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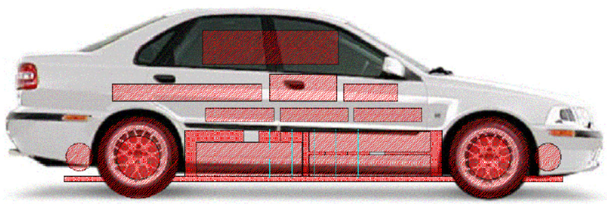
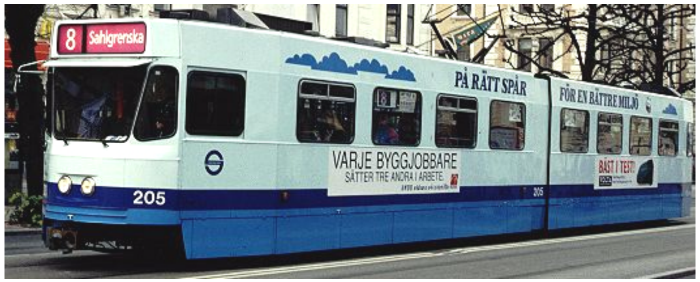
ISSC 21

On Communication Requirements for Control-by-Wire Applications

Roger Johansson, Per Johannessen, Kristina Forsberg,
Håkan Sivencrona, Jan Torin



- Future distributed control systems for safety critical applications



CHALMERS
Chalmers University of Technology
SP
VOLVO
Volvo Car Corporation

Presentation Overview

- Distributed By-Wire Control, background and motivation
- Dependable Real -Time Control
- Bandwith requirement, case studies
- Summary and conclusions

Background

Ongoing efforts aim to develop a common standard for communication protocols within the fly- and drive-by-wire industry.

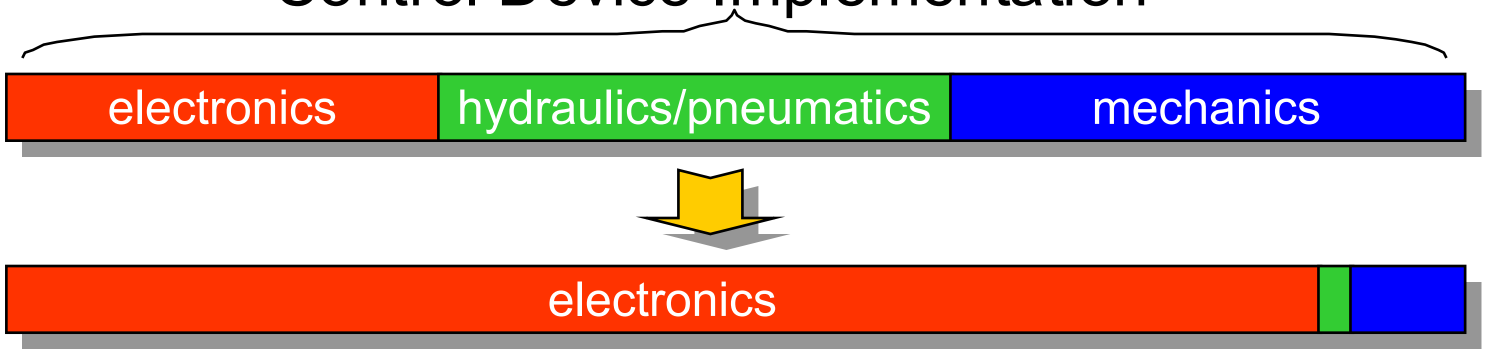
- Four major standards
  - FlexRay - Currently under development by BMW, Daimler-Chrysler, Motorola, Philips, et.al.
  - SAFEbus - Developed by Honeywell and in operation in Boeing 777
  - TTCAN - Developed by Bosch and extends the existing CAN protocol. Sample chips are available.
  - TTP/C - Developed by the Technical University of Vienna and TTTech. Commercial chips are available.
- Instead of starting with the protocol specification we investigated the requirements derived from the application.

Distributed By-Wire Control, a brief background

Drivers
- New demands
- Microelectronics evolution

Goals
- Reduce costs (production and maintenance)
- Increase reliability
- Maintain safety

Control Device Implementation



"*If the automobile had followed the same development cycle as the computer, a Rolls-Royce would today cost $100, get a million miles per gallon, and explode once a year, killing everyone inside*."

