On the cable-car feed support configuration for FAST

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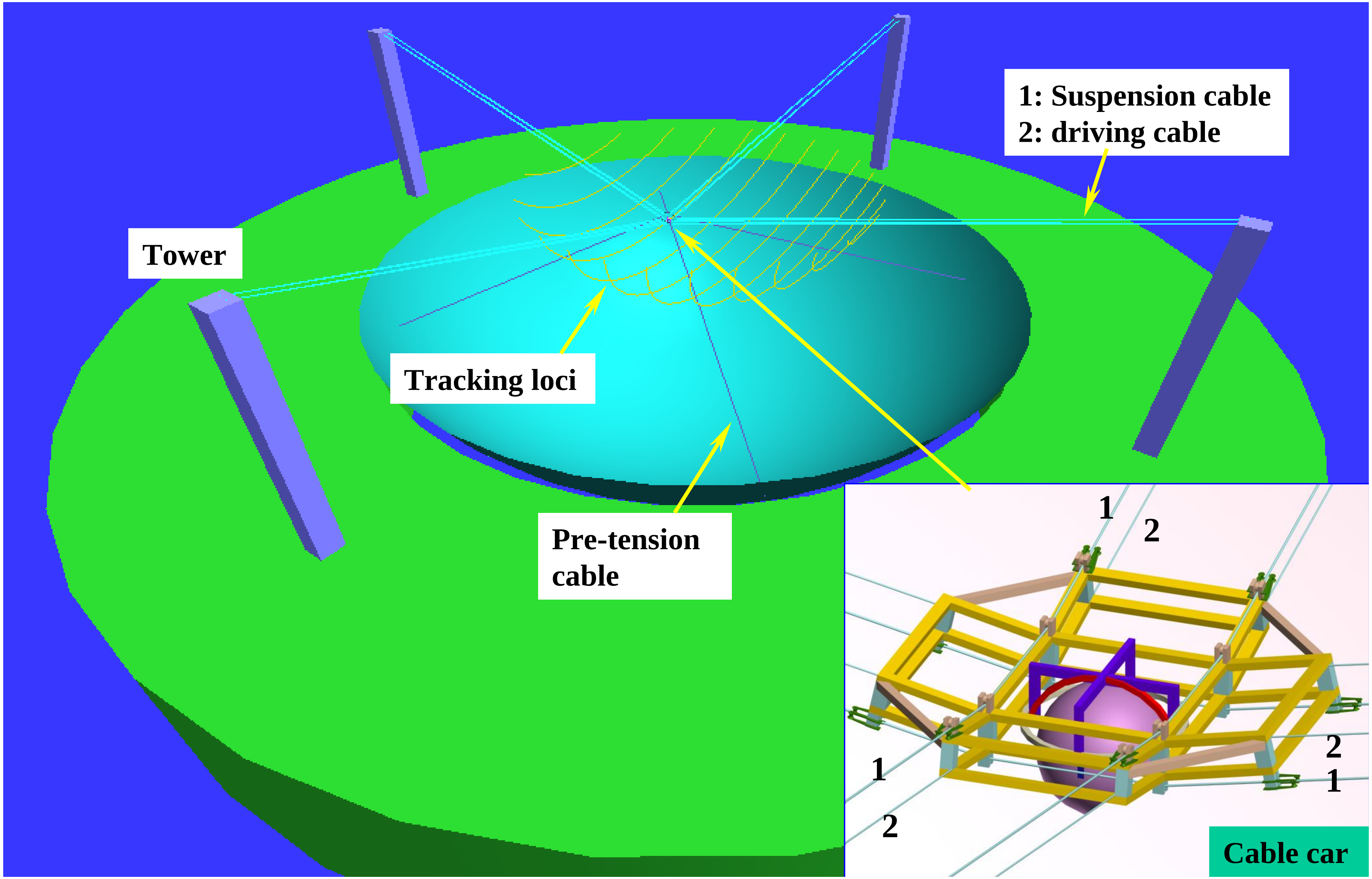
Contents

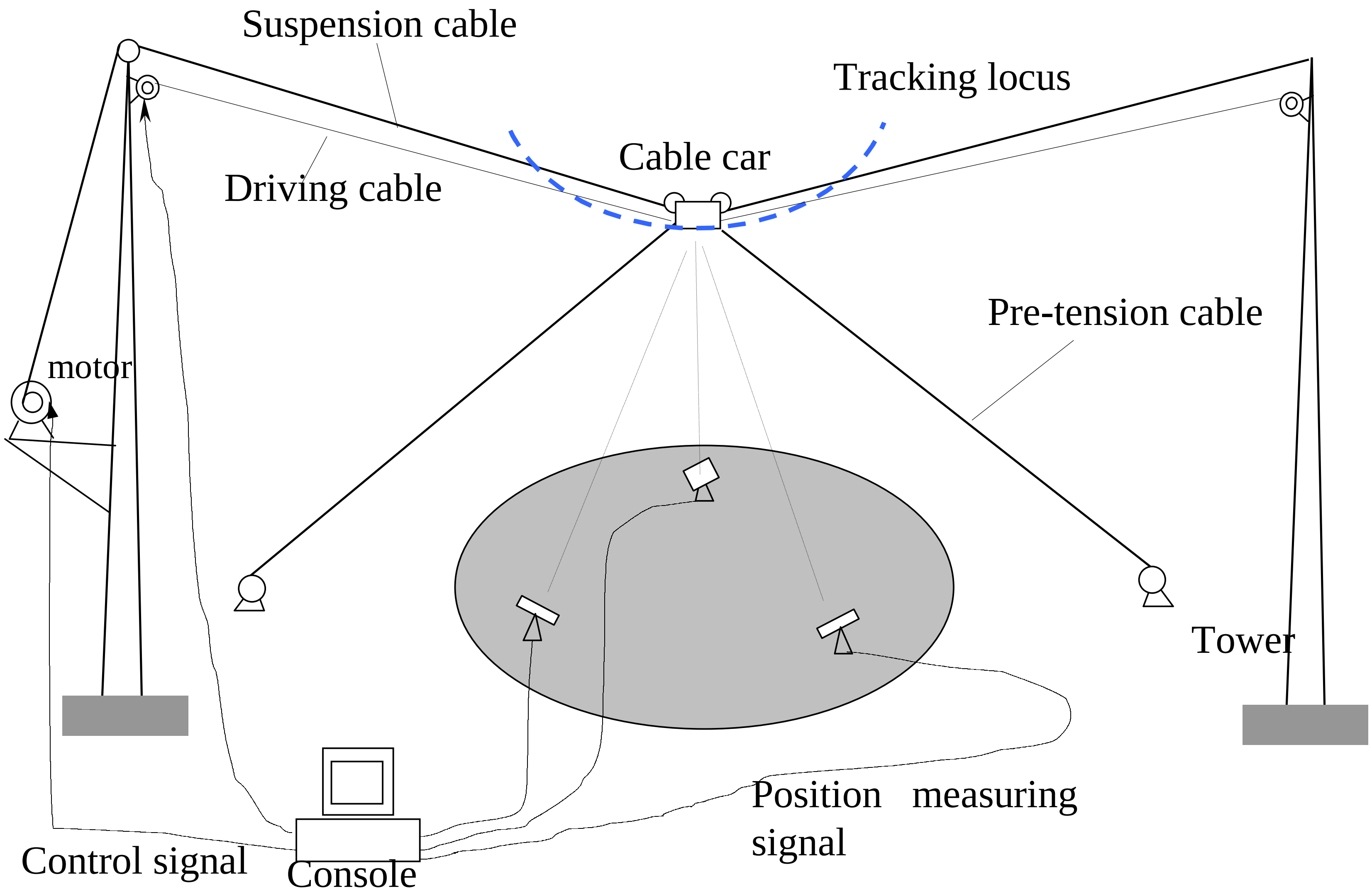
The cable-car feed support configuration



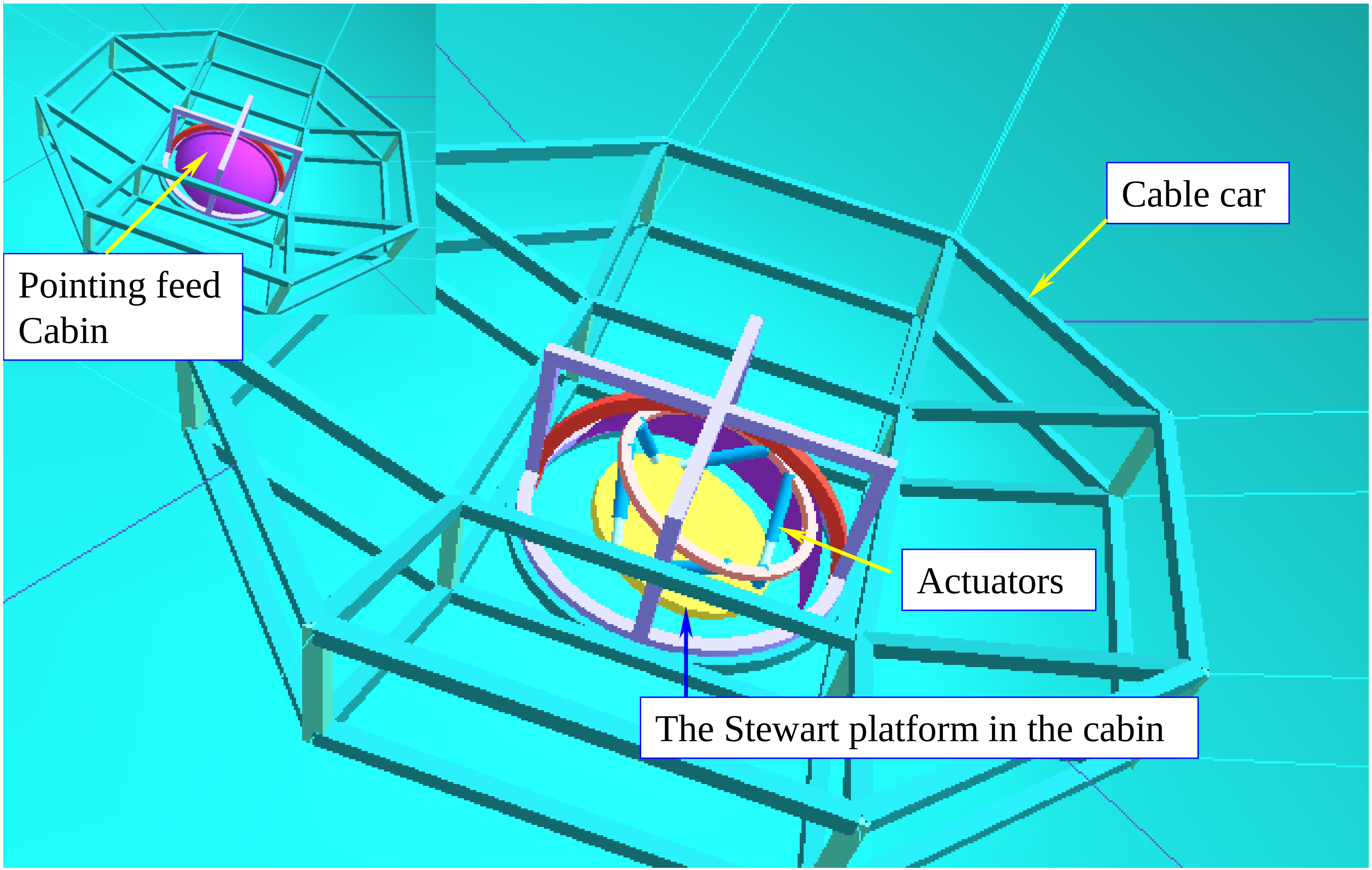
The cable-car feed support configuration includes

