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ARCHITECTURE OF RESOURCE CONFIGURATION IN AVIONICS BASED ON CONTROL ALLOCATION

Chengzhi Chi[1,2], Jianmin Wu[1,2], Jingkai Zhang[1,2], Tieying Li[1,2], Guojing Xu[1,2]
1.Science and Technology on Avionics Integration Laboratory, Shanghai, China
2.China National Aeronautical Radio Electronics Research Institute, Shanghai, China

Abstract

It is wildly realized that the capability of avionics systems to meet operational and functional requirements has been embedded in, and distributed across, every single hardware and software components of an Integrated Modular Avionics (IMA) system. This paper presents an incremental approach towards the resource configuration/reconfiguration of IMA architecture across the various mission phases and system states.

Control allocation (CA) is used in the resource configuration of IMA architecture. The control effectiveness matrix, translated from the mapping relationship of which processors run which applications and which physical channels host which virtual channels, and the desired control input translated from the mapping relationship of applications and resource, are detailed in the paper. CA contains controller and allocator, optimization method is used in allocator for finding the solution to the resource configuration/reconfiguration. So applications can be scheduled in accordance to specific needs and priorities, and system blueprint is available.

Numerical simulations of the resource configuration in mission phases are given to illustrate the effectiveness of the proposed method.

1. Introduction

With the developing of modern aviation, federated avionics could not meet the requirements of the increasing system complexity and isn’t affordable, also, due to the long development cycle and less competitive, federated avionics will be out finally. In order to solve the problem, IMA has arisen. Through the architectures of IMA[1], shared and configurable resources, for example, computing, communication and I/O resource is available. It guarantees the integrator benefit from the enhanced and upgradable systems and by the manner of platform management, the work load of aircraft level integration is reduced. It is forecasted that IMA will be used in modern avionics widely.

The capability that avionics satisfy operations and functions requirement has been embedded in software and hardware of the system. The characteristic of hardware should be consistent with the role it played in the system. Software should be scheduled by sequence priority. For example, the Genesis architecture， developed by Smiths Aerospace, is capable of integrating a large number of avionics functions by using the shared platform resources. The Genesis platform is a hardware/software platform for implementing real-time embedded systems, known as “Hosted Functions”.

For IMA architecture, the shared resources must be allocated among the hosted functions. Hosted functions are allocated to the IMA platform resources to form a “functional” architecture specific to each system, to meet the availability, operational, safety and topological requirements for each hosted function. Hosted functions can “own” unique sensors, effectors, devices and non-platform LRUs (Line Replaceable Unit) which become part of the functional system architecture[2]. Multiple hosted functions share the platform resources within a “virtual system” environment enforced by partitioning mechanisms that are implemented as part of the platform design. The “virtual system” partitioning environment guarantees that hosted functions are isolated from each other. The design of platform guarantees each hosted function can use its allocated computing, communication and I/O resources.

A method of resources configuration/reconfiguration[3] is proposed for IMA system in this paper, which take the method used in control allocation of multi-surfaces aircraft for reference, to indicate the allocated resources for hosted functions. The method is suitable for the IMA system based on ARINC and ASAAC.

2. Control Allocation

Originally, CA is the method of distributing the control requirements among redundant control surfaces for satisfying the optimized objectives in different flight conditions and mission within their range of position and rate limits, meanwhile, the method would re-allocate the left normal control surfaces to keep the robustness in the presence of different partial control surface faults[4].

CA is a modularization design method which designs the control law and allocation law separately. The advantages of the method are list as follow:

(1) Easy to adjust parameters.
(2) Easy to reallocate.
(3) Simplify the control law design.
(4) Could add ranges of limits.

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Due to the similarity between the problem of mission-oriented resources allocation and the flight control problem of multi-surfaces aircraft, both in normal and fault situation, the paper expands the application of the method to solve the resources allocation with IMA architecture.

