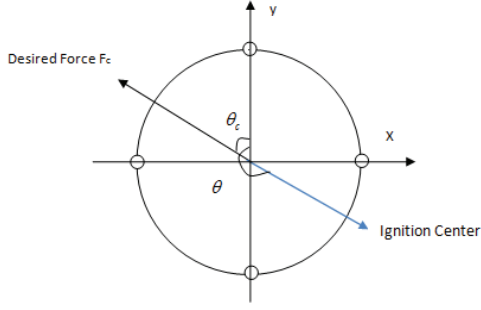


Fig 4. Determination of Ignition Center

According to the reaction effect of RCS, the angle of the ignition center is defined as $\theta = \theta_c + \pi$, which is from the reference position to the ignition center in a counterclockwise direction.

After determining the ignition center, select the adjacent columns of thrusters as the effective work area. This area determines the number of thrusters involved in ignition logic. Because of single shot of RCS, in order to improve the utilization efficiency of RCS, introduce the work efficiency of the RCS thrusters for evaluation.

The definition as stated in the second section, the intersection angle between the reference position and the m -th column is

$$\theta_m = (m-1)\Delta\alpha. \quad (6)$$

The intersection angle between the ignition center and the m -th column is

$$\Delta\theta_m = \theta - \theta_m. \quad (7)$$

Since the equivalent forces of RCS thrusters in the same column are different, the formula (5) can give out the equivalent forces of the m -th column.

$$\tilde{\mathbf{F}}_J^m = [\tilde{F}_{J,1}^m, \tilde{F}_{J,2}^m, \dots, \tilde{F}_{J,N}^m] \quad (8)$$

Then, the vector decomposition of this column in the direction of the ignition center (define it as y axis, and the direction that deviated from the missile is positive) is:

$$\tilde{\mathbf{f}}_{y,m} = \tilde{\mathbf{F}}_J^m \cos(\Delta\theta_m). \quad (9)$$

The vector decomposition of this column in the vertical direction of the ignition center (define it as x axis, and the right direction is positive toward the warhead) is:

$$\tilde{\mathbf{f}}_{x,m} = \tilde{\mathbf{F}}_J^m \sin(\Delta\theta_m). \quad (10)$$

Through the vector decomposition, it will be seen that the greater of the angle to the ignition center, the smaller the projected moments component in the direction of the desired command. And it shows the cosine relationship. Then let the work efficiency of the RCS thrusters be

$$\eta_k = \cos(\theta_k). \quad (11)$$

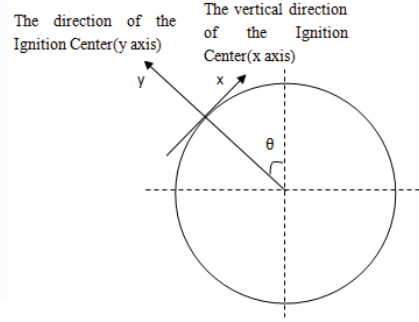


Fig 5. The vector decomposition in the position of the ignition center

Thereinto θ_k is the intersection angle between the ignition center and the k -th column of thrusters.

Let the index of the RCS thrusters which is nearest to the ignition center be m :

$$m = \text{round}(\theta / \Delta\alpha) + 1, \quad (12)$$

where the $\text{round}()$, represents rounding. Select δ columns from each side of its left and right as the work area of RCS as shown in Figure 6.

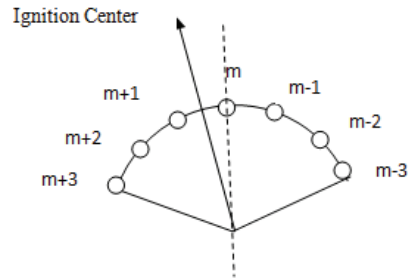


Fig 6. Diagram of thruster efficiency

This ensures that the high efficient RCS thrusters will be used and the work efficiency of the thrusters in this region satisfies the following formula:

$$\eta_{\min} \geq \cos((\delta + 0.5)\Delta\alpha), k \in [m - \delta, m + \delta]. \quad (13)$$

It will avoid the waste of energy through this method and improve calculation efficiency.

