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Vehicle Subsystems Control using the Concept of Moding

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Outline

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  - 4 Alternative ways of functional integration
- Chassis Moding Approach
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Introduction: Framing the Problem

<u>Status Quo:</u>

- After a long technical evolution a modern chassis is now a genuine mechatronic system:
  Almost all forces can be controlled electronically
- Simply adding individual systems to a car is not acceptable anymore because
  - the full performance level in ride comfort, handling and safety cannot be reached
  - there is a risk of inconsistency
    (dampers get to a hard to enhance wheel control while the steering goes soft to enhance comfort etc.)

Introduction: Framing the Problem

4 **Design Goal: Find a control architecture that maximizes performance …**

- Achieve highest level of ride, handling and safety by taking full advantage of a functional integration of the subsystems

4 **… while meeting severe restrictions:**

- Enable to freely combine subsystems from different suppliers with minimum needs for design changes
- Avoid necessity for partners to disclose their systems, protect everyone's intellectual property
- Minimize the complexity of tuning and validating the system
- Minimize the risk of unforeseen system behavior

→ Implication: Avoid closing control loops across subsystems!

Introduction: Framing the Problem

Alternative Solutions:

Co-Existence:

- Subsystems are sourced and developed independently, no integration (brake controller, steering controller, …)

Central Control:

- A central control module reads and processes all sensor signals and creates control signals for all actuators

Moding:

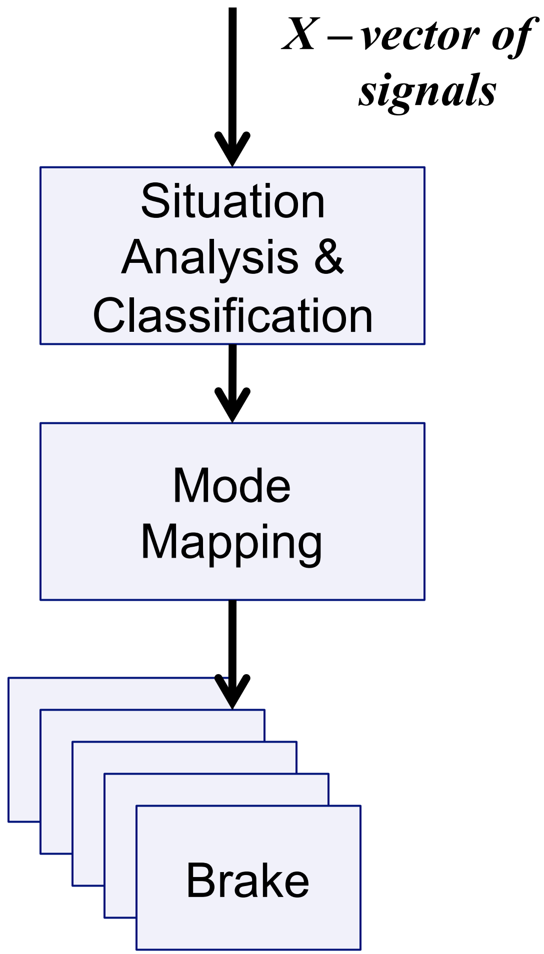
- Subsystems get slightly modified so that they can be operated in different modes or with different sets of tuning parameters
- A central software module processes all sensor signals and selects matching sets of operating modes for the subsystems

Introduction: Framing the Problem
Assessment of the Alternatives

	Achievable performance	Low engineering effort	"Plug & Play"
Co-Existence	--	++	++
Central Controller	++	--	--
Moding	+	+	+