1. The cable car(about 15m×15m×5m, 30 tons). The cable car is either self-driven through the driving cable or driven by the driving cable with motors on towers.
2. Two sets of adjustable suspension cables(maximum length variation: about 70m) and driving cables (maximum length variation about 70m for the self-driven car, 170m for cable-driven car)
3. Four supporting towers for suspension cables and driving cables
4. Four passive pre-tension cables for stabilizing the cable car(maximum length varying: about 200m)

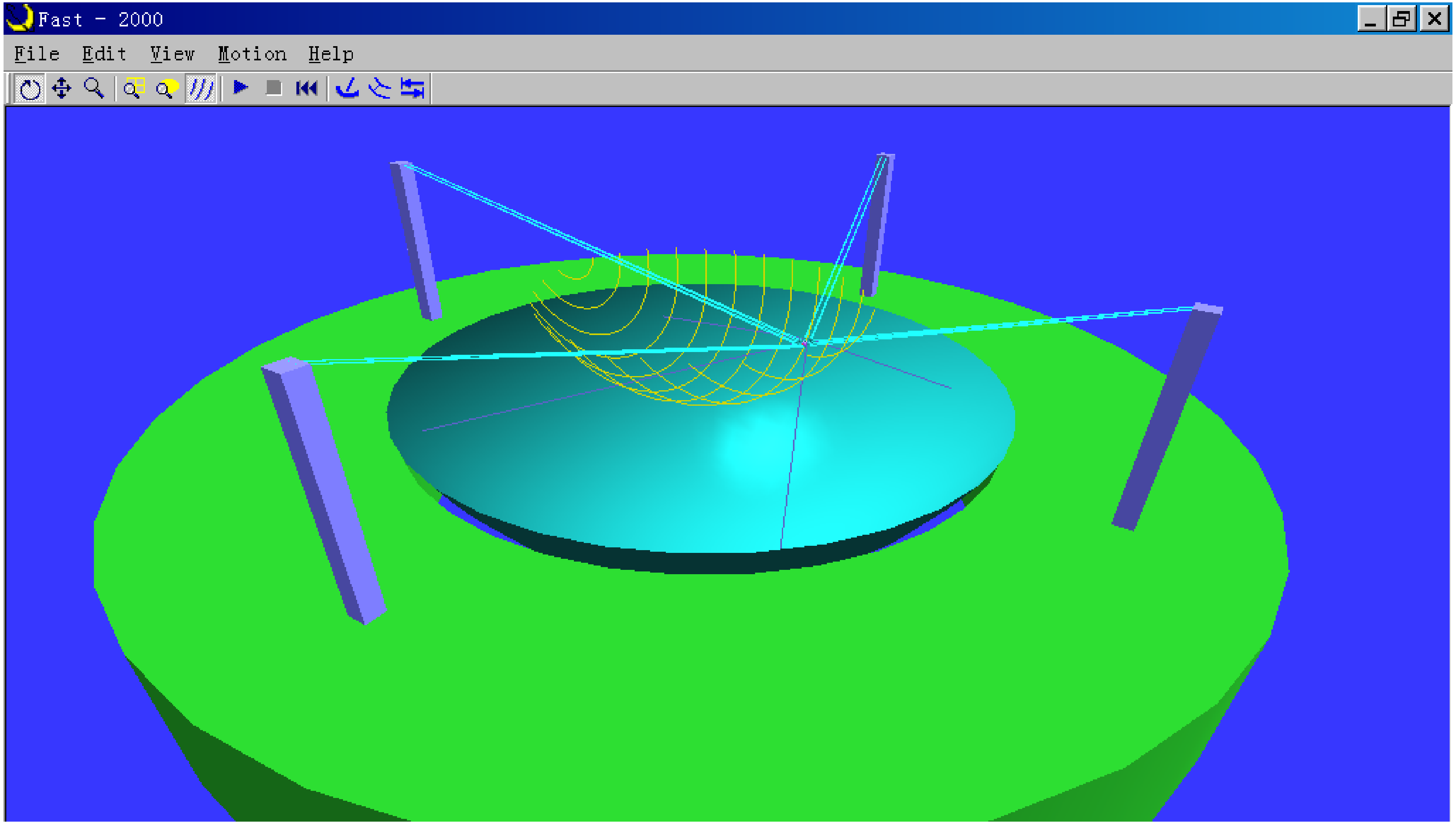
The working diagram of the cable-car feed support configuration



The secondary support: the Stewart Platform for vibration suppression

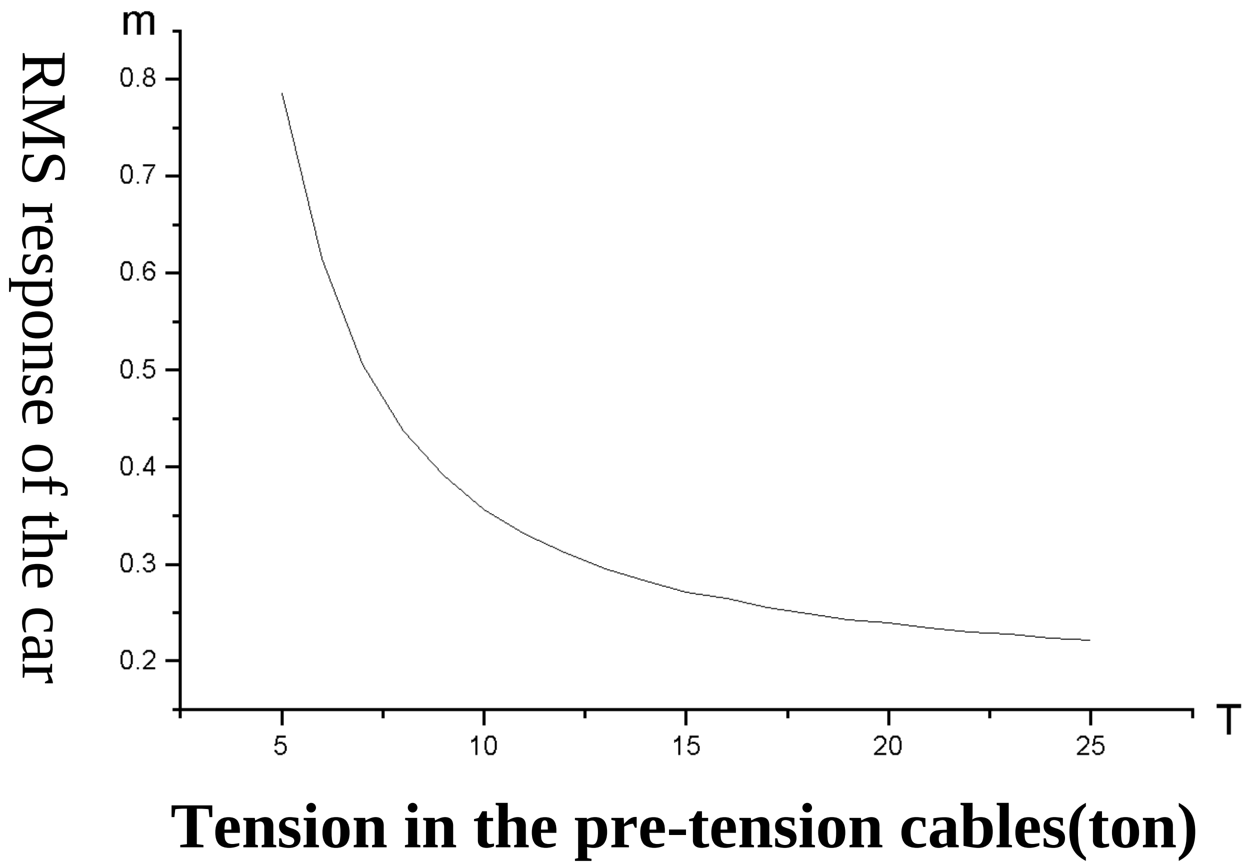


Advances on the first support

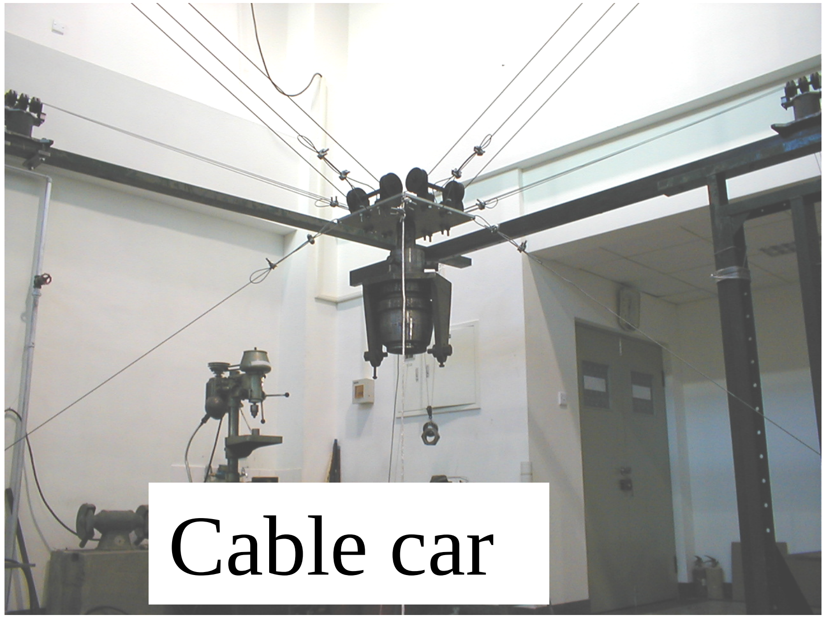


1. The interactive 3D kinematic model is developed to demonstrate the configuration

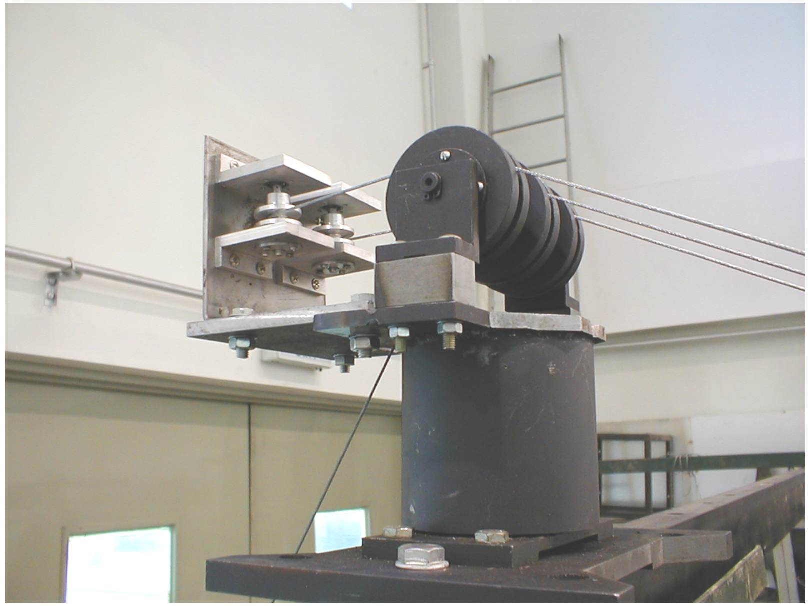
2. The FEM analysis package is developed, the effect of pre-tension cable is assured by FEM computation.



