Real-Time Reliability Optimization of CAN Control Network based on RMA for Independent Drive Electric Vehicle's powertrain

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***Abstract*—According to work principle of controller area network (CAN) protocol, the use of CAN in time-critical and safety-critical control applications such as independent drived electric vehicle's powertrains presented designers with new special problems on the determination of real-time reliability rather than real-time capability. In this paper, real-time reliability analysis of the native event-triggered CAN for a 2-motor independent drive electric vehicle (IDEV) was researched and real-time reliability optimization based on rate monotonic algorithm (RMA) was discussed contrastively. The parameters including real-time capability, maximum response time, maximum bandwidth utilization, maximum periods jitter and jitter margin were evaluated respectively. The calculation results demonstrated that real-time reliability of the CAN based on RMA is better than the native CAN as underlying control network of IDEV's powertrains. The result indicates real-time reliability analysis and optimization can improve the reliability of IDEV's distributed control systems, provides a theory analysis foundation for the engineering design and application of IDEV**

Keywords-Independent Drive Eelectric Vehicle (IDEV); Controller Area Network (CAN); Real-Time Reliability Analysis; Real-Time Reliability Optimization; Rate Monotonic Algorithm

I. INTRODUCTION

The CAN has become the world's most successful in-vehicle network. At the end of the 1980s, CAN was first introduced with the clear intent to serve as a high performance communication system for automotive applications and in particular for controlling the powertrain system. In 1991, CAN developed by Robert Bosch GmbH was deployed first in a motor vehicle, the Mercedes Benz S-Class. At present, distributed powertrain control functions are the most commonly implemented in automotive vehicles and electric vehicles by using real-time networks based on CAN, that is the popular "unofficial" model[1-3].

CAN is a well-designed real-time communication network operating in vehicles' noisy environment, however the work principle majority of CAN protocol is essentially event-triggered[1,4]. CAN is not felt reliable enough for supporting the time-critical and safety-critical control applications such as independent drive electric vehicle's powertrains. Much work has been done to establish the bounded response time of real-time messages in the event-triggered CAN including optimal schedule (e.g. rate monotonic algorithm) and real-time analysis techniques. Regretfully, most analysis techniques can support the determination of real-time or schedulable capability of real-time message transmissions, but can not support the determination of real-time reliability.

The next section will describe a real-time reliability analysis theory of CAN. Section III describes the CAN control network design for IDEV's powertrain. Section IV and V gives real-time reliability analysis and optimization of CAN for distributed control system of IDEV's powertrain and the paper concludes with Section VI.

II. REAL-TIME RELIABILITY ANALYSIS THEORY OF CAN

Tindell et al present real-time analysis to calculate the worst-case response time of CAN frames based on the standard fixed priority response time analysis for CPU scheduling[4]. Real-time reliability analisys is a further work to calculate reliability parameters based on the real-time analysis. So before intrducing the real-time reliability analysis some terms and expressions are quoted and defined.

The term T_m defines the period of a given message *m*. t_{Jm} denotes the jitter on the queueing of the message *m*. n_m defines the number of bytes in the message. The term of maximum transmission delay t_{Cm} denotes the worst-case time taken to transmit the message physically on the network. The term of maximum response time t_{Rm} denotes the worst-case response time of a given message *m*. t_{Dm} defines the deadline of the message. A message is said to be real-time or schedulable if and only if as formula 1:

$$t_{Rm} \le t_{Dm} - t_{Jm} \tag{1}$$

The maximum response time t_{Rm} is composed of the maximum queueing delay and the maximum transmission delay. the maximum queueing delay is denoted as t_{Wm} . t_{Rm} is calculated as:

$$t_{Rm} = t_{Wm} + t_{Cm} \tag{2}$$

The worst-case time taken to transmit a bit on the network-the so-called bit time is defined as τ_{bit} . Accrding

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to the worst-case bit stuffing, thus t_{Cm} is a function of n_m as:

$$t_{Cm} = \left[\left\lfloor \frac{54+8n_m}{5} \right\rfloor + 67 + 8n_m \right] \times \tau_{bit} \tag{3}$$

The maximum queueing delay, t_{Wm} is the longest time that a message can be queued within a station and be delayed because other higher- and lower-priority messages are being sent on the network. t_{Wm} is composed of the longest time that all higher-priority messages can be queued and occupy the network before the message m is finally transmitted and the longest time that any lower priority message can occupy the network which is defined as t_{Bm}. t_{Wm} can be caculated with a recurrence relation as:

$$t_{Wm}^{n+1} = t_{Bm} + \sum_{\forall j \in hp(m)} \left\lceil \frac{t_{Wm}^{n} + \tau_{bit} + t_{Jj}}{T_j} \right\rceil t_{Cj} + t_{Em} \tag{4}$$

$$t_{Bm} = \underset{\forall j \in lp(m)}{Max} \{t_{Cj}\} \tag{5}$$

The term J_{Pm} defines the maximum periods jitter of a given message m. J_{Pm} is the ratio of the maximum queueing delay t_{Wm} and the jitter t_{Jm} with the periods T_m.

