A Method of Constructing Comprehensive Reliability Testing Profile Based on Hardware and Software

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***Abstract*—Test data generation relies on the profile during the reliability testing. However, software and hardware reliability test profile are considered separately in imbedded system, and it is not a true indication of the usage to the system. In this paper, we shall first contrast of the test profile construction flow of hardware and software, and find out the integrating of them. And then advance the method of construct comprehensive reliability testing profile based on hardware/software combination, which on the basis of improved software reliability test profile. Finally, by the factual for an Aeroengine Digital Control System, the rationality, effectiveness and feasibility of this method is proved. Furthermore, it supports the research of the embedded system reliability validation and evaluation.**

Keywords-reliability testing; hardware reliability test profile; software reliability test profile; comprehensive reliability testing profile

I. INTRODUCTION

As the wide application of embedded system in various fields, the demands of safety and reliability should be higher than present requirements. Embedded System reliability relies on both software and hardware because of their tight inosculation. However, software and hardware reliability test profile and reliability testing are considered separately. The software and hardware reliability test profile, which constructed in hardware/software integrated test, dose not considers the consistency from the angle of system. Therefore, it is necessary to inosculate the software and hardware reliability test profile effectively, in order to truly reflect the operational condition of system.

Recently, there is a unified standard GJB899A-2009 for hardware reliability test profile [1], which provides the measures to obtain the environment variable, formula and processing method for the reliability testing. Many domestic scholars have done much research and improvement in the standard. For example, there is a method for design reliability test profile which combines the measured stress with referenced held by literature [2]. The most common software reliability test profiles are Musa test profile and Markov test profile [8]. Literature [3] elaborated the method of construct operational profile which proposed by Musa. Whittaker and Prooe applied Markov theory to the analysis and exploitation of software test profile [4]. Literature [5] proposed the concept of usage profile. It is the expansion of Musa test profile, and the testing data generated by usage profile would be more close to native use.

In the beginning, the integration of the software and hardware reliability test profile has been analyzed through compare their construction flow in this paper. And then advance the method of construct comprehensive reliability testing profile based on improving existing software reliability test profile. Finally, by the factual for an Aeroengine Digital Control System, the feasibility of this method is proved.

II. THE ANALYSIS OF HARDWARE/SOFTWARE RELIABILITY TEST PROFILE (HSRTP)

In this section we will analyze the integration of the software and hardware reliability test profile through Hardware/Software Reliability Test Profile.

A. Contrast of HSRTP

HSRTP describes the usage situation of embedded system from different angles. And their purpose is both reflect the true indication of the system.

The flow of design Hardware Reliability Test Profile (HRTP) is: *1) Confirm mission profile. 2) Protract environment profile based on the mission profile. 3) Simplify the environment profile into testing profile which obeys proper rules.* Where necessary, integrate several mission profiles into a typical synthetic test profile.

The flow of design Software Reliability Test Profile (SRTP) is: *1) Refine the software functions. 2) Identify and set up connections between the running functions. 3) Identify the variables and states to input. 4) Determine the probability of occurrence.*

In addition to the construction process, HSRTP are different in the description method. HRTP is a diagram which provides the environment and time parameters directly for the reliability testing. SRTP is a sample population for the test of reliability testing.

B. Analysis the Integrating of HSRTP

The system performs different tasks, through mission profile and environment profile, is a very influential factor affecting HRTP. SRTP also under the influence of different tasks similarly. Therefore, we can describe the usage situation of software based on system tasks model.

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In addition, real time is one of the most important characters of the embedded system, so time is a main factor to testing profile. HRTP has reflected the relationship between environmental stress and time. Therefore, in addition to considering probability distribution of the test input, it is necessary to take into account the test input changes over time, to reflect real usage of the system.

As stated above, tasks and time are the key point for the integration of HSRTP. We should represent the system testing profile by both HRTP and SRTP.

III. THE CONSTRUCTION OF COMPREHENSIVE RELIABILITY TESTING PROFILE

A. The Method of Construct Comprehensive Reliability Testing Profile

1) The Correspondence Between HSRTP

In this paper, scenario technology and UML modeling toll [6 7] are used to improve existing SRTP, and the detail would be shown in next section. The correspondence between improved SRTP and HRTP can be shown in Fig. 1 and TABLE I.