3.3 Integer programming model

Because the RCS thrusters work in a single shot style, in order to ensure these thrusters are available, the state information of thrusters need be updated in real time. Let the matrix \mathbf{X} be the state information matrix of RCS.

$$\mathbf{X} = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \dots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{2M-1} & x_2^{2M-1} & \dots & x_{N-1}^{2M-1} & x_N^{2M-1} \\ x_1^{2M} & x_2^{2M} & \dots & x_{N-1}^{2M} & x_N^{2M} \end{bmatrix}_{2M \times N} \quad (14)$$

x_j^i represents the state of RCS at the i -th column and the j -th layer. It represents this thruster has been used at this position if $x_j^i = 0$ and it has not been used if $x_j^i = 1$.

Furthermore, according to formulas (11) and (12), the state information matrix of available thrusters is just as follows:

$$\hat{x}_j^i = \begin{cases} 0 & i \notin [m-\delta, m+\delta] \\ x_j^i & i \in [m-\delta, m+\delta] \end{cases}, \quad (15)$$

where k is the number of thrusters which are available in the work area.

$$k = \sum_{i=1}^{2M} \sum_{j=1}^N \hat{x}_j^i \quad (16)$$

It indicates there are k thrusters which are involved in ignition logic.

$$\hat{f}_x = [\hat{f}_{x,1}, \hat{f}_{x,2}, \dots, \hat{f}_{x,k}] \quad (17)$$

$$\hat{f}_y = [\hat{f}_{y,1}, \hat{f}_{y,2}, \dots, \hat{f}_{y,k}] \quad (18)$$

Formulas (17) and (18) are respectively the projection of the equivalent forces of thrusters in the direction of x axis and y axis.

$$q = [q_1, q_2, \dots, q_{k-1}, q_k]^T, q_i \in \{0,1\} \quad (19)$$

Formula (19) is composed of the state variables of the thrusters involved in ignition logic. The corresponding thruster will be selected if $q_i = 1$ and it won't be selected if $q_i = 0$.

Then the ignition logic of RCS is transformed into a mathematical problem based on the 0-1 integer programming model:

$$(1) \begin{cases} \min z = \sum_i^k f_{i,y} q_i \\ \text{s.t. } \sum_i^k f_{i,y} q_i \geq F_c \\ \left| \sum_i^k f_{i,x} q_i \right| \leq \lambda F_c \\ q_i \in \{0,1\} \end{cases} \quad (2) \begin{cases} \max z = \sum_i^k f_{i,y} q_i \\ \text{s.t. } \sum_i^k f_{i,y} q_i \leq F_c \\ \left| \sum_i^k f_{i,x} q_i \right| \leq \lambda F_c \\ q_i \in \{0,1\} \end{cases}, \quad (20)$$

where $\lambda \in [0,0.5]$ and it represents a control coefficient of the component of the resultant forces produced by RCS in the vertical direction of the ignition center. And the size of λ limits the maximum value of the error between resultant forces and the desired force F_c .

Model (1) in the formula (20) means that the algorithm approaches the optimum solution from the direction of greater than F_c . $\sum_i^k f_{i,y} q_i \geq F_c$ and $\left| \sum_i^k f_{i,x} q_i \right| \leq \lambda F_c$ are respectively the restriction of desired force in the direction of ignition center and its vertical direction.

Model (2) in the formula (20) means that the algorithm approaches the optimum solution from the direction of smaller than F_c .

The approximation algorithm consisting of both sides can get the optimum solution and effectively prevent falling into local optimization.

0-1 integer programming algorithm is based on the branch and bound method. Branch and bound method is a very common algorithm for solving integer programming problems, which is based on the enumeration method. Its basic idea is as follows.

Firstly, the optimal solution of the linear programming which is corresponding to the integer programming is calculated without considering the integer restriction. If the solution is integer, this solution is just the optimal solution. And if not, one of the variables which are not integer is chosen optionally to construct new constraints. Meanwhile parts of the solutions will be excluded which are not integer.

