INFORMATION SOCIETY TECHNOLOGIES (IST) PROGRAMME

FRICTION

FP6 - IST - 2004 - 4 - 027006

D 10: Description of passenger car demonstration system

Dissemination	**PU**
Work package	WP6 – System Integration
Authors	Vincenzo Murdocco, CRF
	Marco Pesce, CRF
Due date	01.10.2008
Delivery date	27.11.2008
Status	Final
This document	FRICTION_Deliverable_D10.doc

Short description	This document contains a description of the passenger car demonstration system.

PART 0 - Preliminaries

Authors

Editor

Mr. Marco Pesce	CRF	CRF_MP

Contributors

Mr. Vincenzo Murdocco	CRF	CRF_VM
Mr. Andrea Ghiro	CRF	CRF_AG
Mr. Andre Nepote	MM	MM_AN

Consortium participants:

Technical Research Centre of Finland, VTT (FIN)
Centro Ricerche FIAT S.C.p.A, CRF (ITA)
IBEO Automobile Sensor GmbH, IBEO (D)
Rheinisch-Westfaelische Technische Hochschule Aachen, ika (D)
Magneti Marelli Sistemi Elettronici S.p.A, MM (ITA)
Nokian tyres plc, NR (FIN)
Pirelli Tyre S.p.A, PI (ITA)
Siemens AG, SI (D)
Helsinki University of Technology, TKK (FIN)
Volvo Technology Corporation, VTEC (SWE)

Revision history

Version	Date	Description	Author
0.1	2008-09-22	First issue	CRF_VM CRF_MP
0.2	2008-10-06	Added information and pictures about vehicle architecture	CRF_VM CRF_AG
0.3	2008-10-15	Added information about PReVENT applications	CRF_VM
0.4	2008-10-27	Added information about additional sensors and HMI application	CRF_MP
0.5	2008-10-30	Spell check of document	CRF_VM
1.0	2008-11-26	Update of HMI and final revision	MM_AN CRF_MP

Document structure

The document is divided as follows:

PART 0 – Preliminaries
Contains meta information about the document and its contents.

PART 1 – General Passenger Car Description
Contains a description of the Fiat Stilo with an overview of the car and its main characteristics.

PART 2 – Demonstration System Description
Description of the demonstration system on the Fiat Stilo.

PART 3 – Safety Application Description
Describes the selected safety application from the PReVENT project APALACI.

PART 4 – Appendices
Contains references.

Abbreviations and acronyms

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
AEB	Automatic Emergency Braking
ALA	Alasca laserscanner
ASIC	Application Specific Integrated Circuit
BAS	Brake Assist
CAN	Controller Area Network
CAS	Collision Avoidance System
CMbB	Collision Mitigation by Braking
COR	Correvit
CW	Collision Warning
EFF	Environmental Feature Fusion
EMC	Electromagnetic Compatibility
ESP	Electronic Stability Program
FOV	Field Of View
HMI	Human Machine Interface
HW	Hardware
IMU	Inertial Measurement Unit
IP	Integrated Projects
IVSS	Intelligent Vehicle Safety Systems
LSB	Least Significant Bit
MSB	Most Significant Bit
N/A	Not Applicable
OEM	Original Equipment Manufacturer
PSD	Position Sensitive Diode
REY	Road eye
RFE	Road Friction Estimation
RPU	Rapid Prototyping Unit
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SRIS	Slippery Road Information System
STREP	Specific Targeted Research Project
SUV	Sport Utility Vehicle
SW	Software
TCS	Traction Control System
TFF	Tyre Feature Fusion
TMC	Traffic Message Channel
TYR	Tyre Sensor secondary RPU
VSC	Vehicle Stability Control
WP	Work Package
WT	Work Task