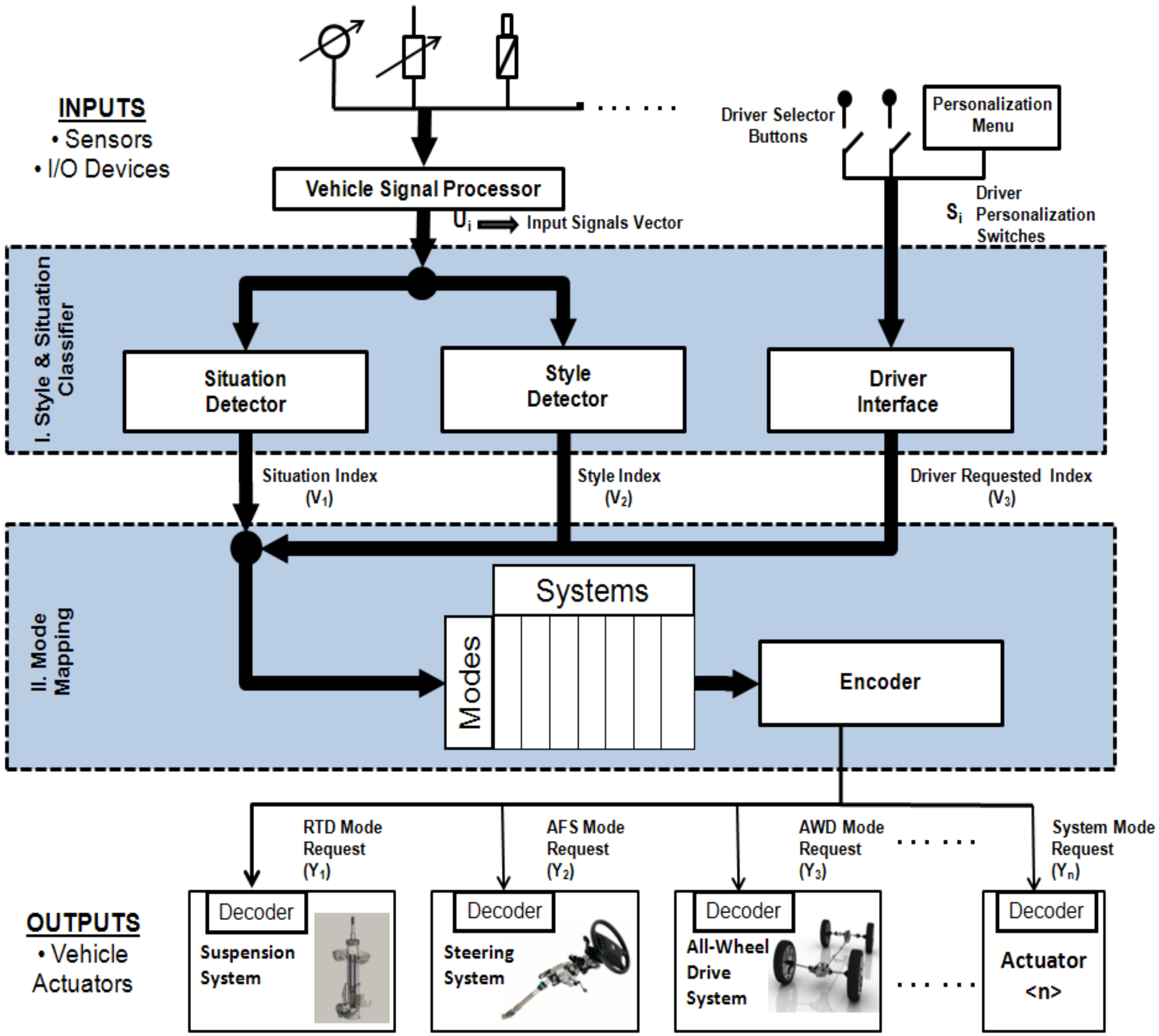
The Chassis Moding Approach

The control architecture has three main layers:



- **Analyis:**
  - Recognize in which operating mode the car is driving
- **Mode selection:**
  - Select the operating mode of the subsystems
- **Subsystems:**
  - Switch to the commanded operating mode