3. CA Based Quadratic Programming

The CA problem studied in the paper is achieved by solving a quadratic programming(QP) problem which involves the minimization of a quadratic cost function subject to both equality and inequality constraints:

$$\min_{u} \quad J = \|W_u(u-u_d)\|_2^2 + \gamma\|W_v(Gu-v)\|_2^2 \tag{1}$$

$$\text{Subject to } \underline{u} \le u \le \bar{u} \tag{2}$$

Here u_d is the desired control input and v is virtual control input, W_u and W_v are weighting matrices. G is control effectiveness matrix, $\gamma > 0$ is the weighting factor. Eq.(1) can be rewritten by :

$$\begin{aligned} J &= (u-u_d)^T W_u (u-u_d) + \gamma (Gu-v)^T W_v (Gu-v) \\ &= u^T W_u u - u^T W_u u_d - u_d^T W_u u + u_d^T W_u u_d + \gamma (u^T G^T W_v G u \\ &\quad - u^T G^T W_v v - v^T W_v G u + v^T W_v v) \\ &= u^T (W_u + \gamma G^T W_v G) u + u^T(-2W_u u_d - 2\gamma G^T W_v v) \\ &\quad + u_d^T W_u u_d + \gamma v^T W_v v \\ &= \frac{1}{2} u^T T u + u^T d + r \end{aligned}$$

Here $T = 2W_u + 2\gamma G^T W_v G$, $d = -2W_u u_d - 2\gamma G^T W_v v$, $r = u_d^T W_u u_d + \gamma v^T W_v v$.

Because r is a constant value in a sampled cycle, so the solution will be the same if we remove r from the cost function. Then, the control allocation problem based on QP can be reduced to

$$\min_{u} \quad J = \frac{1}{2} u^T T u + u^T d \tag{3}$$

$$\text{Subject to } \underline{u} \le u \le \bar{u} \tag{4}$$

When $u_d = 0$, Eq.(1)-(2)can be rewritten by[3],[4]:

$$J = \frac{1}{2}[(1-\varepsilon)(Gu-v)^T Q_1 (Gu-v) + \varepsilon u^T Q_2 u] \tag{5}$$

$$\text{Subject to} \quad \underline{u} \le u \le \bar{u} \tag{6}$$

Here $Q_1 = W_v^T W_v > 0$, $Q_2 = W_u^T W_u > 0$, $\varepsilon = (1+\gamma)^{-1}$.

Suppose $u = (u_1, \cdots, u_m)^T \in R^m$, which satisfies

$$s_i(u) = \begin{cases} \underline{u}, & u_i \le \underline{u} \\ u_i, & \underline{u} < u_i < \bar{u}, \quad i = 1, 2, \cdots m \\ \bar{u}, & u_i \ge \bar{u} \end{cases} \tag{7}$$

$s(\cdot)$ is the vector saturator, then the algorithm becomes

$$u = s[(1-\varepsilon)\omega G^T Q_1 v - (\omega T - I)u] \overset{\Delta}{=} f(u) \tag{8}$$

Here $\omega = \|T\|_F^{-1} = (tr(T^T T))^{-\frac{1}{2}}$, which decides the step length $T = (1-\varepsilon)G^T Q_1 G + \varepsilon Q_2$, $\varepsilon \in (0,1)$.

So the iterative formula of fixed point (FXP)[7]-[13] method is listed as follow:

$$u^{k+1} = f(u^k)(k = 0, 1, \ldots, N) \tag{9}$$

4. Architecture of resource configuration in avionics based on control allocation

The architecture of resource configuration in avionics based on control allocation is shown in Fig.1, includes system reconfiguration in the presence of detecting a fault.

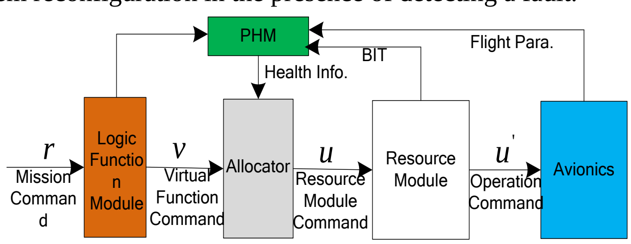

Figure 1. Architecture of Resource Configuration in Avionics Based on Control Allocation

Suppose r is the mission command of a moment, including function A, B, C, D, E, refer to GPM (Graphic Processing Module), NSM (Network Support Module), DPM (Data Processing Module), MMM (Mass Memory Module), but not all functions need all the modules. The mapping relationship between functions and modules is shown in Table.1, in which, √ means there is a mapping, × means no mapping.