Table of contents

PART 0 - PRELIMINARIES **2**

AUTHORS 2
REVISION HISTORY 3
DOCUMENT STRUCTURE 4
ABBREVIATIONS AND ACRONYMS 5
TABLE OF CONTENTS 6

PART 1 – GENERAL DESCRIPTION OF PASSENGER CAR DEMONSTRATOR **7**

1 PASSENGER CAR DESCRIPTION 7
1.1 Overview 7
1.2 Electronic Vehicle Architecture 8

PART 2 – DEMONSTRATION VEHICLE SYSTEM DESCRIPTION **9**

2 DEMONSTRATOR VEHICLE ARCHITECTURE 9
3 ADDITIONAL SENSORS 10
3.1 IMU 10
3.2 Steering torque sensor 12
3.3 Brake pressure sensors 12
4 HMI HARDWARE 13
5 FRICTION ESTIMATION SYSTEM 13

PART 3 – SAFETY APPLICATION DESCRIPTION **15**

6 PREVENT APPLICATIONS WITHIN THE FIAT STILO 15
7 FIAT STILO DEMONSTRATOR SAFETY APPLICATION 17
8 HMI APPLICATION 21
8.1 The FRICTION application 22
8.2 The APALACI application 25
8.3 The FRICTION-APALACI application 26

PART 4 – APPENDICES **28**

REFERENCES 28

PART 1 – General Description of passenger car demonstrator

1 Passenger car Description

This chapter describes the main features of the passenger car demonstrator vehicle within the FRICTION project.

1.1 Overview

A Fiat Stilo, 5 doors hatchback, is used as passenger car demonstrator vehicle for the FRICTION project.
The vehicle is a typical compact car, with five doors and five seats. Wheel base is 2.60 meters, weight without passengers is about 1350 kg. It is equipped with a 1.8 liters gasoline engine, that outputs 130HP max power, and allows the vehicle to reach 190 kph max speed. Gear box is manual, five gears. The steering system has electrical power assistance on the steering column.
The vehicle is equipped with ABS, ESP and navigation system.
The vehicle is fitted with 205/55 R16 Pirelli P6000 tyres.

Figure 1 The Fiat Stilo used as passenger car demonstrator

This vehicle was used to develop and implement several ADAS functions within EU projects APALACI and LATERAL SAFE, which are PReVENT subprojects. Among the functions developed within APALACI, the Forward Collision Mitigation (semi-autonomous and autonomous) is the one that can take major advantages from the integration with FRICTION. This specific function was developed in order to operate in conjunction with the FRICTION application, using the estimated friction potential in order to change the intervention thresholds of the system.

1.2 Electronic Vehicle Architecture

The basic electronic architecture of the Fiat Stilo is similar to most passenger cars.
According with the normal production configuration, it relies mainly on two CAN buses:

- C-CAN (500 Kbit/s)
- B-CAN (250 Kbit/s)

The main data related to the vehicle motion are available on these two CAN buses. In particular, the main functions of the car, related to safety, engine and chassis control refer to the C-CAN, supporting high rate data transmission. Among these functions:

- ABS
- ESP
- TCS

The B-CAN supports other functions related to on-board life and comfort, such as climatization, entertainment and telematics, and others.

The vehicle is equipped with a number of standard on board sensors that are used by the normal production applications. Sensors related to ABS/ESP functions are of interests for the FRICTION VFF application too, that is developed in order to use as much as possible normal production technology.
The following table lists the most important signals among the ones available on board. All these signals are available on the vehicle C-CAN.

Physiscal quantity	Signal name	Unit	Range		Remarks
			min	max	
steering wheel angle	delta	rad	-15	+15	
longitudinal acceleration	ax	m/s^2	-20	+20	
lateral acceleration	ay	m/s^2	-20	+20	
yaw rate	yawRate	rad/s^1	-1.5	+1.5	
wheel velocity	vWheelij	m/s^1	0	70	one for each wheel
brake signal	brakeSignal	Boolean	0	1	1 bit
engine torque	MEngine	Nm	0	400	

i,j € {FL, FR, RL, RR}

Table 1 – Main vehicle sensors

PART 2 – Demonstration Vehicle System Description

2 Demonstrator vehicle architecture

The architecture of the Fiat Stilo demonstrator used in the FRICTION Project is conceived in order to allow easy connection of sensors according to flexibility and modularity concepts.
In order to avoid interferences with normal vehicle functions, dedicated buses are integrated in the vehicle in addition to the normal production configuration. In particular a dedicated CAN bus connecting the FRICTION and APALACI sensors and the control units is fitted. Accordingly to the Standard CAN protocol (version 2.0A), it is characterised by the following parameters:

- Baudrate: 500 KBd
- Message ID: Standard 11 bit

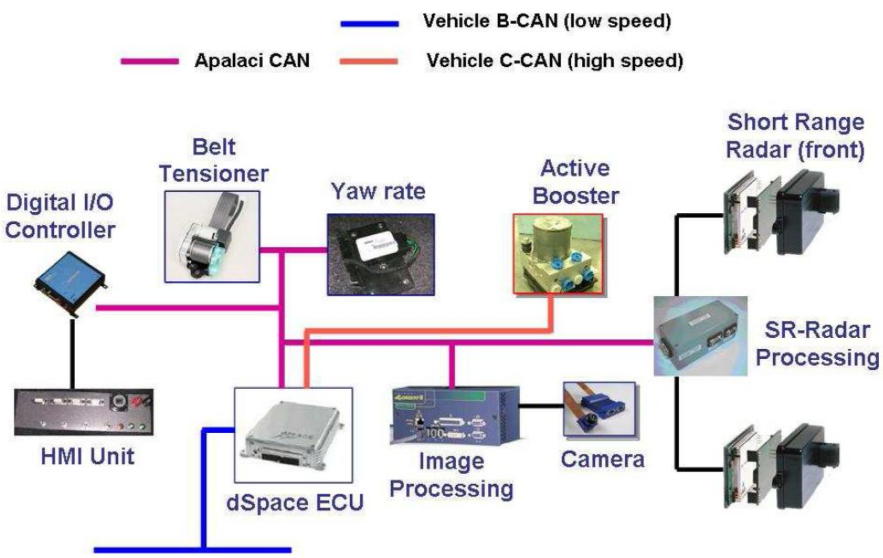


Fig. 1 – Passenger car demonstrator: FIAT Stilo architecture

The Fiat Stilo is equipped with the following conventional sensors:

- Wheel speed (x4)

- Lateral acceleration
- Yaw rate
- Longitudinal acceleration
- Steering wheel angle (EPS)
- Steering wheel torque (EPS)

These sensors are connected on the C-CAN bus and are available for the normal on-board functions and for the demonstration functions as well, through the rapid prototyping ECU (dSPACE) and additional CAN buses.
Additional sensors, used for the APALACI applications, are connected to specific buses and/or pre-processing unit.

3 Additional sensors

In the following table a list of additional sensor signals used for the FRICTION system is given:

Physical quantity	Corresponding signal	Unit	Range		Sensor / Remarks
			min	max	
longitudinal acceleration	ax	$m.s^{-2}$	-20	+20	IMU
lateral acceleration	ay	$m.s^{-2}$	-20	+20	IMU
vertical acceleration	az	$m.s^{-2}$	-20	+20	IMU
pitch rate	pitchRate	$rad.s^{-1}$	-1.5	+1.5	IMU
roll rate	rollRate	$rad.s^{-1}$	-1.5	+1.5	IMU
yaw rate	yawRate	$rad.s^{-1}$	-1.5	+1.5	IMU
brake pressure	pBrakeij	MPa	0	20	Analog sensors. One for each wheel
steering torque	MSteering	N.m	-50	50	Additional sensors. In future application provided by EPS on C-CAN

Table 2 – Additional Sensor Signal Definitions

3.1 IMU

The Inertial Measurement Unit (IMU) is developed by Continental AG (former Siemens VDO) to provide key data for vehicle dynamics control systems. The IMU applied in the EU-project contains three Yaw Rate Clusters (YRC). The three same YRCs are mutually perpendicularly mounted in the IMU housing (see Figure 2 below). The YRC is designed by using MEMS (Mirco Electromechanical sensors) technology to provide an angular velocity and two accelerations. It indicates that the combined IMU can provide the three angular velocities and three accelerations of vehicle body, i.e., yaw, roll and pitch rates, and longitudinal, lateral and vertical accelerations. By using the IMU, the 3-dimensional movement and 3-dimensional attitude of vehicle body can be precisely estimated. The integrated IMU in a single unit has been applied in ECU in 2007.