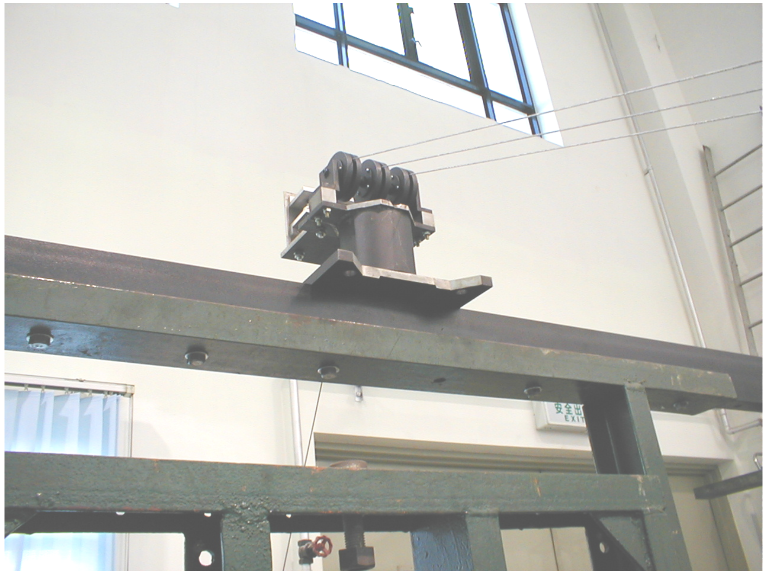
3. A 5m ×5m ×2.5m kinematic model setup.

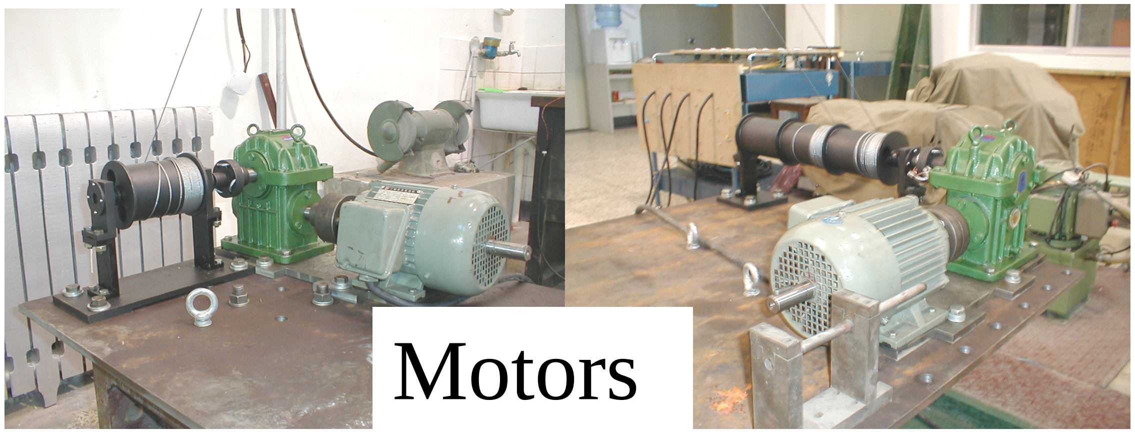


Cable car



Pulleys on top of tower



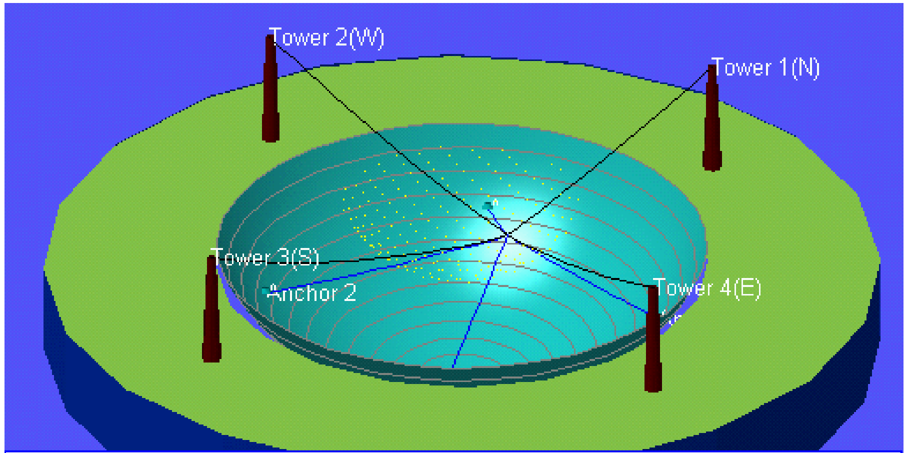


Motors

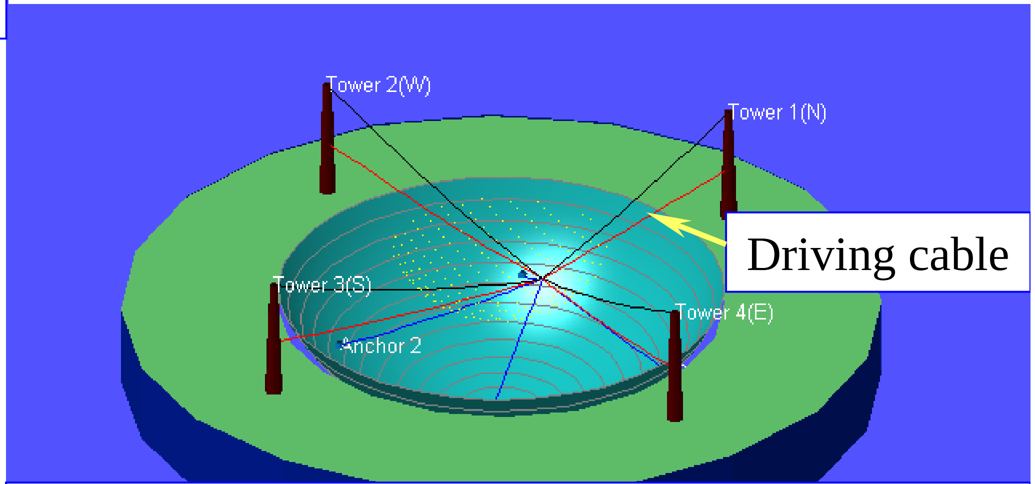
(1) The main control system and the CCD position measuring system for the cable car are finished and are now being integrated and adjusted.

(2) A system capable of controlling the velocities of 4 motors simultaneously is undertaken and will be integrated with the main control system. The Variable frequency technology for 3 phase asynchronous electrical motors is used.

(3) The Quasistatic models are developed for the driving law of two types of cable car and will be tested on the kinematic models.