Chassis Moding – Detailed Architecture



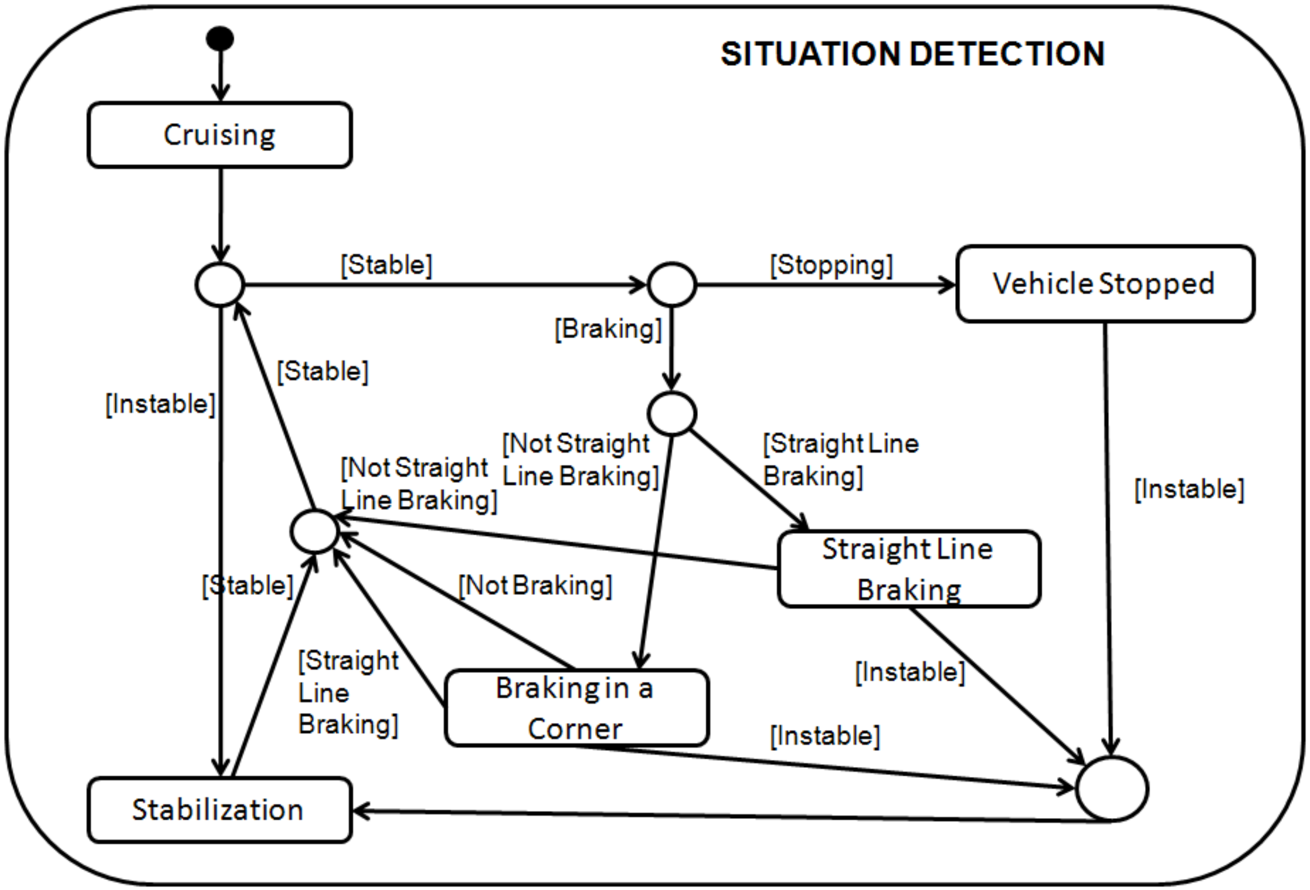
The classifier detects three dimensions

1. the driving situation
2. the driving style
3. the requests of the driver

Chassis Moding – Analysis Layer

Situation Detector:

State-machine Implementation using a 3-layered logic



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Chassis Moding – Analysis Layer

Situation Detector has three sublayers

Layer 1 Logic: Check of triggering conditions in a defined order (sequence)

Description	Conditions
Vehicle is in stable state	***Stable***
Vehicle is Decelerating	***Braking***
Vehicle is Decelerating along a straight line	***Straight Line Braking***

Layer 2 Logic: Conditions are logical combinations of individual conditional elements