- Robert X. Cringely

Real-Time Control Strategies

Local control

- Local information processing
- No data dependencies between control objects

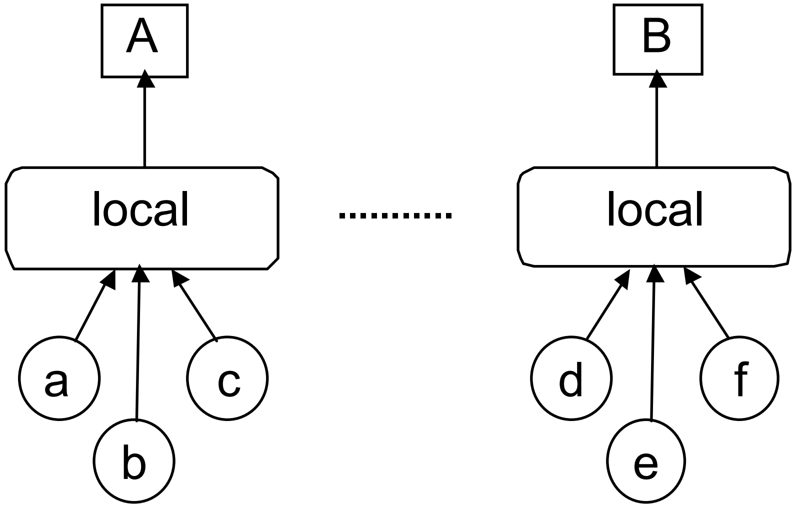
Centralized global control

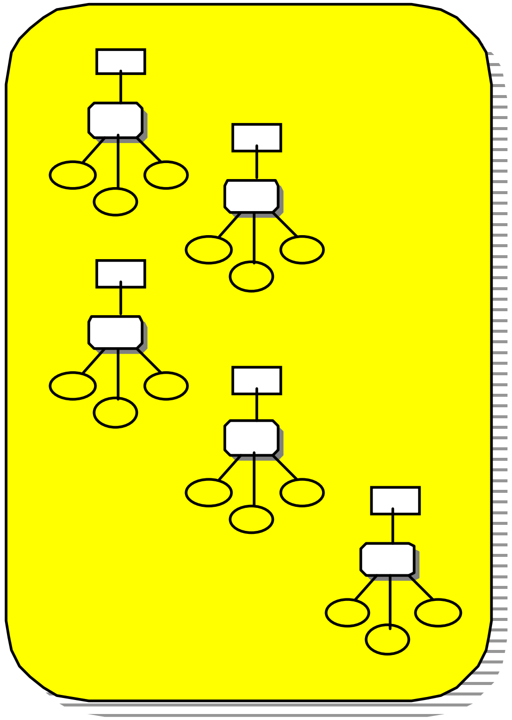
- Local and global information processing
- Data dependencies between control objects

Distributed global control

- Local and distributed information processing
- Data dependencies between control objects