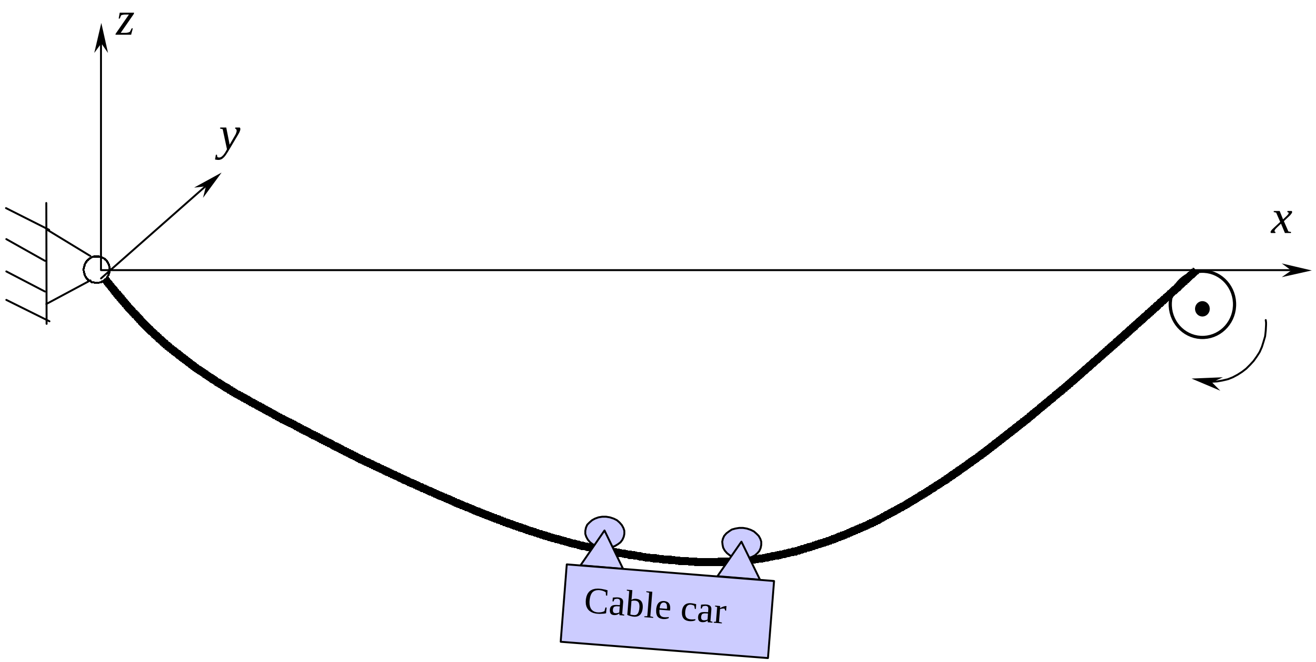


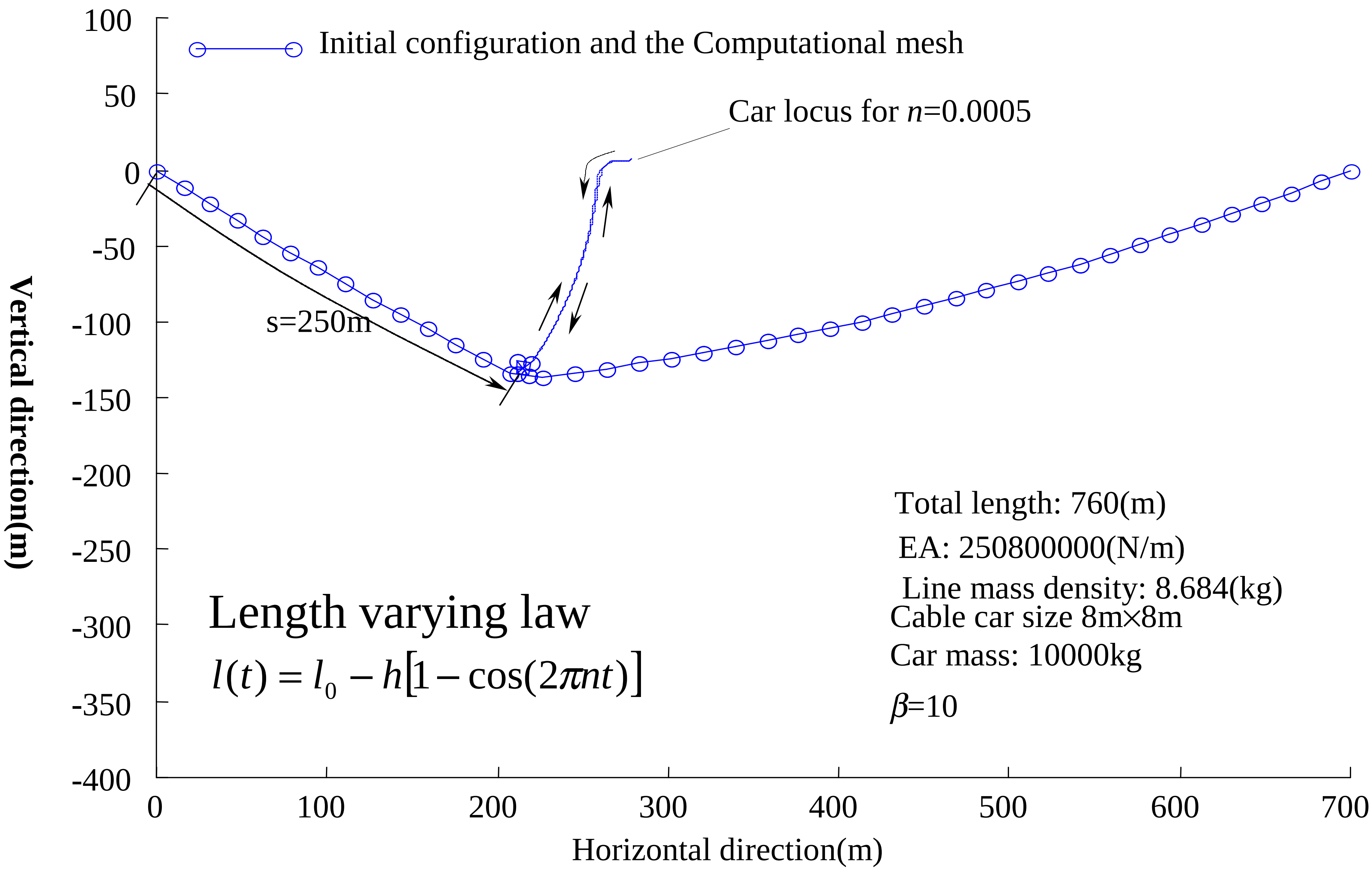
Self-driven car configuration



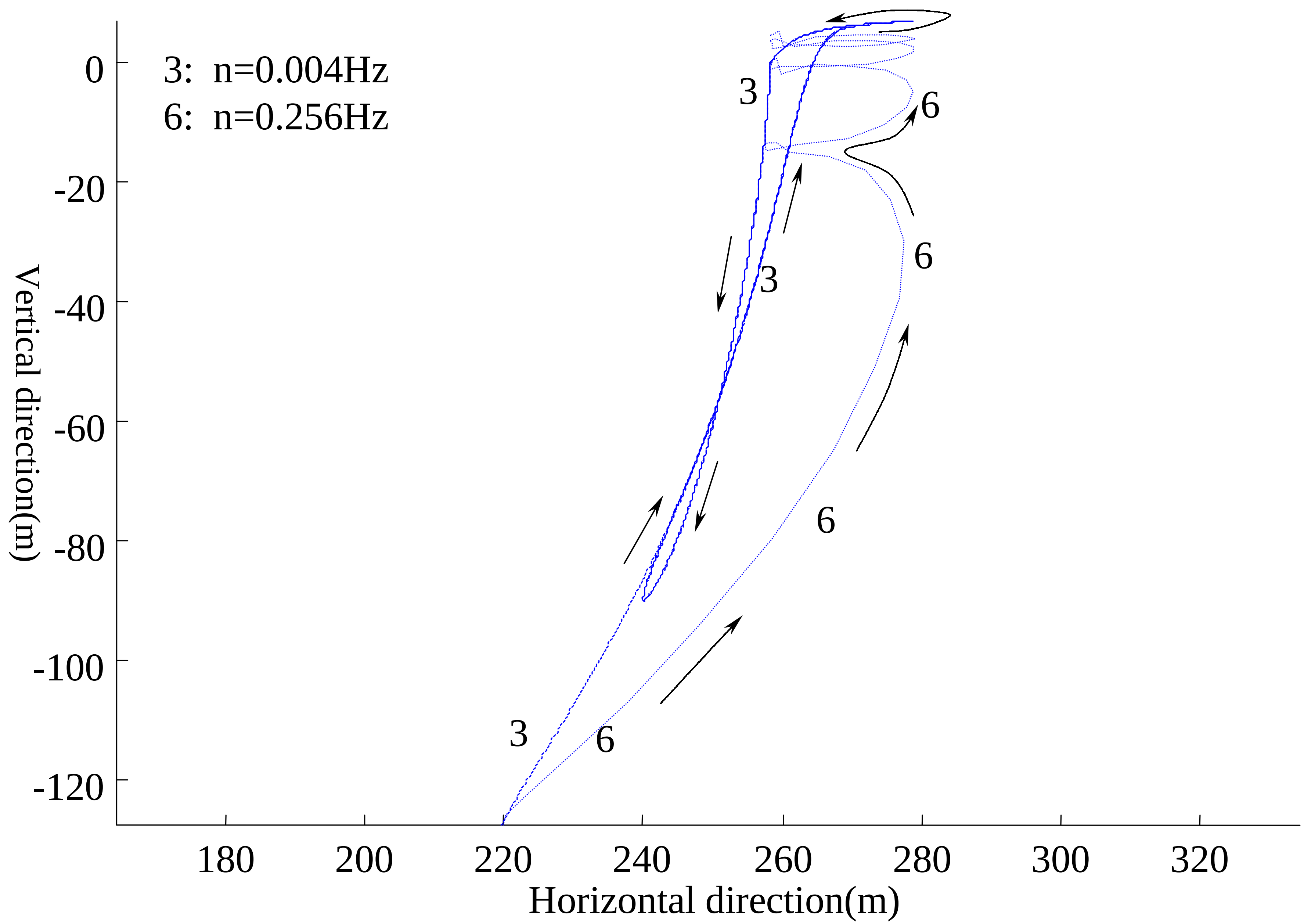
cable-driving car configuration

(4) The time-varying analytical models are also developed.





Initial configuration and the Computational mesh
Car locus for n=0.0005
s=250m
Total length: 760(m)
EA: 250800000(N/m)
Line mass density: 8.684(kg)
Cable car size 8m×8m
Car mass: 10000kg
β=10
Length varying law
l(t) = l0 − h[1 − cos(2πnt)]
Vertical direction(m)
Horizontal direction(m)
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
0
100
200
300
400
500
600
700

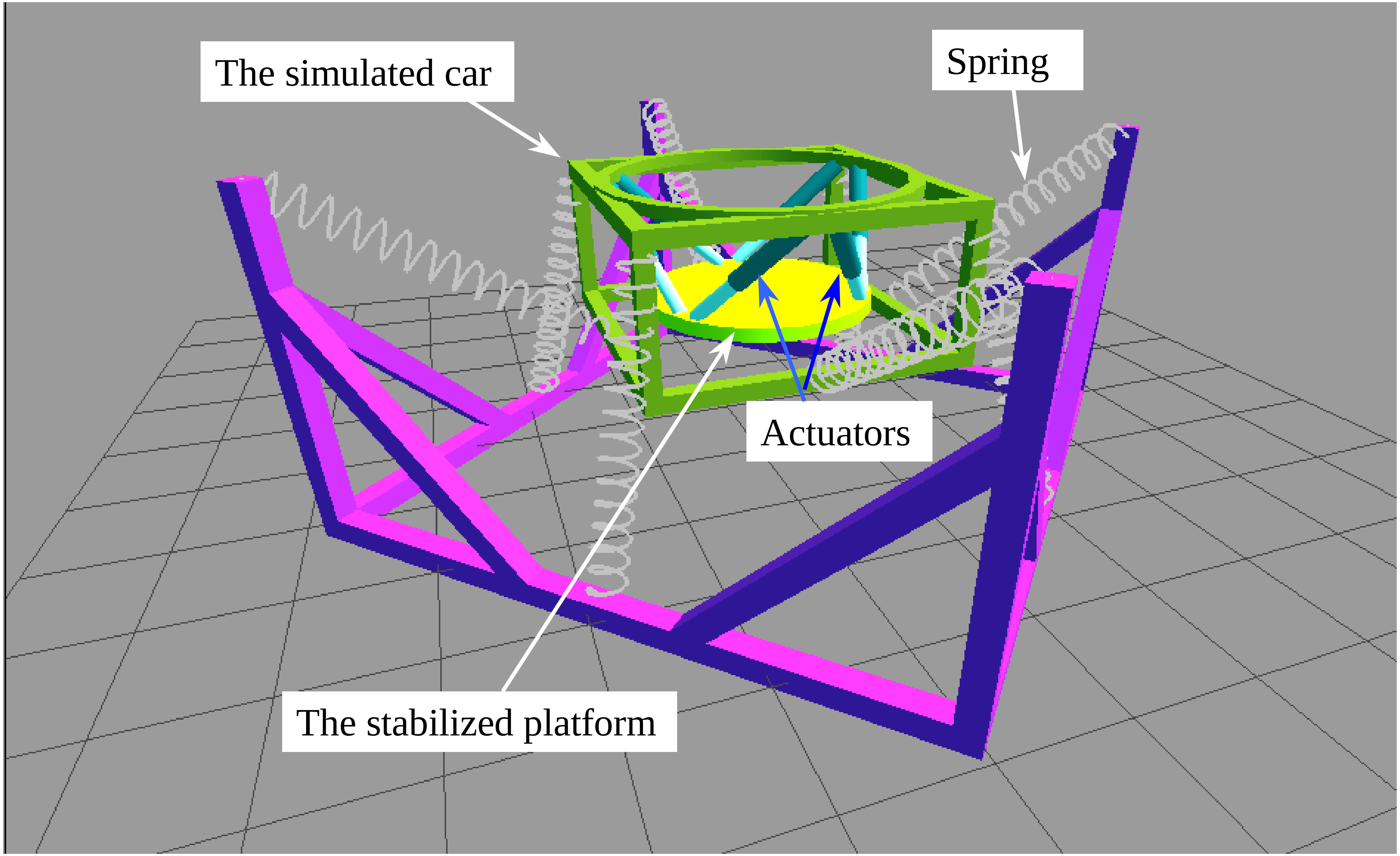


3: n=0.004Hz
6: n=0.256Hz
3
6
3
6
6
3
6
0
-20
-40
-60
-80
-100
-120
Vertical direction(m)
180
200
220
240
260
280
300
320
Horizontal direction(m)