Description	Conditional	Value
Vehicle Moving Straight	StraightLineFlag	TRUE
Vehicle Not Stopped	VehStopFlag	FALSE
Vehicle Braking	BrakeFlag	TRUE
Vehicle Still Moving	VehLowSpdFlag	FALSE
Vehicle Not in Transient	VehTransFlag	FALSE
Vehicle Not in Reverse	RevGearAct	FALSE

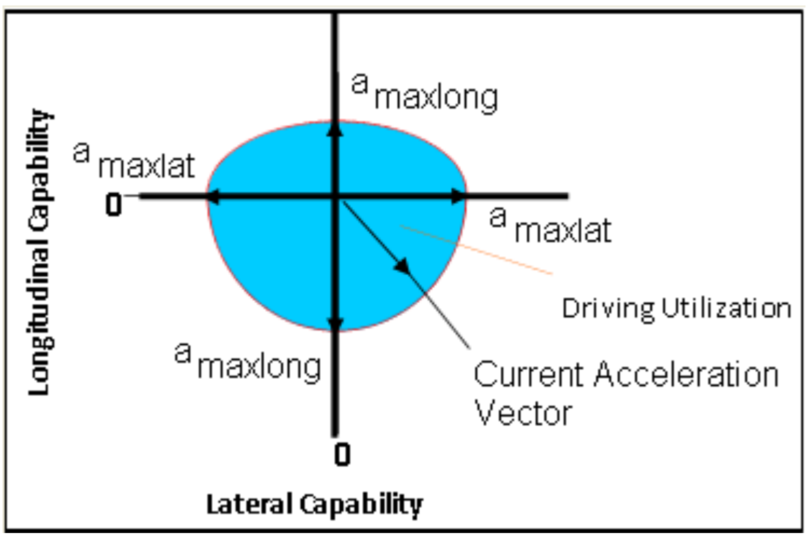
Layer 3 Logic: Conditional elements are Boolean valued functions of input signal values

Description	Boolean Function Element
Brake pedal pressed	***brk_pedal_press > brk_pedal_press_threshold***
Vehicle is decelerating	***veh_long_acc ≤ long_dec_brk_threshold***

Chassis Moding – Analysis Layer

Driving Style Detector:

- A distinction is made between “normal” (comfort-oriented) and “dynamic” (sport-oriented) driving styles
- The Dynamic Driving Index (DDI) is determined by monitoring the acceleration components and estimating how much of the available road friction capability is used (“circle of forces”)