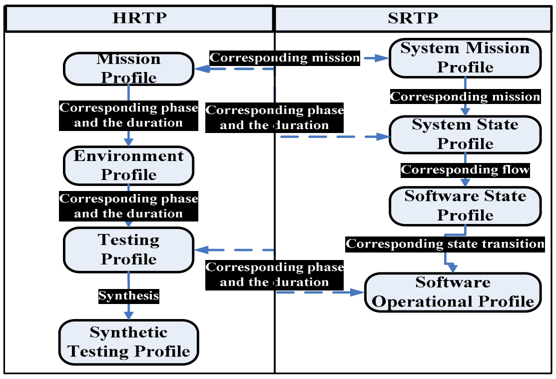

Figure 1. HSRTP correspondence.

TABLE I. THE DESCRIPTION OF RELATIONS

Profile			Description
HRTP	Software operational profile based on a system task	***Mission Profile***	Task characteristics
		Environmental Profile	Environmental parameters
		Testing Profile	Relationships between environmental parameters and time
SRTP	***Mission Profile***		Task classification
	System State Profile		Phasing and the state transition of tasks
	Software State Profile		State transition of software
	Software Operational Profile		Relationship between input and time
Comprehensive Reliability Testing Profile			Software operational profile based on all system task

2) The Combination of HSRTP

The definition of profile slice is as follow:

Definition 1: Profile Slice is the partitions of profile from a mission phase that according the given principle.

The profile could be expressed as follow:

$$P= \{<PH, DA, tt>\} \tag{1}$$

$$PH= \{<ph_i, t_0, t_l>; i=1,2,3,\ldots,n; 0<t_0<tt; 0<t_0+t_l<tt\} \tag{2}$$

$$DA= \{<da_j, da_t>; j=1,2,3,\ldots.m;0<t<tt\} \tag{3}$$

P refers to the profile; PH refers to the relevant information of mission phase; DA refers to the relevant information of profile data; tt refers to the testing time; ph_i refers to the i^{th} mission phase of large system; t_0 refers to the initial time of ph_i; t_l refers to the time of duration of phi; da_j refers to the j^{th} data class in the profile; da_t refers to the value when da_j at time t.

The profile slice could be expressed as:

$$PS= \{<ps_k, ph_k, da_k>; 1<k<n\} \tag{4}$$

$ph_k \in PH$, $da_k \in DA$; ps_k refers to the k^{th} slice of P; ph_k refers to the mission phase information when slicing; da_k refers to the data change under ph_k.

Hardware testing profile is sliced in accordance with the principles of task phase. Each HRTP slice corresponds to all the SRTP test scenarios (i.e. one of the SRTP slice) in the task. The comprehensive testing profile slice is obtained by correspond the HRTP slice to SRTP slice with time.

The correspondence between HRTP and testing scenes of SRTP obeys on definite probability distribution which was defined by Definition 2.

Definition 2: Combination Probability means in the SRTP slice, the probability of being the same system usage between the testing scene partition and the HRTP slice.

3) The Analysis of Comprehensive Reliability Testing Profile Construction

We should integrate HRTP and SRTP in accordance with the corresponding relations, what to construct comprehensive testing profile, after Understudied the system information. The integrated thought of construction is: parallel construct the HRTP and SRTP in accordance with the corresponding relations, and then integrate them. We give the defined as follows:

Definition 3: The HRTP, SRTP and their combination of embedded system form the System Reliability Testing Profile (SyP).

It could be expressed as follow:

$$SyP= \{<HP, SP, Cmb>\} \tag{5}$$

HP refers to the HRTP of system; SP refers to the SRTP of system; Cmb refers to the combination, which the corresponding between these two kinds of profile on time under the same system usage.

B. *The Profile Constructing Process*

There are six steps for construct SyP (Fig. 2): system analysis, system mission analysis, system flow analysis, core profile construction, probability ensuring and HSRTP combination. The last step is the key in the whole process, and the other ones are elements. They will be introduced in detail as follows.