Advances on the secondary support

1. Experiment model
2. Control simulations

1. Experiment model(1:5): *Mechanical design finished and equipment under purchasing*



2. Control Simulation

<u>The FEM model</u>

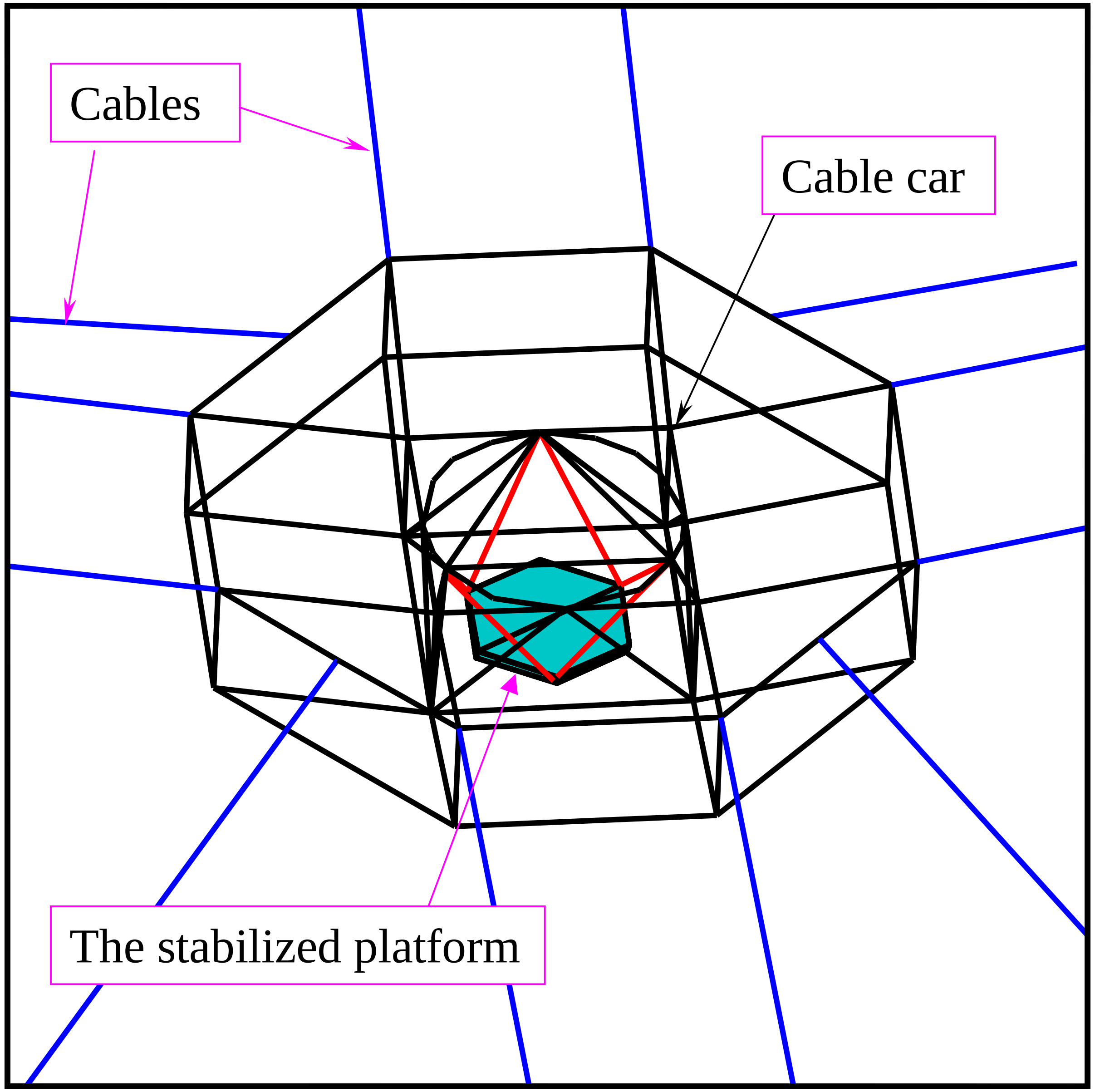
(*15*m ×*15*m ×*5*m)

Mass of car: *50111*(kg)

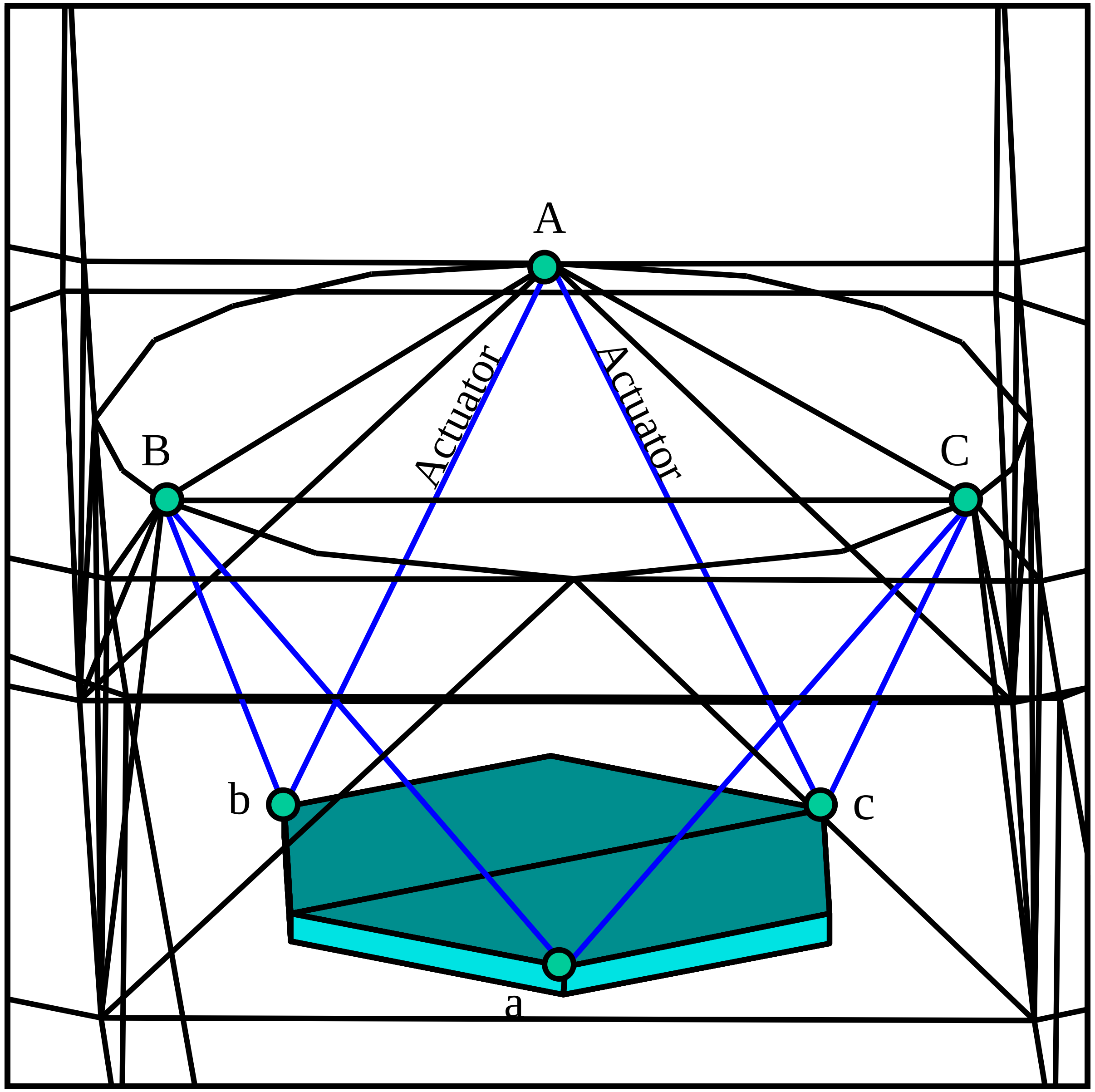
mass of the stabilized platform : *5564*(kg)

Natural freq. of the model（Hz）

0.28517, *0.28761,*
0.28882, *0.30642,*
0.66995, *0.67143*



The actuators



Governing Equations

$$M\ddot{x} + C\dot{x} + Kx = f^{e}(t) + Bu(t)$$

M, C, K, B **Mass, damping, stiffness and control matrix**

$x = \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix}$ **Car displacement vector** / **Stabilized platform displacement vector**

$$u(t) = \{\Delta l_1(t) \quad \Delta l_2(t) \quad \Delta l_3(t) \quad \Delta l_4(t) \quad \Delta l_5(t) \quad \Delta l_6(t)\}^T$$

Control vector： strokes of actuators

Description of the control problem for stabilizing the platform

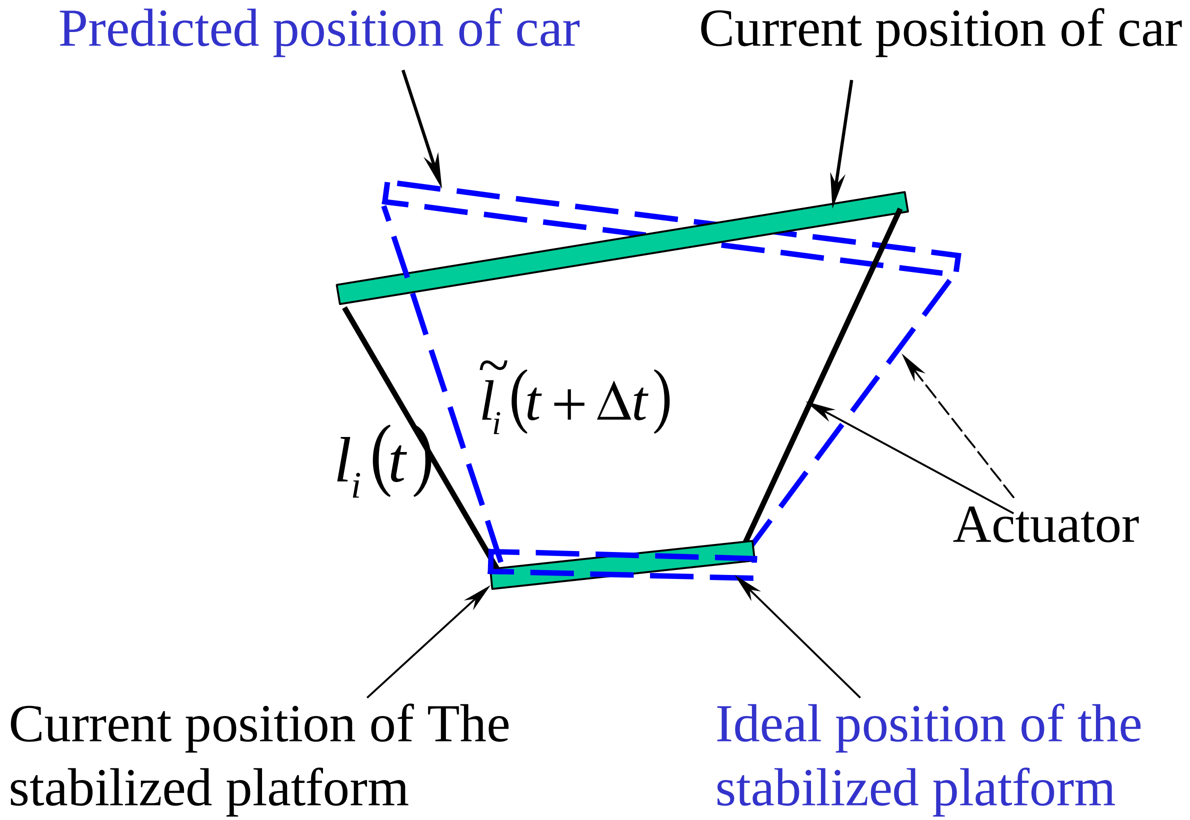
By observing the partial or all the state response x_1 of car, determine a control $u(t)$, to suppress the response x_2 of the stabilized platform to within the given tolerance:

$$\left\| x_2(t) \right\| \leq \delta$$

A control law based on the finite difference prediction

$$u(t+\alpha\Delta t)=\left\{l_1(t)+\alpha\left[\tilde{l}_1(t+\Delta t)-l_1(t)\right],\quad \cdots,\quad l_6(t)+\alpha\left[\tilde{l}_6(t+\Delta t)-l_6(t)\right]\right\}^T$$