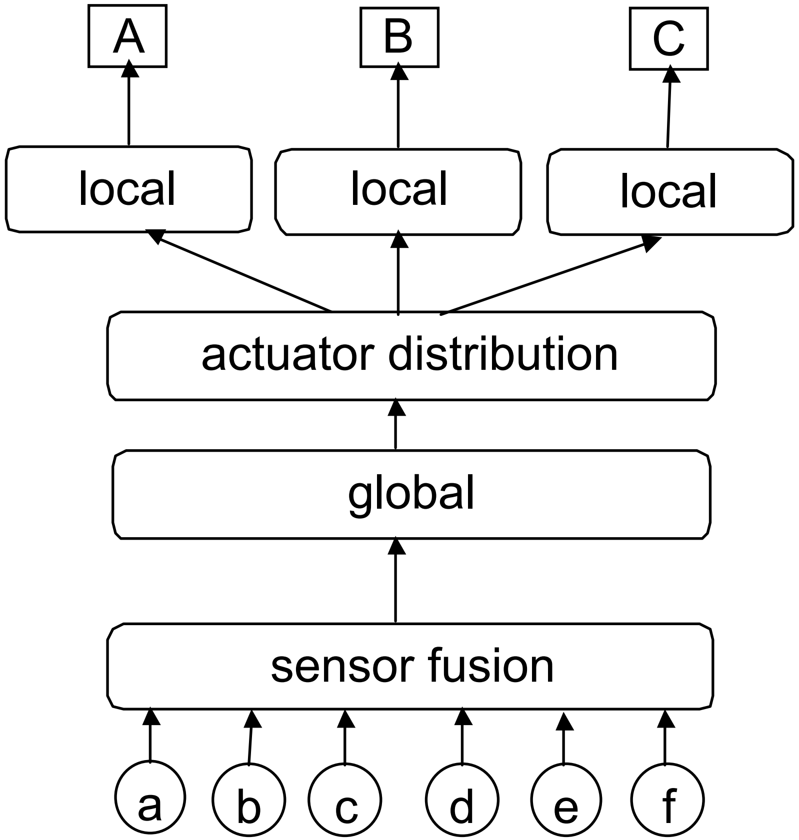
Local control





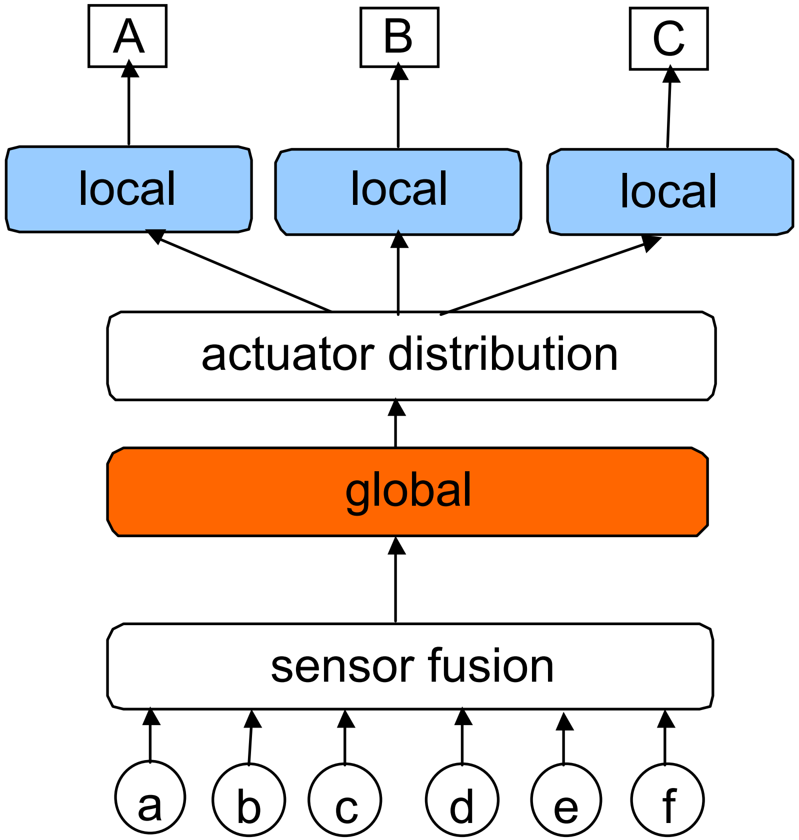
Drawback: Can’t support global control strategies…

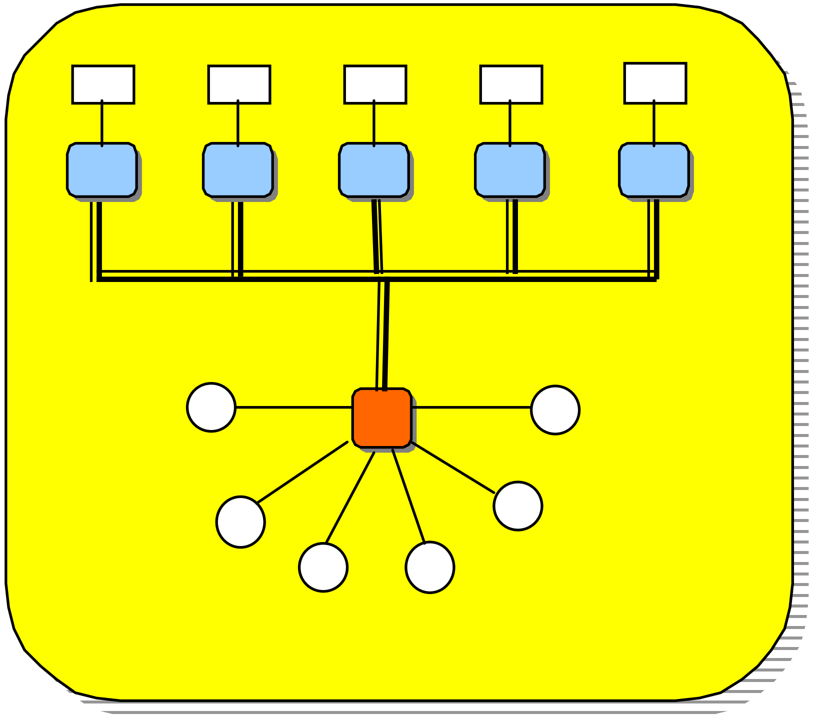
Global control



Strategy combine local control performance (closed loops >500 Hz) with global control features e.g. stability system