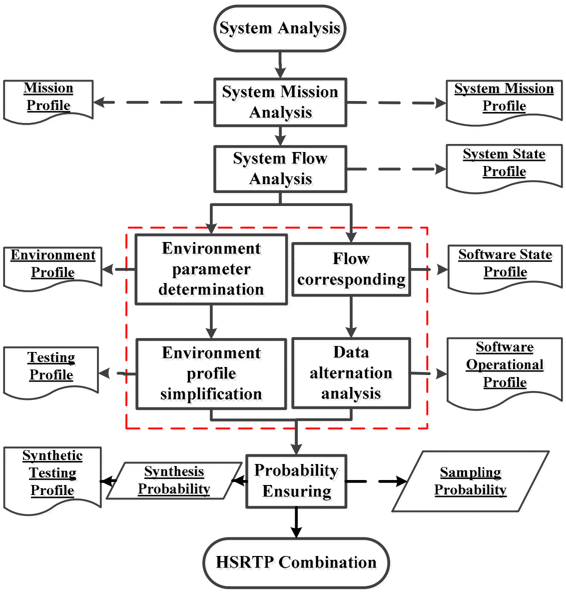

Figure 2. SyP constructing process.

1) *System Analysis*

The meaning of system analysis is to identify the describing objects of SyP, includes the information of the System Under Test, the Large System, the Interactive System and the User. We can obtain them from the documents such as developing assignment, requirement document standard and criterion.

a) System Under Test (SUT): the least embedded cell which the testing software (TS) belongs to, it must satisfy all the software requirements.

b) Large System (LS): usually can be used by user directly which the SUT belongs to. Besides, it is easy to obtain the relationship between LS and User or other systems.

c) Interactive System (IS): usually has data interaction with SUT, and be used to accomplish appointed assignment.

d) User (Us): does operations actively according to the requirements of TS. Generally there is some definite retardation of the operations.

2) *System Mission Analysis*

System Mission Analysis: analyze based on LS, achieve the mission profile of HRTP and the system mission profile of SRTP, the performing probability of mission should be gained and consider the low frequency mission. Information can be obtained from the following: 1. the datum provided by system designer, e.g. requirement document and mission profile. 2. the standard GJB899A-2009.

3) *System Flow Analysis*

System flow analysis describes the main transition of system state. There are several key jobs: Analyse the LS states of each phase under different missions, and obtain basic flows and alternative flows; Merge the basic flows and the alternative flows. Protract the system state profile of SRTP.

4) *Core Profile Construction*

Core profile refers to environment profile, testing profile, software state profile and software operational profile. The relation of the hardware stress and software input with time should be shown as follows:

a) Environment parameter determination. The main parameters in environment profile are: temperature, oscillation, humidity, input pressure and the time of duration of them.

b) Environment profile simplification.

c) Flow corresponding. Analyse TS states, and be corresponded with LS states.

d) Data interaction analysis. All of the software inputs should be classed and described.

5) *Probability Ensuring*

The performing probability of LS and the probability of occurrence when the TS states transferring should be combined for obtain the sampling probability of each testing scene.

6) *HSRTP Combination*

There are some implications as follows:

The mission information of LS:

$$M= \{<M_i, Ph_{ij}, p_i, d_{ij}>; i=1,2,3,\dots,m_1; j=1,2,3,\dots,m_2\} \quad (6)$$

$$HP= \{<M, ES, tt>\} \quad (7)$$

The related factors of environment stress in HP:

$$ES= \{<ES_i, SV_{it}>; i=1,2,3,\dots,n; 0< t<tt\} \quad (8)$$

$$SP= \{<M, St, In>\} \quad (9)$$

The state information St and the input data In:

$$St=\{<SySt_k,SSt_l,p_o>;k=1,2,\dots,a_1;l=1,2,\dots,a_2;o\in Z,1<o<a2\} \quad (10)$$

$$In=\{<C_x,I_y,Msg_z>;x=1,2,\dots,b_1;y=1,2,\dots,b_2;z=1,2,\dots,b_3\} \quad (11)$$

The procedure for combination as follows:

1) Slice the synthetic testing profile based on the environment profile and all the missions, and then describes the slices. *2)* Select and analysis slices in chronological order, and the sampling probability should be obtained. *3)* Analysis SRTP slice. *4)* Integrate all the slices of the synthetic testing profile and SRTP .Finally obtain the SyP. The SyP including three parts: mission phase information, HRTP slices and SRTP slices, which expressed as follows:

$$Cmb= \{<PH_r, HS, SS, It, Et>; r=1,2,3,\ldots,c\} \quad (12)$$

$$HS \in HP_t, I_t<t<E_t \quad (13)$$

$$SS= \{<Ts_u, p_u, Ms_t, Da_t>; u=1,2,3,\ldots,d; It<t<Et\} \quad (14)$$

SyP mainly applied to the system reliability testing. It can be used for generate reliability testing data, analysis and evaluation the reliability of system before and after reliability testing.