Table.1 The Mapping Relationship Between Different Functions and Modules

Function	GPM	NSM	DPM	MMM
Function A	√	√	√	√
Function B	√	√	×	√
Function C	×	√	√	√
Function D	√	√	√	×
Function E	×	√	√	√

Suppose there are three GPMs, GPM1, GPM2, GPM3, three DPMs, DPM1, DPM2, DPM3, two NSMs, NSM1, NSM2, and two MMMs, MMM1, MMM2.

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Suppose the priority of the functions is $A > B > C > D > E$, then we allocate the resources for A first. In view of 4 types of module and 10 modules in all, according to Table.1, the control effectiveness matrix of A is

$$\mathbf{G}^A = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix} \quad (10)$$

Suppose $\mathbf{U}^A$ is the CA output of function A, $\mathbf{U}_d^A$ is the expected CA output, $\mathbf{V}^A$ is required input of function A, then the resources allocation problem of function A is

$$\min_u \quad J = \left\| W_{\mathbf{U}^A}(\mathbf{U}^A - \mathbf{U}_d^A) \right\|_2^2 + \gamma \left\| W_{\mathbf{V}^A}(\mathbf{G}^A \mathbf{U}^A - \mathbf{V}^A) \right\|_2^2 \quad (11)$$

$$\textit{Subject to } 0 \le u_{ij} \le 1 \quad (12)$$

Here $W_{\mathbf{U}}^A = W_{\mathbf{U}}$ (for different functions, the measures of health are the same), $W_{\mathbf{V}^A} = I$. From above, the solution to the problem of resource allocation of function A is $\mathbf{U}^A$ which satisfies equations (12), and (13):

$$\mathbf{U}^A = s[(1-\varepsilon)\eta \mathbf{G}^{AT} Q_1 \mathbf{V}^A - (\eta H - I)\mathbf{U}^A] \stackrel{\Delta}{=} f(\mathbf{U}^A) \quad (13)$$

After obtaining $\mathbf{U}^A$, we can analyze the resources allocation problem of function B in consideration of the resources used by function A. So we have

$$\min_u \quad J = \left\| W_{\mathbf{U}^B}(\mathbf{U}^B - \mathbf{U}_d^B) \right\|_2^2 + \gamma \left\| W_{\mathbf{V}^B}(\mathbf{G}^B \mathbf{U}^B - \mathbf{V}^B) \right\|_2^2 \quad (14)$$

$$\textit{Subject to } 0 \le u_{ij} \le 1 - u_{ij}^A \quad (15)$$

The resources allocation analysis of function C, D, E, is similar to function B. Once there is a fault, set the corresponding line to 0, the process of reconfiguration is the same.

Now simulations are given to show the effectiveness of the method. Suppose the virtual function commands obtained from the mission command are shown in Table.2.

Table.2 Virtual function commands

Function	GPM	NSM	DPM	MMM
Function A	0.1	0.2	0.3	0.4
Function B	0.3	0.2	0	0.3
Function C	0	0.2	0.3	0.4
Function D	0.2	0.2	0.3	0
Function E	0	0.3	0.2	0.3