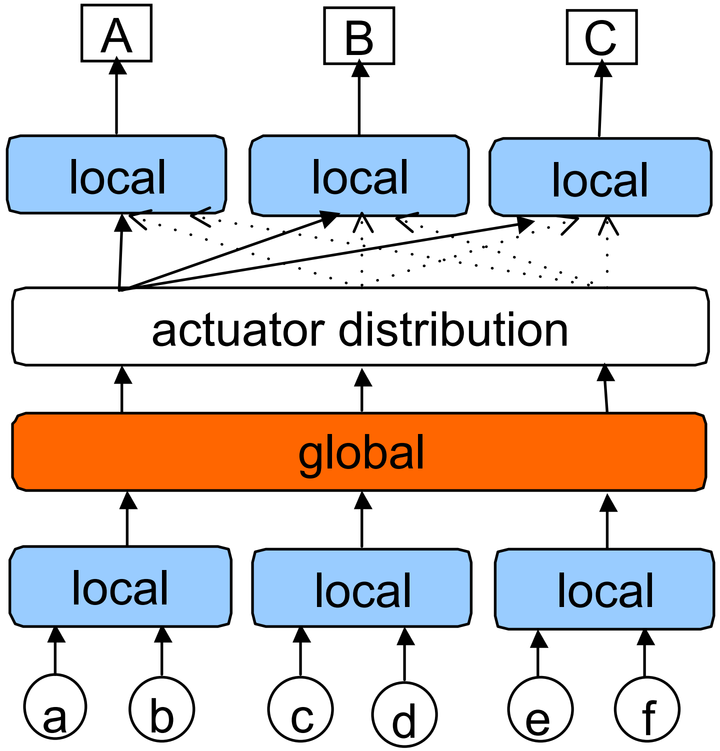
Centralized global control





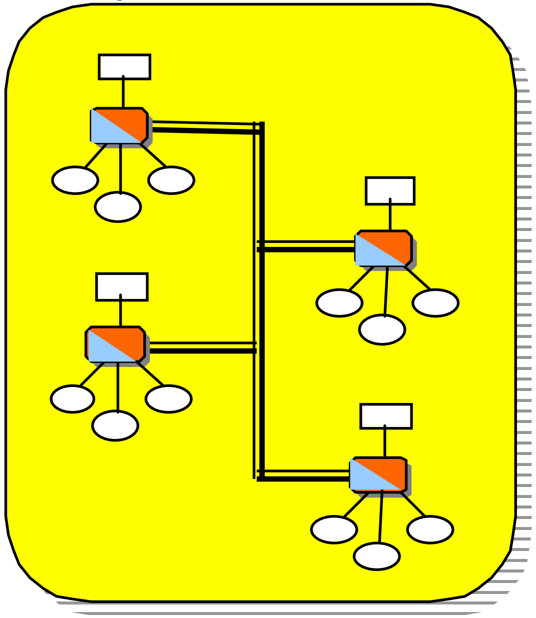
Drawback: Requires extra node (fault-tolerant) for global information processing…

Distributed global control



Distributed (parallel) data processing

Implementation



Drawback: Requires local control node processors with higher processing capacity…