Then, the newly constructed linear programming is solved after reducing the feasible region.

Finally, the optimal solution of the original integer programming is got by solving a series of linear programming problems.

4 SIMULATION RESULTS AND ANALYSIS

For comparison, the paper sets PAC-3 missile model as the reference object and references the data from Reference [3] for simulation. $N = 5$ and $M = 8$ are layout parameters of RCS; $L = 0.41m$ is the width of RCS, $L_1 = 1.232m$ is the distance from the area of RCS to the warheads and $F_p = 238.92N$ is the average jet force of a single thruster.

(1)The size of F_c ranges widely from small to large and it is representative. The simulation results are as follows.

Table1. Simulation Results

Desired Force F_c	Side Jet Force	Error	Number of Thrusters
300	300.7617	0.25%	1
400	413.8216	3.46%	2
700	699.2149	0.11%	3
1000	999.7847	0.02%	4
1500	1499.5	0.00%	6
2500	2501.5	0.10%	9
4000	3997.3	0.10%	15
6000	6002.4	0.00%	23

Through the comparison of data in the Table 1 and the results from Reference [3], it indicates that the errors of results obtained by this algorithm are obviously small.

In addition, through the comparison in Number of Thrusters, we can find that 62.5% of the results are better than those in Reference [3], 12.5% are the same and 25% of the results are worse while the gap is just less than one.

(2)In order to verify the reliability when the algorithm is applied to engineering practices, the paper gives out the simulation when it is working continuously.

The following ten sets of data are different and range widely from 0° to 360° . And the desired forces are also different, which range from 300N to 6400N covering all the allowable range.

Table2. Simulation Results

Desired Force F_c	Side Jet Force	Error	The Cumulative Number of Thrusters
300	300	0.00%	1
1011	1011.7	0.10%	4
1722	1722.3	0.00%	10
2433	2432.3	0.00%	19
3144	3143	0.00%	29
3855	3858	0.10%	44
4566	4562.7	0.10%	57
5277	5278.8	0.00%	75
5988	5746.7	4.00%	93
6199	6199	0.00%	114

For the continuous work of RCS, there are almost no simulations given out up to now. And through simulation analysis of this paper, the errors of the results given by the algorithm are obviously very small. Besides in these ten sets of data, nine errors are within 0.1%, and the maximum error is also less than 5%.

5 CONCLUSION

This paper gives out the innovated ignition logic of RCS based on 0-1 integer programming algorithm. Meanwhile,

the simulation to the representative data, comparing with the results from Reference [3], proves that the algorithm of this paper has the advantages in small error, consuming less number of thrusters and high efficiency of the single thruster. In addition, considering the engineering practices, the paper conducts a simulation to the ignition logic of RCS and gets better results. The results show that the errors are in allowed limits while the number of thrusters and engine efficiency are all optimal. Finally, it is obvious that the algorithm provides a feasible reference method for further applications in engineering practices.

REFERENCES

- [1] Nelson Steve, Marquart Tim Diamond Mike, Low-Cost, Networked Attitude Control Thruster System(ACTS). AIAA Paper,2003-4962.
- [2] William Prins, Alan Spencer, Jim Roberts, SM-3 SDACS Flight Test Successes. AIAA Paper,2003-4664.
- [3] Yang Rui, Xu Min, Chen Shilu, An Approximate but Fast Combined Ignition Algorithm for Attitude Control Thrusters System (ACTS) of Kinetic Interceptor (KI),Journal of Northwestern Polytechnical University,Vol.24,No.1, 2006.
- [4] Zhu Jing, Research on Ignition Logic of Attitude Control Engine, Modern Defence Technology, Vol.35,No.3, 2007.
- [5] Zhan Jianchao, Ren Yongqiang, Zhang Li, Zhu Zhu, The Research on Fire Logic of Attitude Control Pulse Engine, Journal of Projectiles, Rockets, Missiles and Guidance, Vol. 31,No.6, 2011.