$$J_{pm} = \frac{t_{Wm} + t_{Jm}}{T_m} \times 100\% \tag{6}$$

The term θ_{Jm} denotes jitter margin of the message. θ_{Jm} is used to evaluate the real-time reliability of the message m.

$$\theta_{Jm} = 1 - J_{Pm}/100 \tag{7}$$

The term U_m denotes the network utilization factor of the message m. The network utilization factor of system is defined as U_{Net}. U_{Net} is the sum of the network utilization factors of all N messages.

$$U_m = \frac{T_{Cm}}{T_m} \tag{8}$$

$$U_{Net} = \sum_{i=1}^{N} U_i \tag{9}$$

III. CAN CONTROL NETWORK DESIGN FOR IDEV'S POWERTRAIN

The distributed powertrain system of a 2-motor IDEV is composed of power battery system (PBS), vehicle controller (VC), left motor controller (LMC), left motor (LM), information system (IS), right motor controller (RMC), right motor (RM), power coupling system (PCS), left drive wheel (LDW), right drive wheel (RDW) and so on as in Fig.1.

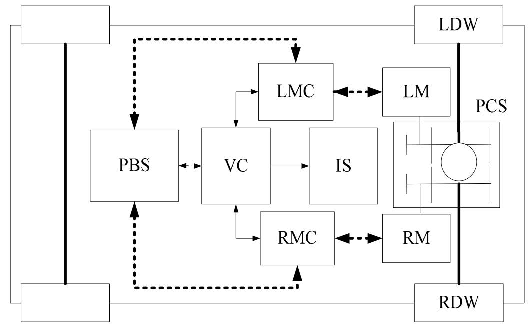


Fig.1 IDEV's powertrain system sketch

The distributed control system of the powertrain system is composed of power battery system controller (PBSC), VC, LMC, RMC, information system controller (ISC), power coupling system controller (PCSC) and drive assistant controller (DAC). The PCSC and DAC are linked to VC by other wire or bus such as low-speed CAN. Other controllers are interlinked by CAN as in Fig.2.

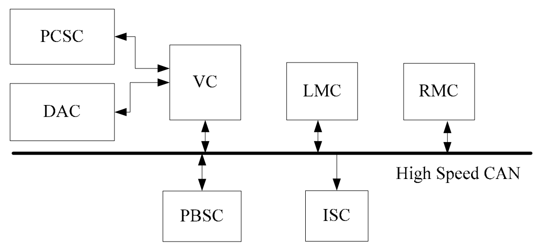


Fig.2 CAN topology of IDEV's powertrain system

The VC is used to implement the managements of motors, PBS, PCS and drive assistant system and so on. LMC and RMC are respectively used to control and detect left motor and right motor. PBSC is used to monitor of power battery system. The messages of IDEV's powertrain are defined as in Tab.1

Tab.1 Messages in CAN of IDEV's powertrain system

Source	Message	Period /ms	N.O	size /byte	Data definition
VC	VCUC0	10	M1	8	Work mode set and control command
	VCUC1	50	M2	8	State and fault data of vehicle
LMC	MCL1	10	M3	8	State data of Left motor
	MCL2	50	M4	8	State data of Left motor
RMC	MCR1	10	M5	8	State data of Right motor
	MCR2	50	M6	8	State data of Right motor
PBSC	BMS1	50	M7	8	State data of power battery system
	BMS2	100	M8	8	State data of power battery system

IV. REAL-TIME RELIABILITY ANALYSIS FOR NATIVE CAN

To implement the real time reliability analysis of the CAN system , the CAN system baudrate is set as 250kbsps. The valuble of t_{Jm} is 0.1*ms*. The priority of each message is set up as in Tab.2. the valuble of t_{Dm} is equal to T_m. The analysis results of parameters including real-time capability, maximum response time, maximum period jitter, jitter margin and maximum bandwidth utilization are showed in Tab.2.