IV. INSTANCE VALIDATION

An electronic controller (EC) of an engine numerical control system (NCS) is taken to instance validation in this paper. The SyP of EC construction would be shown as follows.

A. System Analysis

The related information has been determined at the beginning:

B. System Mission Analysis

The fly training (M1), one of the fly mission profiles, is shown in TABLE II.

TABLE II. M1 MISSION PROFILE

Mission Phase Ph_{ij}	Height (ES_1/km)	Mach Number (ES_2/Ma)	Duration (d_{ij}/min)
Ground	0	0	60
Flying-off	0	0.5	1
Climbing	0.3~11	0.5	4
Cruise	11	0.74	160
Falling-down	11~0.3	0.35	12
Landing	0	0	2

The system mission profile of ECS can be constructed as in Fig. 3.

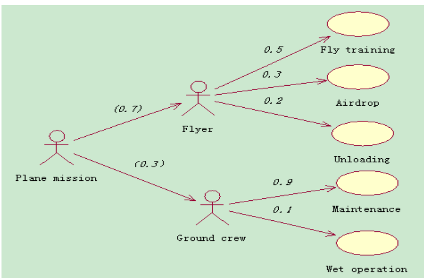

Figure 3. System mission profile of ECS.

C. System Flow Analysis

The concrete state transition is shown in Fig. 4, and it is the system state profile under M1 of ECS.

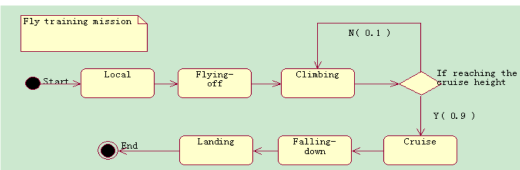

Figure 4. System state profile of ECS under M1.

D. Core Profile Construction

1) Environment Parameter Determination

The parameter of environment profile is shown in Table III.

TABLE III. ENVIRONMENT PROFILE DATA SHEET OF EC UNDER M1

Mission Phase	Time of duration /min	Height /km	Temperature /℃	Change rate of temperature /℃
Unworked on the ground,cold wether	30	0	0	–
Worked on the ground,cold wether	7	0	0	5
Worked on the ground,cold wether	23	0	0	–
Flying-off	1	0	0.5	6
Climbing	4	0.3~11	0.5	
Cruise	20	11	0.74	–
Falling-down to hot wether	14	11~0	0.35	3.57
Unworked on the ground,hot wether	30	0	0	–
Worked on the ground,hot wether	30	0	0	–
Flying-off	1	0	0.5	10
Climbing	3.5	0.3~11	0.5	
Cruise	20	11	0.74	–
Falling-down to cold wether	20	11~0	0.35	3.5

(a)

Mission Phase	Dynamic pressure /P	W0(m/s2)2/Hz	W1(m/s2)2/Hz	Dew point temperature /℃	Equipment state
Unworked on the ground,cold wether	–	–	–	inapplicability	turn-off
Worked on the ground,cold wether	–	–	–	inapplicability	turn-on
Worked on the ground,cold wether	–	–	–	inapplicability	turn-on
Flying-off	–	0.2	0.1	inapplicability	turn-on
Climbing	9576	0.16	0.08	inapplicability	turn-on
Cruise	10055	0.1	0.05	inapplicability	turn-on
Falling-down to hot wether	4788	0.1	0.05	inapplicability	turn-on
Unworked on the ground,hot wether	–	–	–	31	turn-off
Worked on the ground, hot wether	–	–	–	31	turn-on
Flying-off	–	0.2	0.1	inapplicability	turn-on
Climbing	9576	0.16	0.08	inapplicability	turn-on
Cruise	10055	0.1	0.05	inapplicability	turn-on
Falling-down to cold wether	4788	0.1	0.05	inapplicability	turn-on

(b)

2) Environment Profile Simplification

The Table IV shows the environment profile simplified.