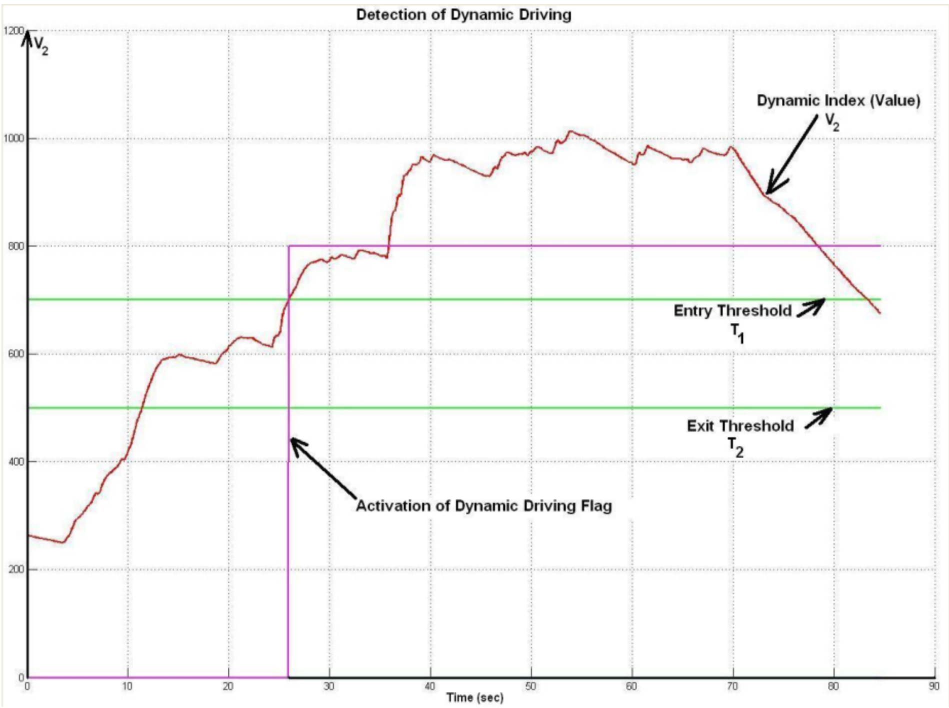


$$a_{rel} = \left\| \begin{pmatrix} a_{long}/a_{maxlong} \\ a_{lat}/a_{maxlat} \end{pmatrix} \right\|$$

Chassis Moding – Analysis Layer

Driving Style Detector:

4 Acceleration capacity limit and its time derivative are low pass filtered and appropriate thresholds are defined. The resulting style index V2 is then compared to predefined thresholds to detect dynamic driving



$$\text{Dynamic Driving Flag} = \begin{cases} 1, & \text{if } V_2 \geq T_1 \\ 0, & \text{if } V_2 < T_2 \end{cases}$$

Chassis Moding – Mode Mapping

- Mode Mapping table maps the recognized modes to chassis actuator commands
- Input is an index vector (i,j,k,s) from the analysis layer, where

  i: driving situation
  j: driving style
  k: driver preference
  s: chassis sub-system index (RTD, AFS, AWD, etc.)

- Output is a commanded index $\boldsymbol{m}_{ijks}$ for the appropriate subsystem operating mode

Vehicle State	Dynamic Driving	Driver Switch	Subsystem Modes CDC	VES	AWD
1. Cruising	Normal	Tour	1	1	1
		Normal	2	1	1
		Sport	3	2	2
	Dynamic	Tour	2	1	1
		Normal	2	2	2
		Sport	3	2	2
2. Accelerating	Normal	Tour	2	1	1
		Normal	2	1	1
		Sport	[illegible]	[illegible]	[illegible]
	Dynamic	Tour	[illegible]	[illegible]	[illegible]
		Normal	[illegible]	[illegible]	[illegible]
		Sport	[illegible]	[illegible]	[illegible]
3. Accelerating & Cornering	Normal	Tour	[illegible]	[illegible]	[illegible]
		Normal	2	1	1
		Sport	3	2	2
	Dynamic	Tour	2	1	1
		Normal	3	2	2
		Sport	3	2	2
4. Braking	Normal	Tour	2	1	1
		Normal	2	1	1
		Sport	3	2	2
	Dynamic	Tour	2	1	1
		Normal	3	2	2
		Sport	3	2	2

$\boldsymbol{m}_{ijks}$

i j k s

Chassis Moding Approach - Encoding

Encoder

4 Mode Mapper output as a vector $\boldsymbol{c} = (\boldsymbol{mi}_{jk1}, \boldsymbol{m}_{ijk2}, \ldots)$

4 Vector $\boldsymbol{c}$ reduced to single value e($\boldsymbol{c}$) to reduce bandwidth

4 No need for separate communication with each target ECU

4 Simultaneous activation of new settings in all sub-systems

Decoder

4 Encoded signal e(c) is decoded by each sub-system “s” to recover actuator command value mijks

4 Decoding algorithm implemented in control unit of each controlled sub-system

Chassis Actuators

4 Take the decoded signal and set new settings for the respective sub-systems optimally suited for the current driving situation

Conclusions

- The concept of moding is a very flexible control architecture that can be adapted to any vehicle easily while achieving high performance levels
- Moding takes explicit driver requests into account along with an automatic analysis of the current vehicle driving situation and the current driver's driving style
- Moding can also be used non-adaptively by taking only the driver switch in to account
- Moding avoids any risk of inconsistent vehicle behavior
- Development work is much simplified because subsystems can be developed independently and the integration work can be done late in the process
- The system can be expanded easily by adding more subsystems in the vehicle or by adding more dimensions to the analysis module