Tab.2 the results of real-time reliability analysis for native CAN system of IDEV's powertrain

message	Period/*ms*	N.O	priority	t_{Dm}/ms	t_{Wm}/ms	t_{Rm}/ms	J_{pm}/ms	θ_{Jm}	U_m/%
VCUC0	10	M1	1	10	0.616	1.232	7.16	0.9284	6.160
VCUC1	50	M2	4	50	3.08	3.696	6.36	0.9364	1.232
MCL1	10	M3	2	10	1.232	1.848	13.32	0.8668	6.160
MCL2	50	M4	5	50	3.696	4.312	7.592	0.92408	1.232
MCR1	10	M5	8	10	4.312	4.928	44.12	0.5588	6.160
MCR2	50	M6	6	50	4.312	4.928	8.824	0.91176	1.232
BMS1	50	M7	7	50	2.464	3.08	5.128	0.94872	1.232
BMS2	100	M8	3	100	1.848	2.464	1.948	0.98052	0.616

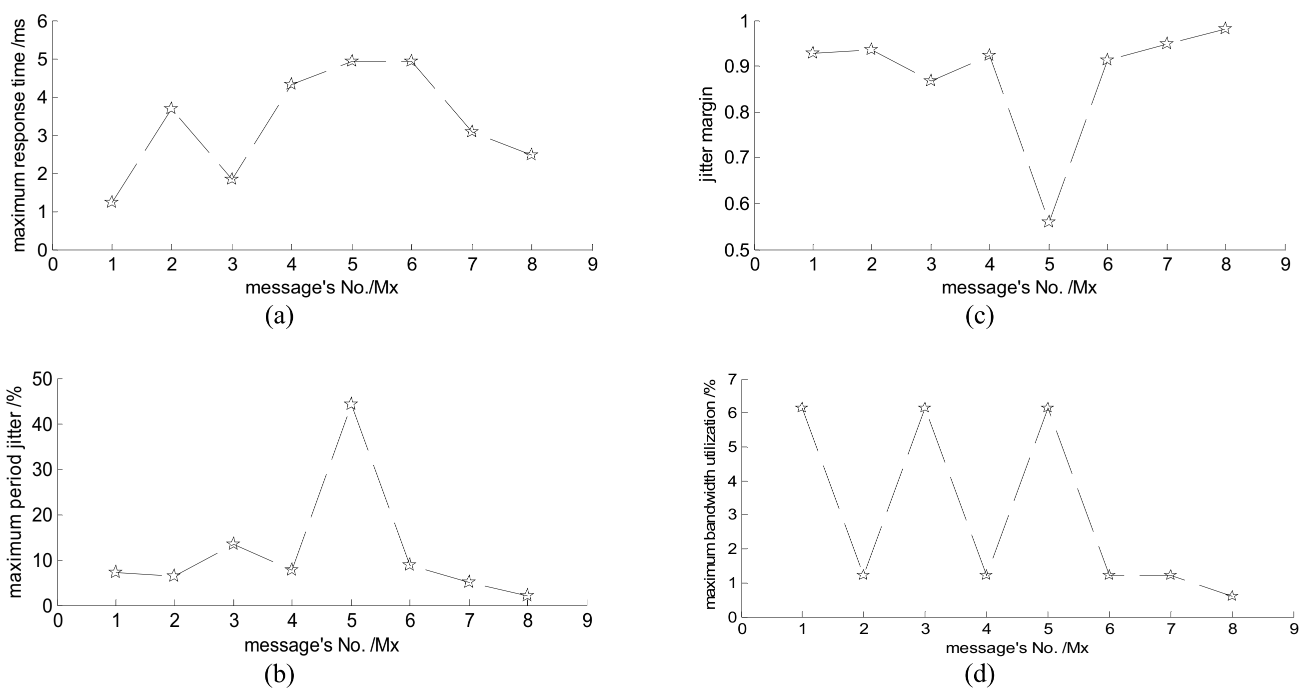


Fig.3 The diagram of real-time reliability analysis of native CAN

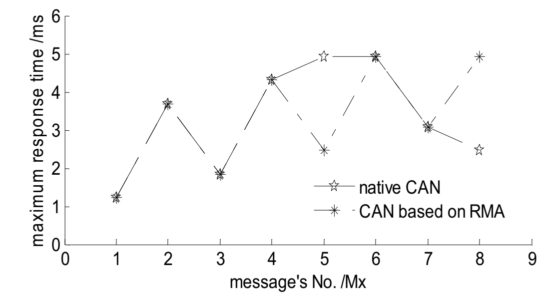
According to formula 1 and Tab.2, every message is real time. The Fig.3(a) illustrates that the maximum response time of every message becomes larger as it's priority becomes smaller. The Fig.3(b) and (c) illustrate that both maximum period jitter of the message M5 is larger and it's jitter margin is smaller. So the message M5, that is the message MCR1, are transmitted with the inferior real-time reliability. The Fig.3(d) illustrates that the maximum bandwidth utilization of every message becomes larger as it's period becomes smaller.