TABLE IV. TESTING PROFILE DATA SHEET OF EC UNDER M1

Mission Phase	Time of duration /min	Temp/℃	Change rate of temp /℃	W0(m/s2)2/Hz	Dew point temp/℃	Equipment state
Unworked on the ground,cold wether	30	-46	–	–	inapplicability	off
Worked on the ground,cold wether	7	-11	5	–	inapplicability	on
Worked on the ground,cold wether	23	-11	–	–	inapplicability	on
Flying-off	1	–	6	0.2	inapplicability	on
Climbing	4	–		0.16	inapplicability	on
Cruise	20	19	–	0.1	inapplicability	on
Falling-down to hot wether	10	–	5	0.1	inapplicability	on
Unworked on the ground,hot wether	30	69	–	–	31	off
Worked on the ground,hot wether	30	69	–	–	31	on
Flying-off	1	–	10	0.2	inapplicability	on
Climbing	3.5	–		0.16	inapplicability	on
Cruise	20	24	–	0.1	inapplicability	on
Falling-down to cold wether	14	–	5	0.1	inapplicability	on

3) *Flow Corresponding*

Software state profile of ECS under M1 is shown in Fig. 5.

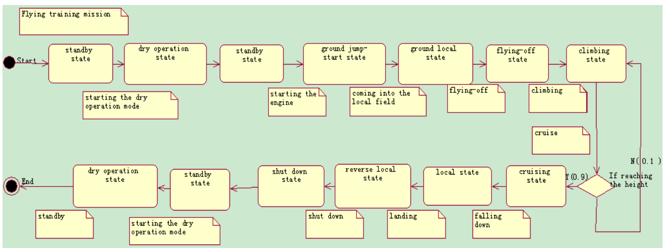

Figure 5. Software state profile of ECS under M1.

4) *Data Interactive Analysis*

A simple example is shown in Fig. 6.

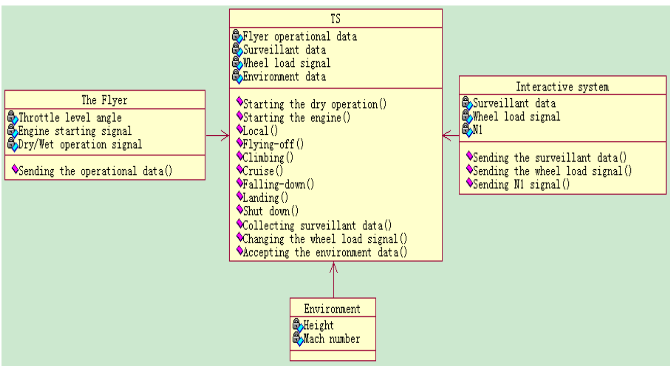

Figure 6. Part 1 in software operational profile of ECS under M1.

The software operational profile of ECS under M1 is shown in Fig. 7.

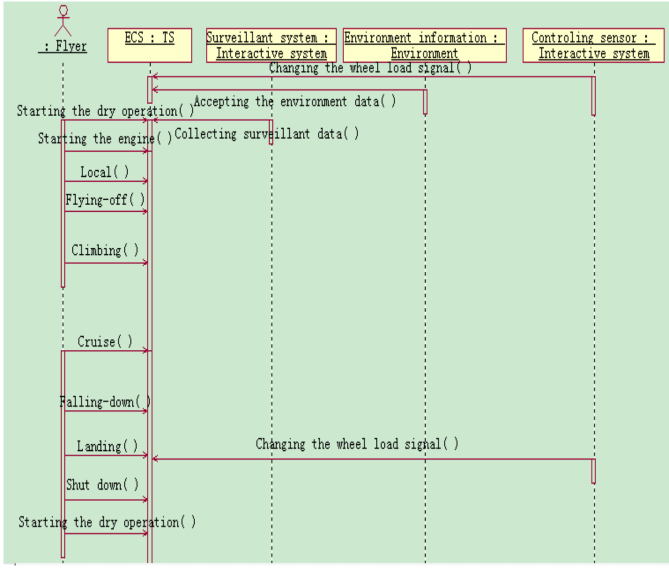

Figure 7. Part 2 in software operational profile of ECS under M1.

5) *Probability Ensuring*

The synthetic testing profile of EC could be obtained as Fig. 8.