$$\alpha\in[0,1]$$



Position prediction based on the finite difference

Measured positions $x(t)$ $x(t-\Delta t)$ $x(t-2\Delta t)$ $x(t-3\Delta t)$

Estimated velocities by difference

$$\bar{v}(t)=\frac{x(t)-x(t-\Delta t)}{\Delta t}$$

$$\bar{v}(t)=\frac{1.5x(t)+0.5x(t-2\Delta t)-2x(t-\Delta t)}{\Delta t}$$

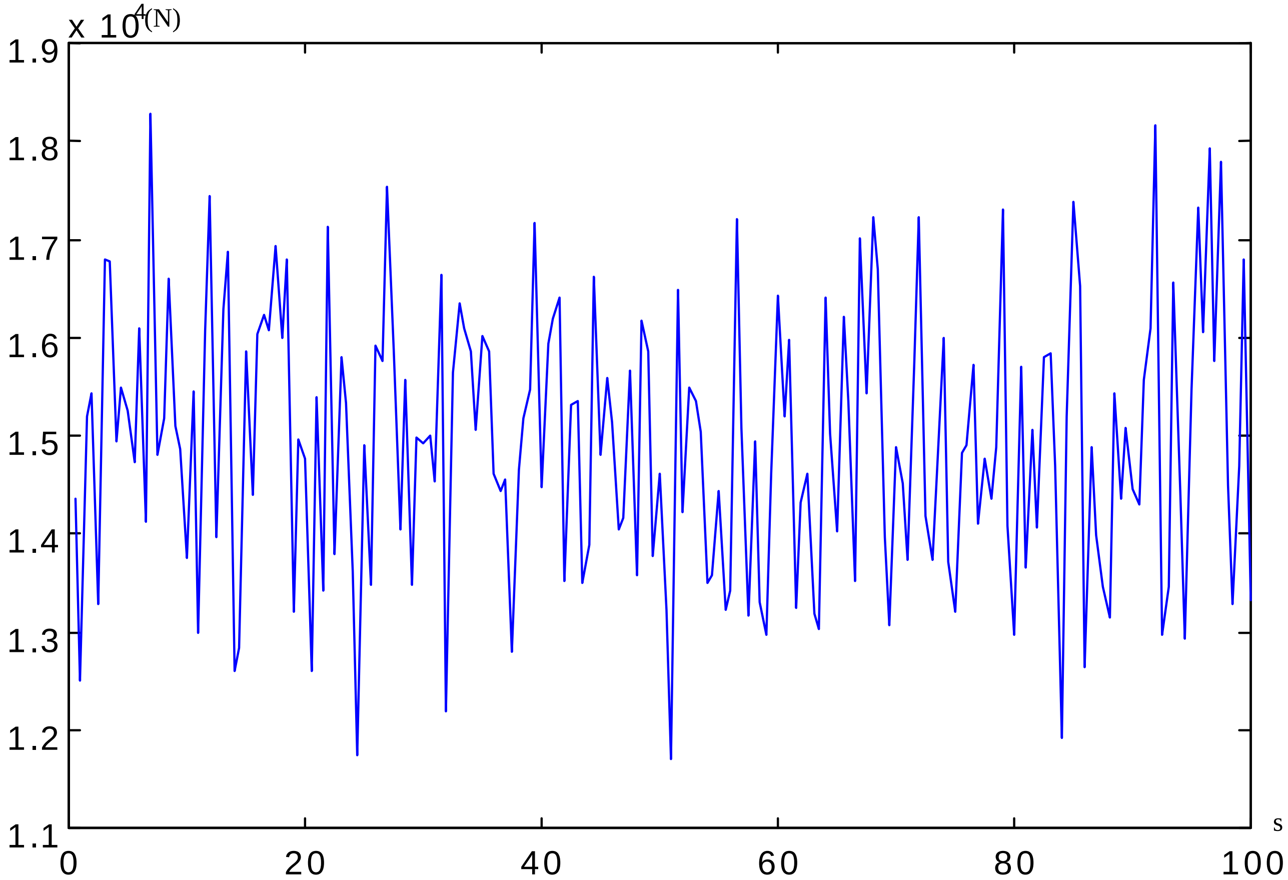
Estimated acceleration by difference

$$\bar{a}(t)=\frac{\bar{v}(t)-\bar{v}(t-\Delta t)}{\Delta t}$$

Predicted position at next $\triangle t$

$$\tilde{x}(t+\Delta t)=x(t)+\bar{v}(t)\Delta t+0.5\bar{a}(t)\Delta t^2$$

Simulated wind (step) load sample on the cable car



The simulated control effects

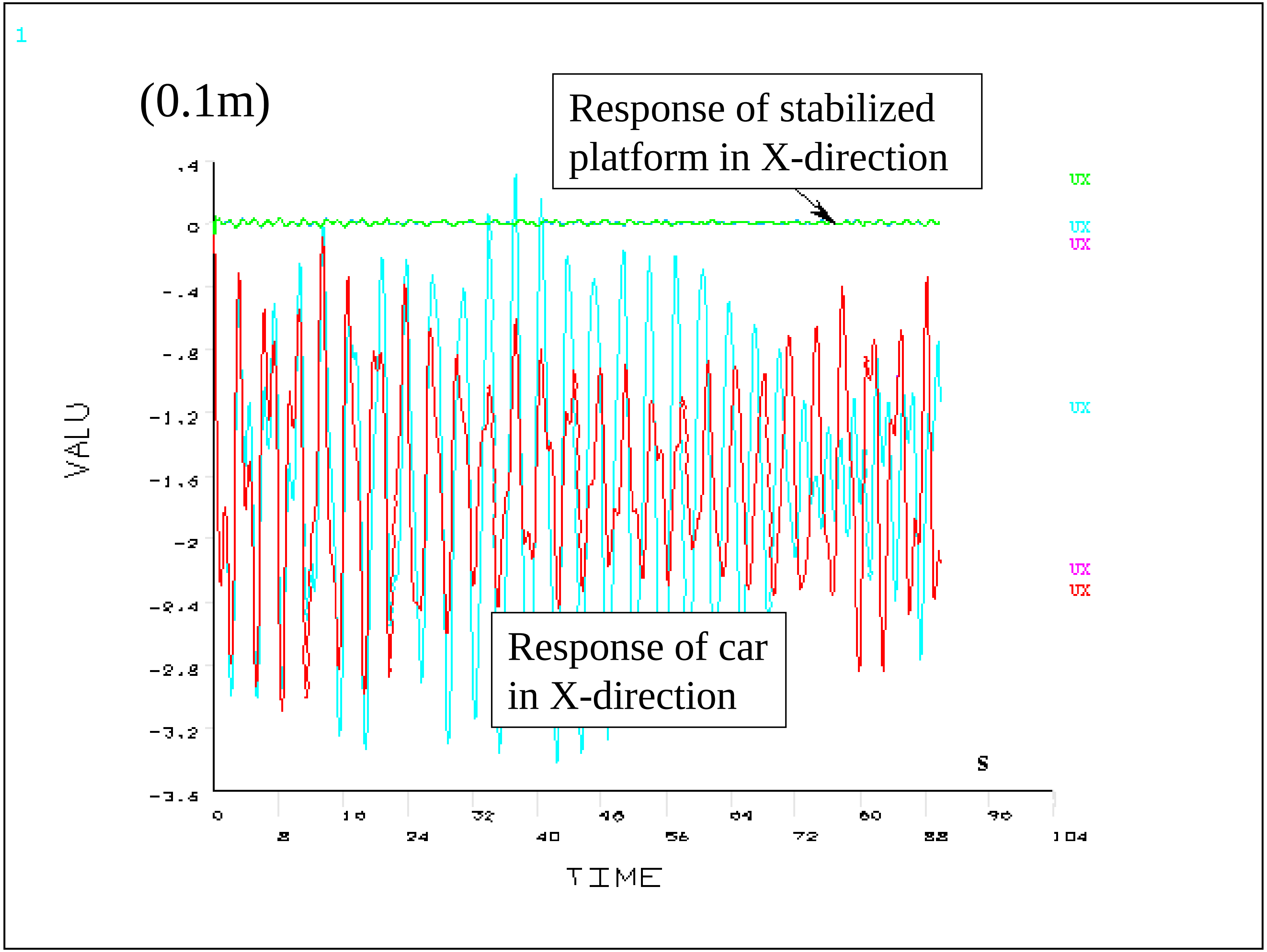
Table 1 The RMS responses of the car and the stabilized platform,
Control updating duration 0.1 second

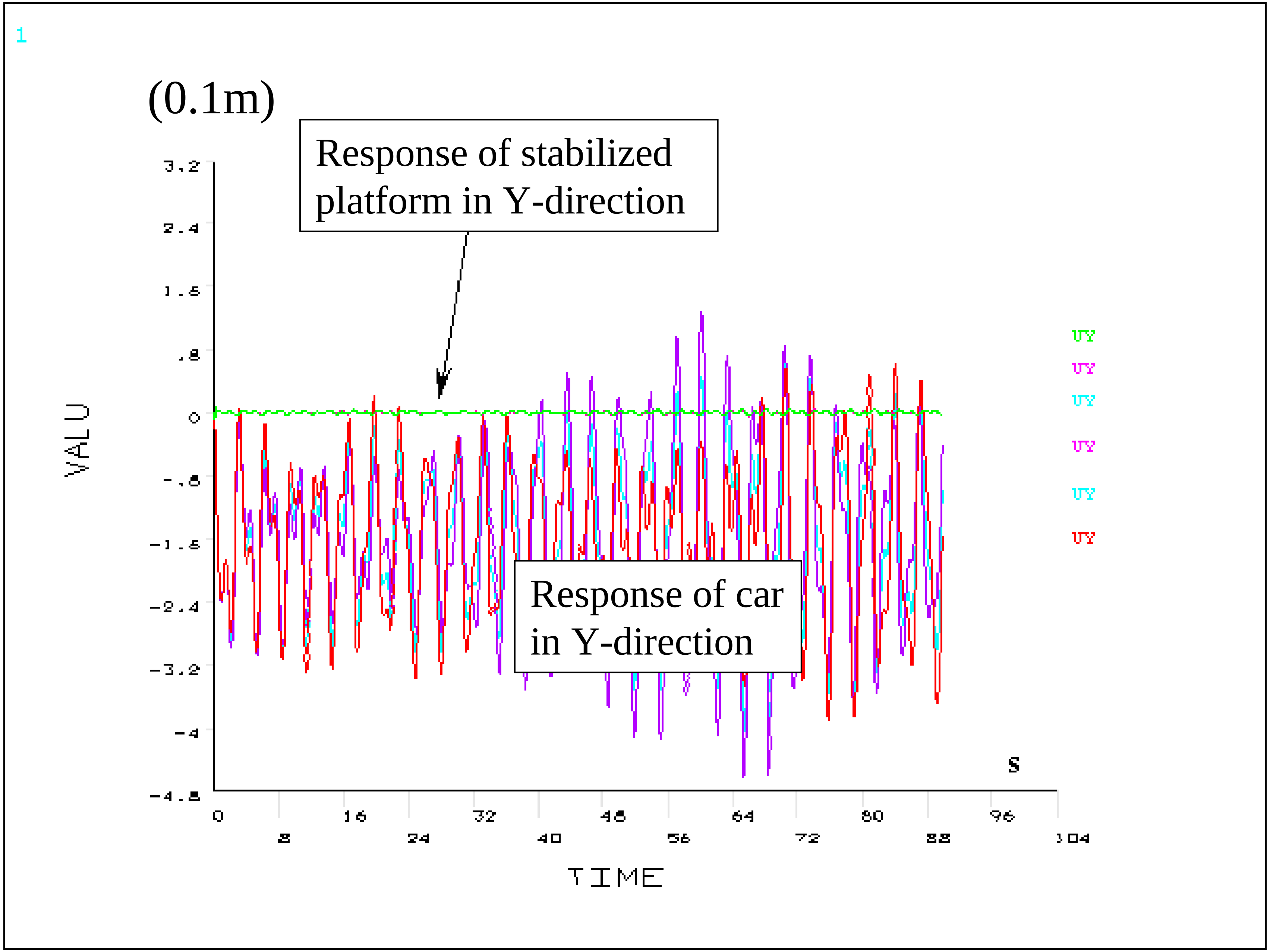
RMS response of the car			RMS response of the stabilized platform		
Point A	Point B	Point C	Point a	Point b	Point c
0.66m	0.50m	0.63m	0.0026m	0.0024m	0.0024m