Increases bus bandwith requirements

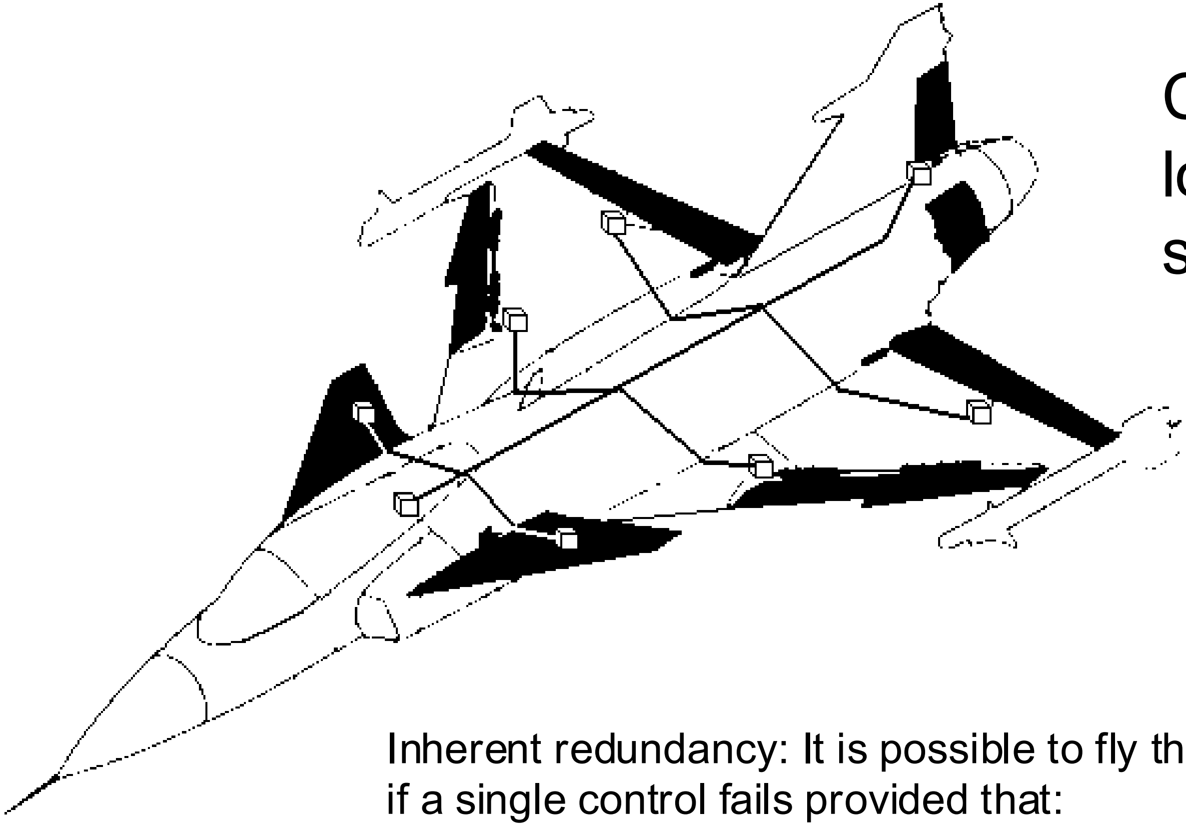
Case: Fly-by-Wire

JAS 39 Gripen, a multi-role, combat aircraft

Research project:

Future Flight Control System (FCS)

FCS: Organisation



Control computers located near control surfaces

Inherent redundancy: It is possible to fly the aircraft (safe landing) even if a single control fails provided that:

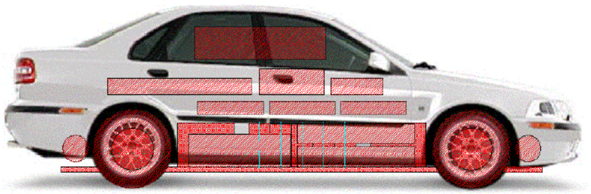
- the faulty control free-flow (fail-safe mode)
- alternate control laws is used (mode change)