We have

$$\mathbf{V} = \begin{bmatrix} 0.1 & 0.2 & 0.3 & 0.4 \\ 0.3 & 0.2 & 0 & 0.3 \\ 0 & 0.2 & 0.3 & 0.1 \\ 0.2 & 0.2 & 0.3 & 0 \\ 0 & 0.3 & 0.2 & 0.3 \end{bmatrix} \quad (16)$$

$$\mathbf{V}^A = \begin{bmatrix} 0.1 & 0.2 & 0.3 & 0.4 \end{bmatrix} \quad (17)$$

$$\mathbf{V}^B = \begin{bmatrix} 0.3 & 0.2 & 0 & 0.3 \end{bmatrix} \quad (18)$$

$$\mathbf{V}^C = \begin{bmatrix} 0 & 0.2 & 0.3 & 0.1 \end{bmatrix} \quad (19)$$

$$\mathbf{V}^D = \begin{bmatrix} 0.2 & 0.2 & 0.3 & 0 \end{bmatrix} \quad (20)$$

$$\mathbf{V}^E = \begin{bmatrix} 0 & 0.3 & 0.2 & 0.3 \end{bmatrix} \quad (21)$$

Then, set $\varepsilon = 0.1$, $W_{\mathbf{U}^A} = W_{\mathbf{U}} =$

$$diag[0.01 \ \ 1 \ \ 1 \ \ 0.01 \ \ 1 \ \ 0.01 \ \ 1 \ \ 0.01 \ \ 1 \ \ 1] \quad (22)$$

$W_{\mathbf{V}^A} = I_{4\times 4}$, set

$$\mathbf{U}^{A0} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (23)$$

Due to (12) and (13), we have

$$\mathbf{U}^A = \begin{bmatrix} 0.1 & 0 & 0 & 0.2 & 0 & 0.3 & 0 & 0 & 0.4 & 0 \end{bmatrix} \quad (24)$$

Then, we have

$$\mathbf{U}^B = \begin{bmatrix} 0.3 & 0 & 0 & 0.2 & 0 & 0 & 0 & 0 & 0.3 & 0 \end{bmatrix} \quad (25)$$

$$\mathbf{U}^C = \begin{bmatrix} 0 & 0 & 0 & 0.2 & 0 & 0.3 & 0 & 0 & 0.3 & 0.1 \end{bmatrix} \quad (26)$$

$$\mathbf{U}^D = \begin{bmatrix} 0.2 & 0 & 0 & 0.2 & 0 & 0.3 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (27)$$

$$\mathbf{U}^E = \begin{bmatrix} 0 & 0 & 0 & 0.2 & 0.1 & 0.1 & 0.05 & 0.05 & 0 & 0.3 \end{bmatrix} \quad (28)$$

So we have

$$\mathbf{U} = \begin{bmatrix} 0.1 & 0.3 & 0 & 0.2 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\ 0 & 0 & 0 & 0 & 0.1 \\ 0.3 & 0 & 0.3 & 0.3 & 0.1 \\ 0 & 0 & 0 & 0 & 0.05 \\ 0 & 0 & 0 & 0 & 0.05 \\ 0.4 & 0.3 & 0.3 & 0 & 0 \\ 0 & 0 & 0.1 & 0 & 0.3 \end{bmatrix} \quad (29)$$

The above example indicates that the CA method is effective and simple in solving the problem of resources allocation in avionics.

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5. Conclusions and Recommendations

The CA method is referenced to solve the problem of resources configuration architecture in avionics, is appropriate for resources configuration to the situation across different mission phase, system state (normal/failure).

The construction of control effectiveness matrix from the mapping relationship between functions and resources is detailed. According to the characteristic of IMA resources configuration, objective function based on FXP method and iterative steps are given. Through the method, we can allocate resources by health measure. Finally, example indicates the effectiveness of the method in allocating resources in avionics.

The architecture is general, easy to achieve, which can be applied in static and dynamic configuration. But compared to real mission environment, the granularity of architecture is still rough. Research on more accurate architecture and fast optimization algorithm to configuration will be the future work.

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Biographies

CHENGZHI CHI received the B.S. degree in Information and Computing Science, the M.S. degree in Pattern Recognition and Intelligent System and the Ph.D. degree in Control Science and Engineering from Northwestern Polytechnical University, Xi'an, Shaanxi, in 2005, 2009 and 2012, respectively. Currently, he is an Engineer at China National Aeronautical Radio Electronics Research Institute. His main research interests include Flight Control and Simulation, Flight Management System, Prognostic and Health Management of Avionics.

Dr. CHI may be reached at chi_chengzhi@careri.com