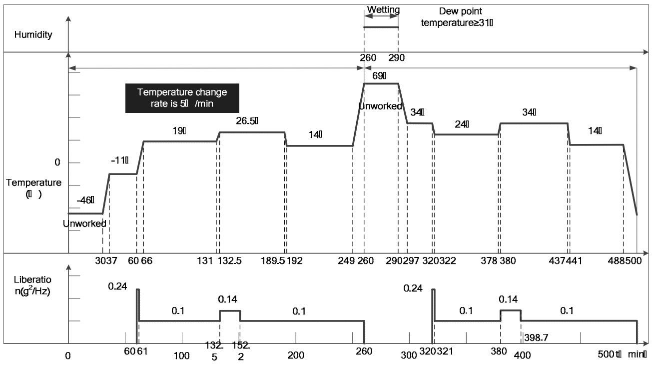

Figure 8. Synthetic testing profile of EC.

According to Fig. 4 and Fig. 8, we can obtain the sampling probability of basic flow under M1: 0.7×0.5×0.9=0.315; the sampling probability of alternative flow: 0.7×0.5×0.1=0.035.

6) *HSRTP Combination*

HSRTP combination for EC is shown in Fig. 9.

7) *Result Analysis*

As shown in Table V, the partial data are generated by the SyP of EC.

In the first period, for hardware testing data, the temperature stress raises from -11°C to -6°C, and the change rate is 5°C/min; The liberating stress value is 0.24 (m/s2)2 /Hz, which is the flying-off liberating value. So this period is the flying-off phase, and the engine is on the flying-off state. For software, the throttle level angle is 120°, and the height is 0 km; the number of Mach is 0.5 and there is no wheel hold signal, so the corresponding engine state is flying-off state too. The second period can be done in the same manner, both of hardware testing data and software testing data are corresponding with the engine climbing state.

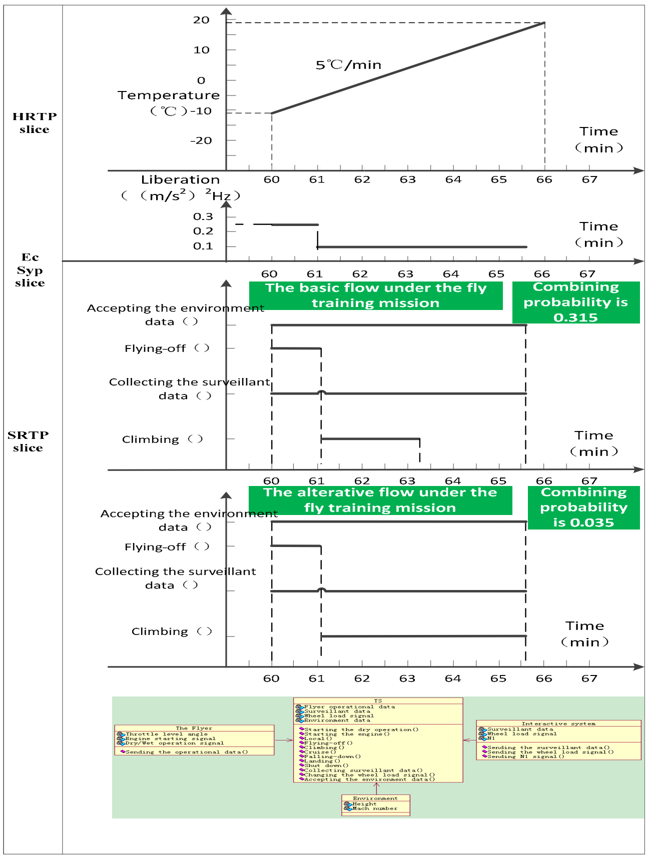

Figure 9. Example of HSRTP combination for EC.

TABLE V. TESTING DATA BASED ON THE SYP OF EC

	Hardware testing data		
Period (min)	***Temperature ES1(°C)***	***Temperature change rate ES2 (°C/min)***	***Liberation ES3 (m/s2)2/Hz***
(60,61)	-11~-6	5	0.24
(61,65)	-6~19	5	0.1
	Software testing data		
Period (min)	***Throttle level angle Da1 (°)***	***Wheel hold signal Da2 (0,1)***	***Height Da3(km)***
(60,61)	120	0	0
(61,65)	110	0	0.3~11

The above example demonstrates the effectiveness and feasibility of the SyP construction method proposed in this paper.

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