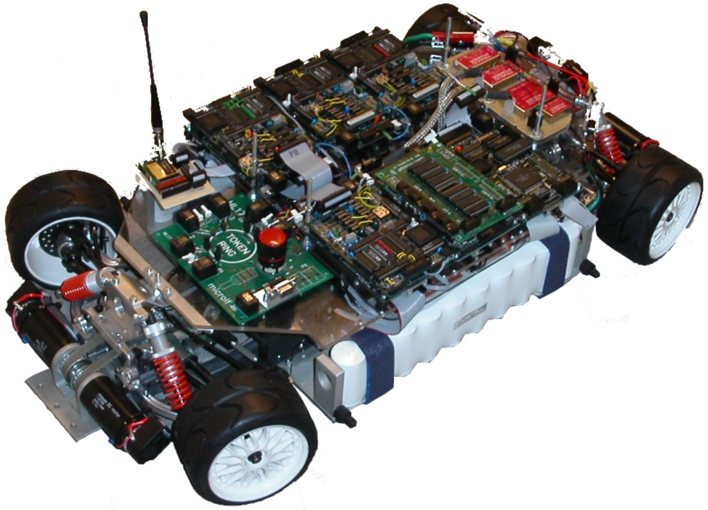
Fly-by-Wire communication bandwidth

Advanced Air Data sensor: 15 Hz: Pressure static, Mach number, Altitude, 60 Hz: Angle of attack, Angle of sideslip (duplicated)	3 x 32 bits x 15 Hz 2 x 32 bits x 60 Hz x 2	10560
Angular Rate Gyro sensor. 60 Hz: Pitch, Roll and Yaw (duplicated)	3 x 32 bits x 60 Hz x 2	11520
Accelerator Sensor : 60 Hz: Acceleration in z- and y-axle (duplicated)	2 x 32 bits x 60 Hz x 2	7680
Cockpit node 60 Hz: Pilot command for Pitch, Roll and Pedal. Assume 16 bits for discrete signals (duplicated)	3 x 32+16 bits x 60 Hz x 2	13440
Interconnection node: 60 Hz: Acceleration x-axle, Pitch, Roll and Aircraft weight	4 x 32 bit x 60 Hz	7680
Actuator nodes 60 Hz: Seven command words (16 bits) and one status word (16 bits) from all seven nodes	(7 x 16 bits + 16 bits) x 7 x 60 Hz	53760
Secondary control surfaces and Engine 60 Hz: Assumed 32 bits from these four nodes	4 x 32 bits x 60 Hz	7680
	Resulting bandwidth	**112.320** bits/s

Case: Steer-by-Wire

FAR –
Scale 1:5 experimental drive-by-wire





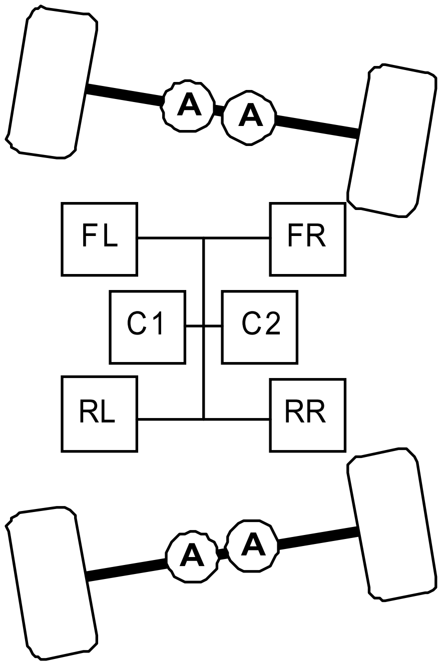
SIRIUS –
Scale 1:1 experimental drive-by-wire

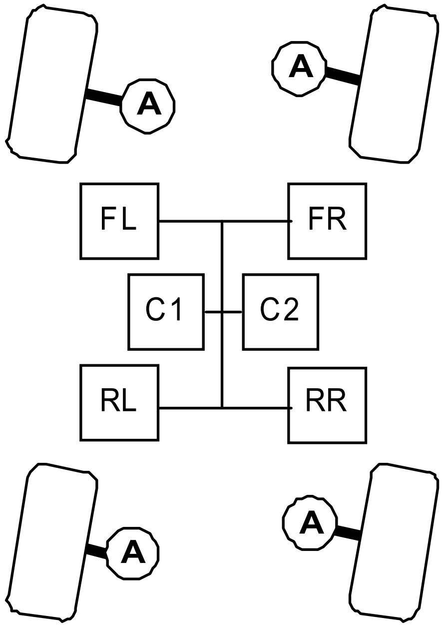
Case: Steer-by-Wire

FAR

TTCAN network

Independent Front/Rear axles steering





SIRIUS

TTP/C network

Independent 4-wheel steering

Inherent redundancy: In the case of a wheel node failure it is still possible to steer SIRIUS provided that:

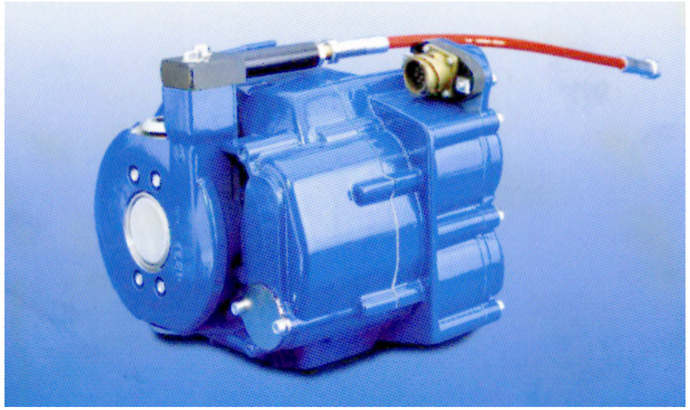
- the faulty wheel is locked in a fixed position (fail-safe mode)
- the global steering algorithm is modified (mode change)