V. REAL-TIME RELIABILITY OPTIMIZATION OF CAN BASED ON RMA

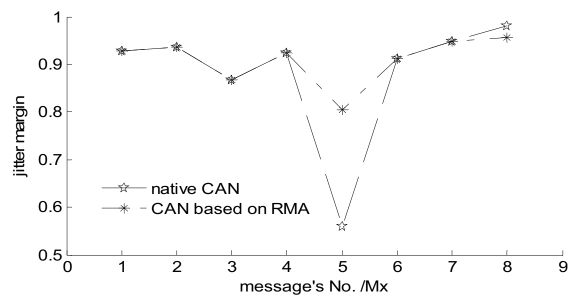
To improve the real-time reliability of CAN system, rate monotonic algorithm (RMA) is quoted to optimize the scheduling mechanism of native CAN. According to RMA, The priority of a given message becomes larger as it's period becomes smaller[5]. So the priority of M5 is promoted to 3, while the priority of M8 is descended to 8. The real-time reliability analysis of CAN based on RMA as the native CAN and the analysis results are as in Tab.3.

Tab.3 the results of real-time reliability analysis for CAN system based on RMA of IDEV's powertrain

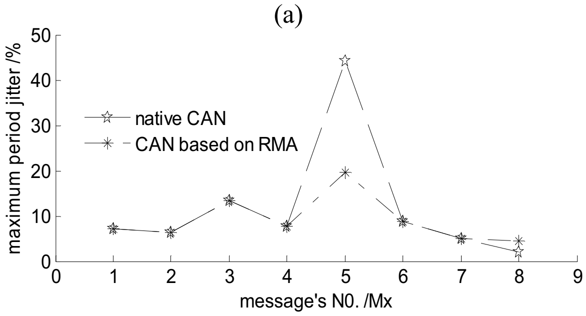
message	Period/*ms*	N.O	priority	t_{Dm}/ms	t_{Wm}/ms	t_{Rm}/ms	J_{pm}/ms	θ_{Jm}	U_m/%
VCUC0	10	M1	1	10	0.616	1.232	7.16	0.9284	6.160
VCUC1	50	M2	4	50	3.08	3.696	6.36	0.9364	1.232
MCL1	10	M3	2	10	1.232	1.848	13.32	0.8668	6.160
MCL2	50	M4	5	50	3.696	4.312	7.592	0.92408	1.232
MCR1	10	M5	3	10	1.848	2.464	19.48	0.8052	6.160
MCR2	50	M6	6	50	4.312	4.928	8.824	0.91176	1.232
BMS1	50	M7	7	50	2.464	3.08	5.128	0.94872	1.232
BMS2	100	M8	8	100	4.312	4.928	4.412	0.95588	0.616



(a)



(c)



(b)

Fig.4 The diagram of real-time reliability analysis optimization

The Fig.4(a) illustrates that both native CAN and CAN based on RMA are real time. According to Fig.4(b), even if the maximum period jitter of M8 is enlarged slightly, the maximum period jitter of M5 is effectively improved. The Fig.4(c) illustrates that the real-time reliability of CAN system for IDEV's powertrain is optimized.

VI. CONCLUSIONS

The real-time reliability is very important for time- and safety-critical control applications[1,4,6], particularly for distributed controlling of IDEV's powertrain systems. This paper proposed the real-time reliability analysis and optimization to optimize and improve the designs of real-time applications. Those analysis and optimization can also be used to design other time- and safety-critical control applications in industry, manufacture and automatic control system.

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REFERENCES

[1] G.Cena, A.Valenzano, S.Vitturi. Advances in automotive digital communications. Computer Standards & Interfaces, 2005,27:665-678.

[2] G.Leen, D.Heffernan. TTCAN: a new time-triggered controller area network. Microprocessors and Microsystems, 2002,26:77-94.

[3] Hans-Peter Schŏner. Automotive mechatronics. Control Engineering Practice, 2004,12:1343-1351.

[4] K.Tindell, A.Burns, A.J.Wellings. Calculating controller area network (CAN) message response times. Control Engineering Practice, 1995,3:1163-1169.

[5] GIORGIO C.BUTTAZZO. Rate Monotonic vs. EDF: Judgment Day. Real-Time Systems, 2005, 29:5-26.

[6] Thomas Nolte, Hans Hansson and Christer Norstrŏm. Minimizing CAN response-time jitter by message manipulation. The Proceeding of the Eighth IEEE Real-Time and Embedded Technology and Applications Symposium, 2002.