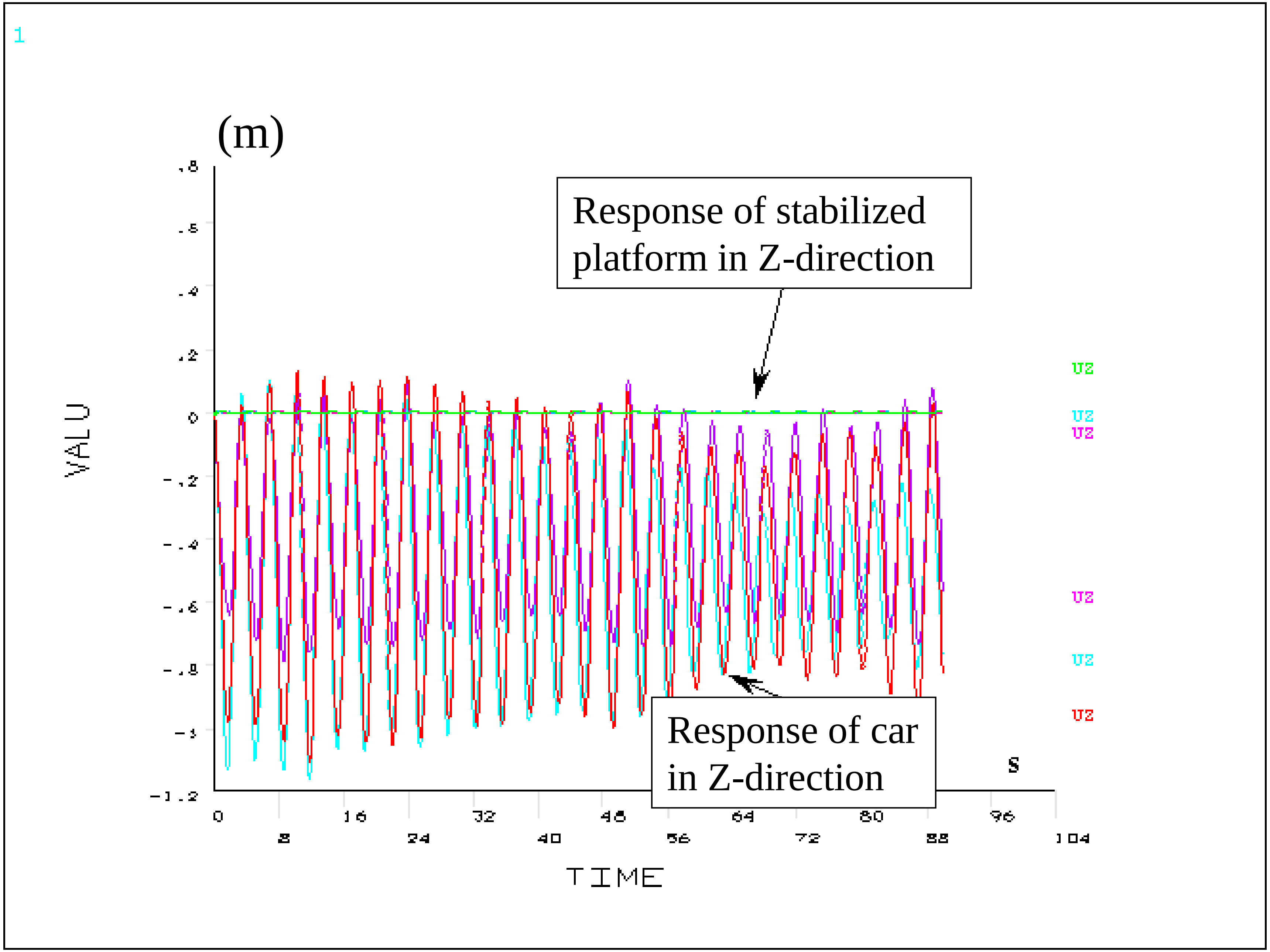
Table 2 The RMS responses of the car and the stabilized platform,
Control updating duration 0.2 second

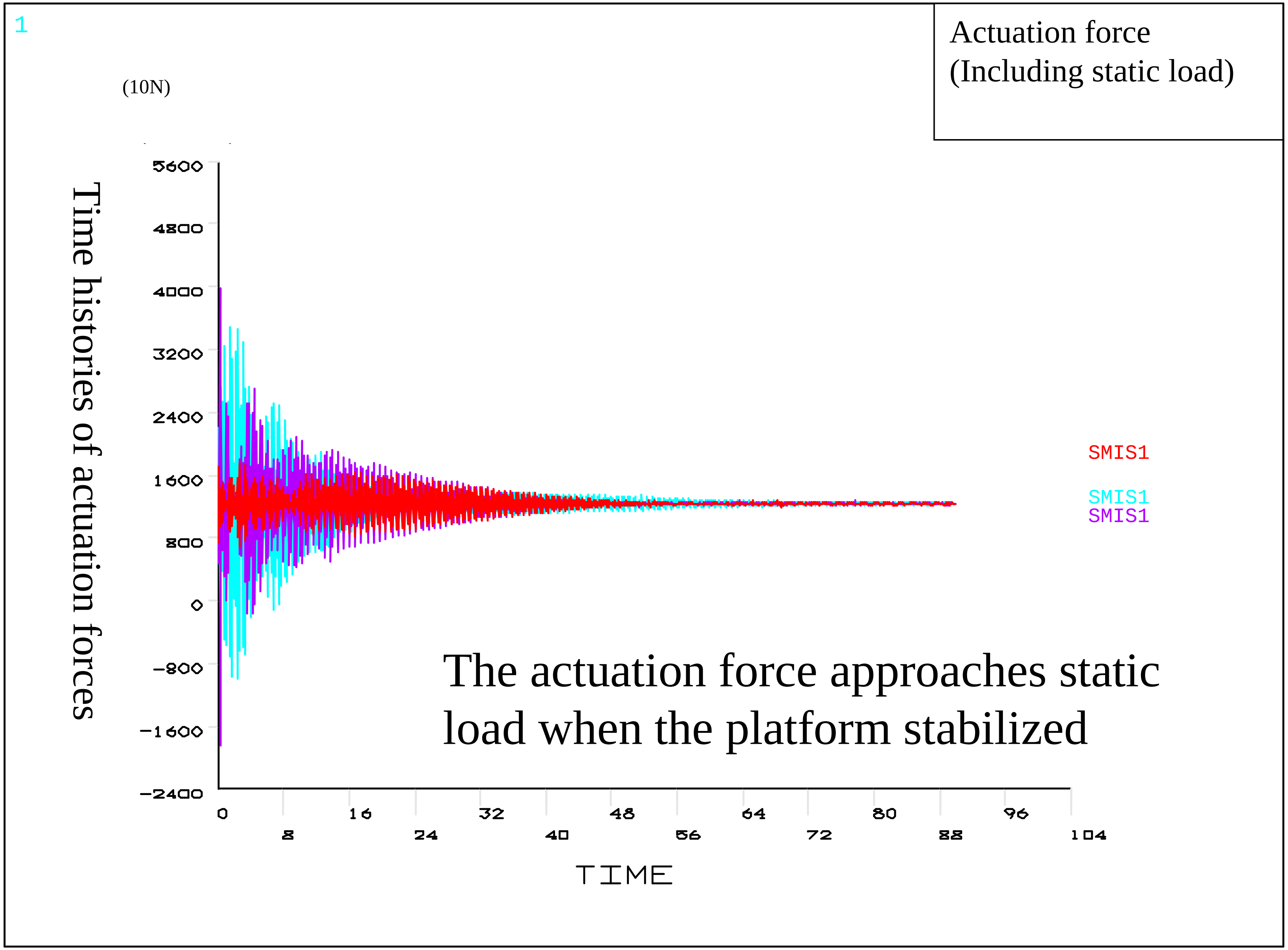
RMS responses of the car			RMS response of the stabilized platform		
Point A	Point B	Point C	Point a	Point b	Point c
0.64m	0.48m	0.61m	0.019m	0.017m	0.017m

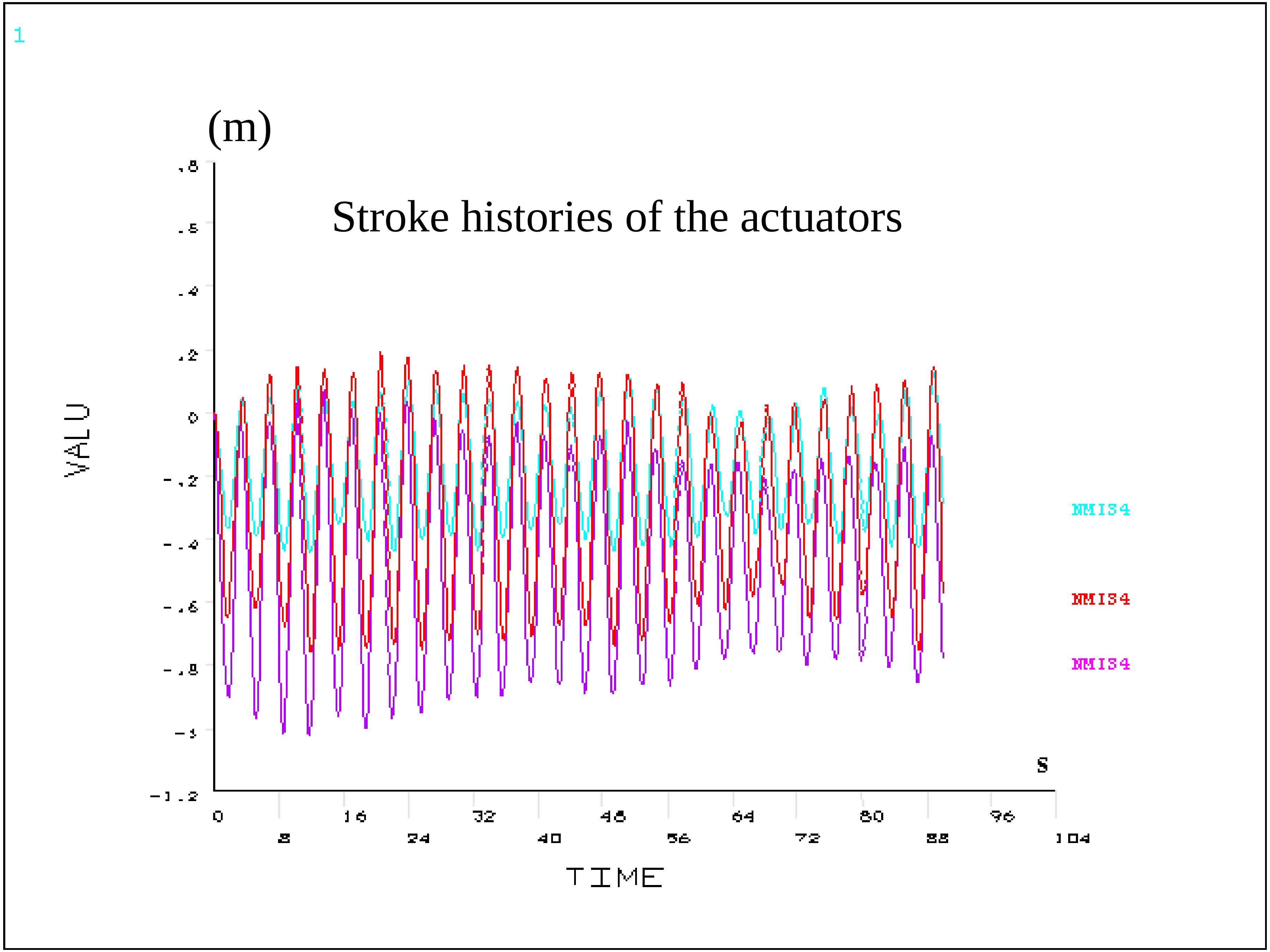
The Point RMS response definition $R_A = \sqrt{E\left[x_A^2(t) + y_A^2(t) + z_A^2(t)\right]}$