Steer-by-Wire communication bandwidth

Central node (C1 and C2)		
100 Hz: steering wheel angle (14 bits) 10 Hz: steering mode (2 bits) Sensor redundantly allocated to C1 and C2.	14 bits x 100 Hz 2 bits x 10 Hz X 2	2840
Wheel node (FL,FR,RL and RR)		
100 Hz: wheel speed and steer angle (12 bits) steer angle sensor duplicated 100 Hz: Four command words (14 bits) and one status word (16 bits) from all four nodes	3 x 12 bits x 100 Hz ((4 x 14 bits) + 16 bits) x 4 x 100 Hz	32400
	Resulting bandwidth	35.240 bits/s

Case: Brake-by-Wire

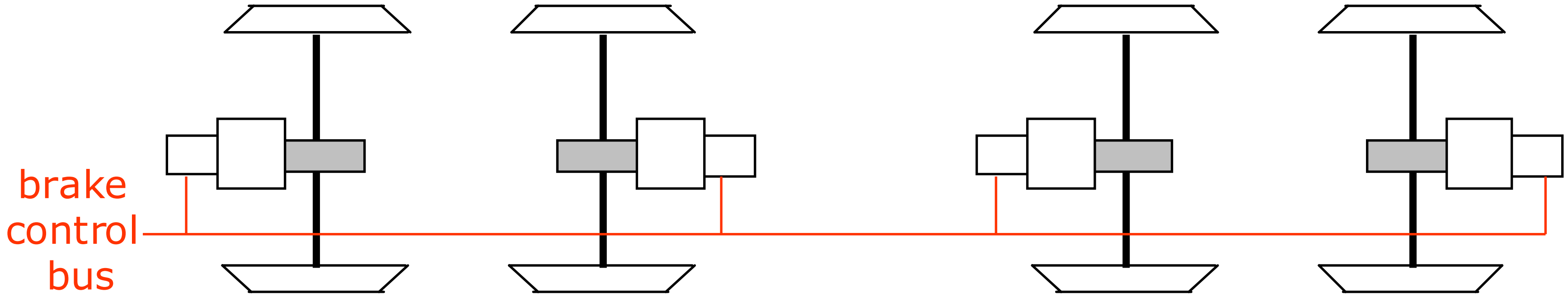
A Research project at CHALMERS with industrial partner SAB WABCO



Case: Brake-by-Wire

Inherent redundancy:

- It is always possible to brake the vehicle (possibly with reduced performance) assuming that at least one control (actuator) is working properly.
- Fail safe mode is due to operating environment e.g.
  - ❑ In open air : brake
  - ❑ In tunnel : free wheels



Brake-by-Wire communication bandwidth

Wheel node (four identical)		
50 Hz: Required disc pressure actuator	4 x 10 bits x 50 Hz	2000
50 Hz: applied pressure sensor The sensor is duplicated	4 x 10 bits x 50 Hz x 2	4000
50 Hz: rotational speed sensor The sensor is duplicated	4 x 10 bits x 50 Hz x 2	4000
	Resulting bandwidth	10.000 bits/s

Bandwith consumption

Application	Effective	TTCAN	FlexRay	SAFEbus	TTP/C
Fly-by-wire	112 320	235 680	187 680	148 320	156 000
Steer-by-wire	35 240	139 040	113 440	80 800	93 600
Brake-by-wire	10 000	19 200	19 200	12 800	19 200

Actual bandwith requirements are small

Protocol overhead is application dependent

Conclusions

- The communication subsystem is vital to assure system safety.
- The control-by-wire system should not host any other functionality than vehicle dynamics control.
- Inherent redundancy should be used by the application for cost effective fault-tolerance.
- The communication system must guarantee a sufficient data rate, as well as constant and limited time delays.
- The communication system should be a COTS with basic required functionality and limited autonomous behavior.
- The communication protocol should not guarantee application consensus, it is best accomplished at the application level.

Acknowledgments

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