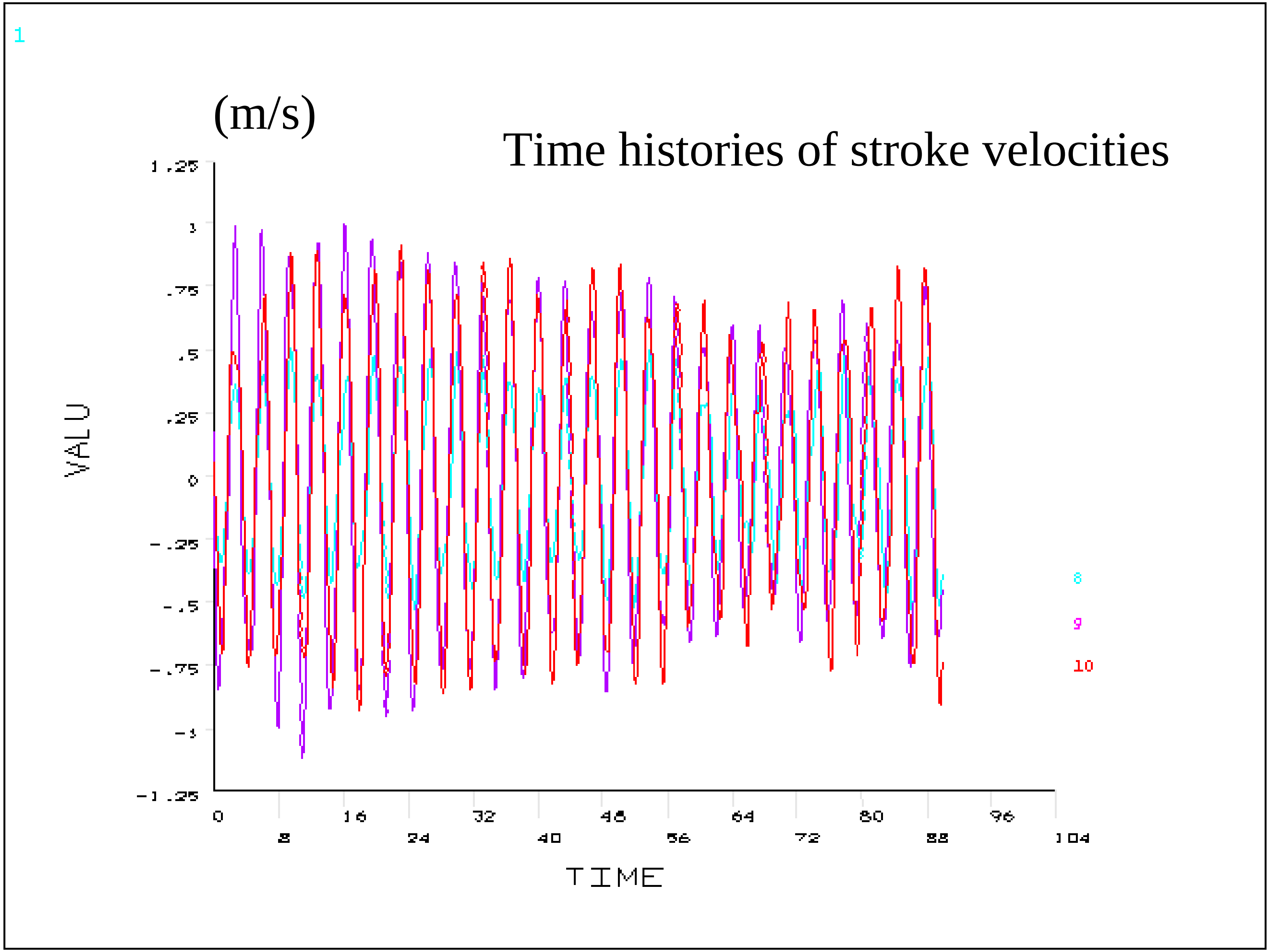

1
(0.1m)
Response of stabilized platform in X-direction
Response of car in X-direction
VALU
TIME
S
UX
UX
UX
UX
UX
UX
.4
0
-.4
-.8
-1.2
-1.6
-2
-2.4
-2.8
-3.2
-3.6
0
8
16
24
32
40
48
56
64
72
80
88
96
104

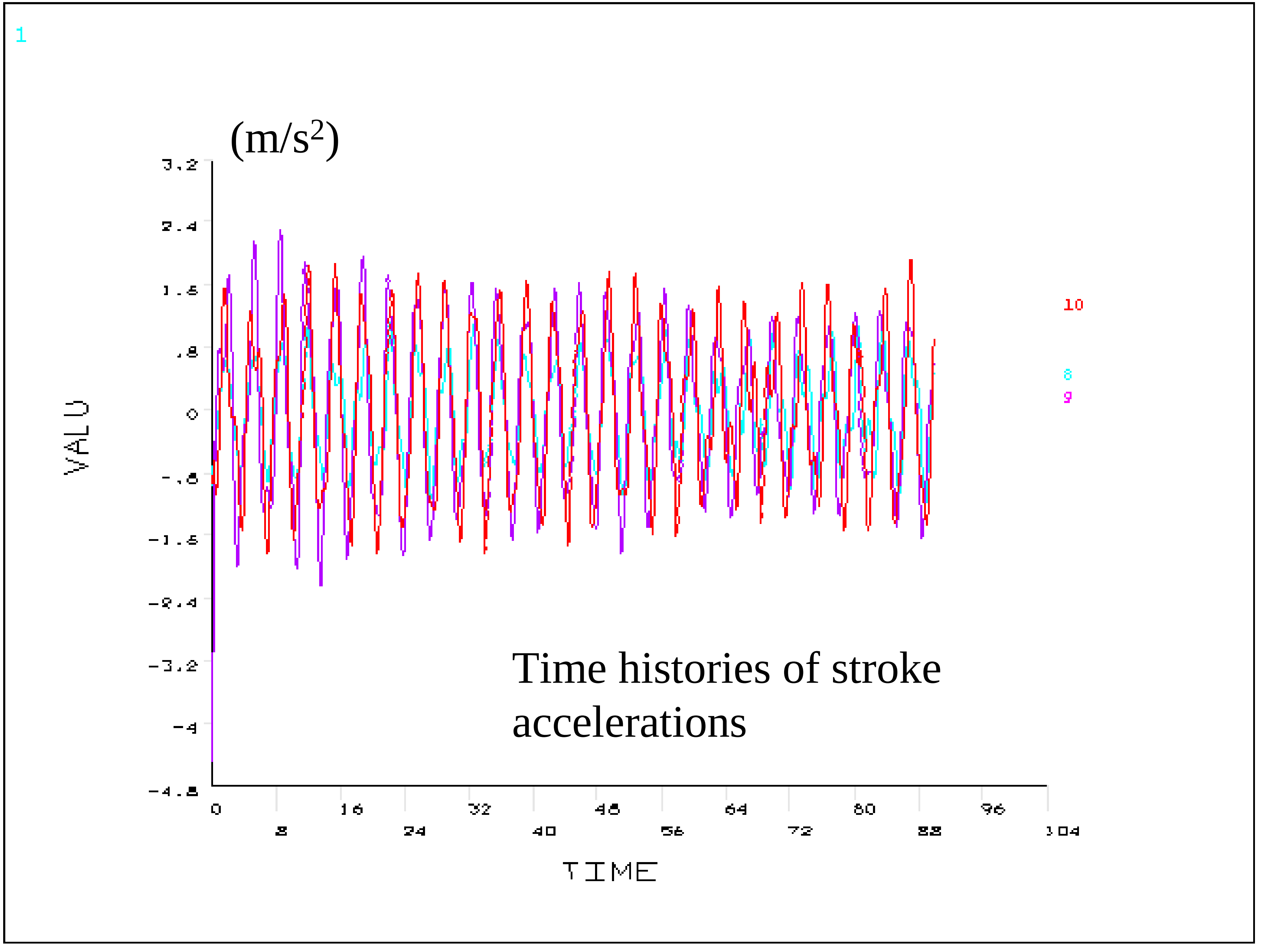

1
(0.1m)
Response of stabilized platform in Y-direction
Response of car in Y-direction
VALU
3.2
2.4
1.6
.8
0
-.8
-1.6
-2.4
-3.2
-4
-4.8
0
8
16
24
32
40
48
56
64
72
80
88
96
104
TIME
S
UY
UY
UY
UY
UY
UY


1
(m)
.8
.6
.4
.2
0
-.2
-.4
-.6
-.8
-1
-1.2
VALU
Response of stabilized platform in Z-direction
Response of car in Z-direction
UZ
UZ
UZ
UZ
UZ
UZ
s
0
8
16
24
32
40
48
56
64
72
80
88
96
104
TIME


1
Actuation force
(Including static load)
(10N)
Time histories of actuation forces
5600
4800
4000
3200
2400
1600
800
0
-800
-1600
-2400
0
8
16
24
32
40
48
56
64
72
80
88
96
104
TIME
SMIS1
SMIS1
SMIS1
The actuation force approaches static load when the platform stabilized


1
(m)
Stroke histories of the actuators
VALU
.8
.6
.4
.2
0
-.2
-.4
-.6
-.8
-1
-1.2
0
8
16
24
32
40
48
56
64
72
80
88
96
104
TIME
S
NMIS4
NMIS4
NMIS4


1
(m/s)
Time histories of stroke velocities
1.25
1
.75
.5
.25
0
-.25
-.5
-.75
-1
-1.25
VALU
0
8
16
24
32
40
48
56
64
72
80
88
96
104
TIME
8
9
10



Time histories of stroke accelerations

The simulations indicate:

1. **With an updating control duration of 0.1 second, the control law based on the finite difference position prediction achieves positioning precision(4mm r.m.s.) for FAST.**

2. **The simulations are carried out on a model with dimensions and dynamic properties approaches those of FAST.**

3. **The required maximum stroking velocity and stroking acceleration for actuators are 1m/s and $2.4 m/s^2$ respectively. These requirements are within the performance of commercialized products(out of China)**

Further work ahead

1. Kinematic experiments for the car driving control law on the physical model. The self-propelling car and the cable-driven car will be tested.
2. Vibration experiments on the model with dynamic similarities to study the performance of the cable-car configuration. Possible wind-induced instabilities and stabilizing methods.
3. Control experiments on the Stewart platform used as the secondary feed stabilizer.

Acknowledgements

1. The research fund for large radio telescope, Chinese National Astronomical Observatories

2. The fundamental research fund (JC1999031) of Tsinghua university.