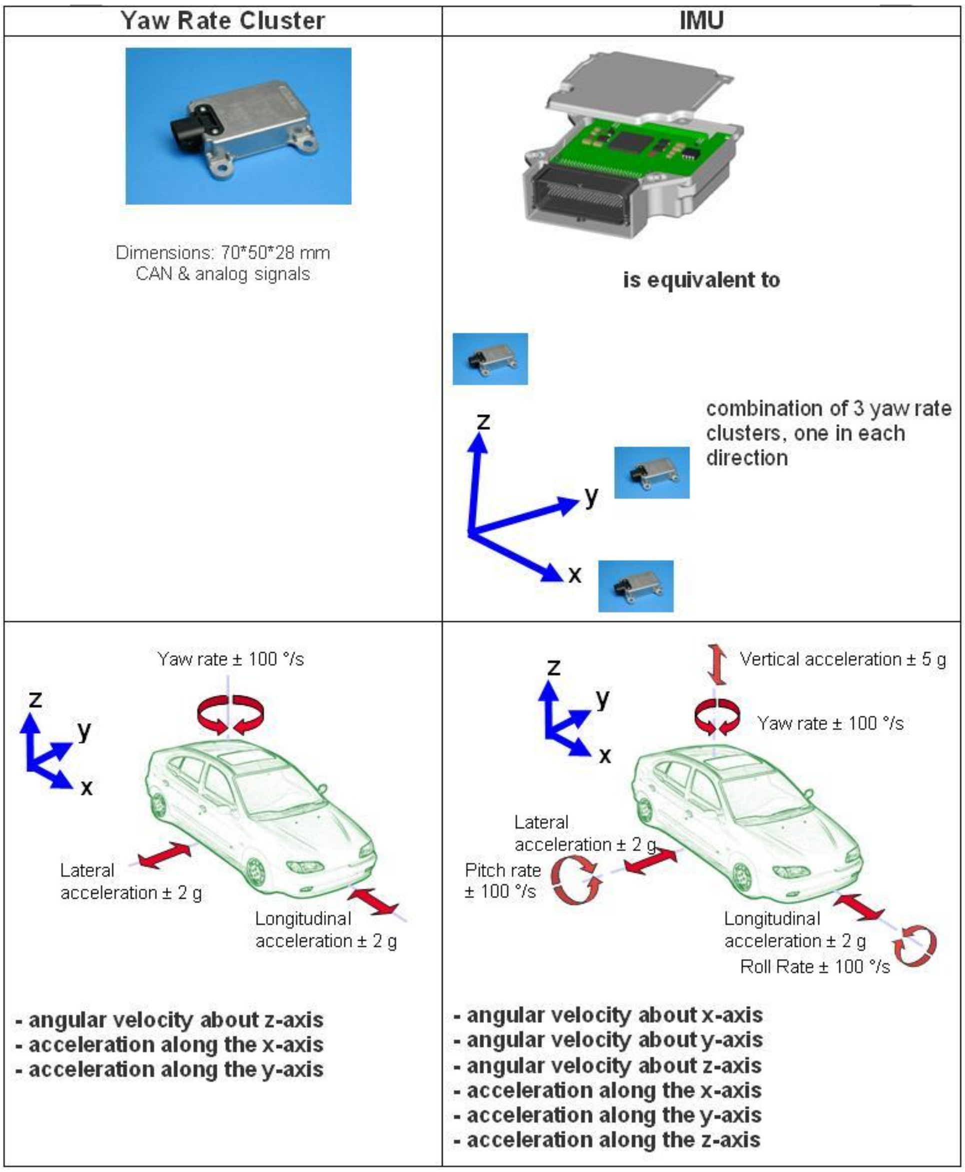


Figure 2 The IMU applied in the EU-project contains three Yaw Rate Clusters (YRC).

The IMU was installed under the driver's seat, as close as possible to the vehicle's centre of gravity. The original package of the IMU (three bi-axial sensors fixed to the orthogonal faces of a cube) was too big in order to fit in the narrow place under the seat, so a new box, with orthogonal surfaces but lower height, was used in order to fix the three basic sensors that forms the complete IMU. Signals from the additional IMU cluster are sent on a specific CAN bus.

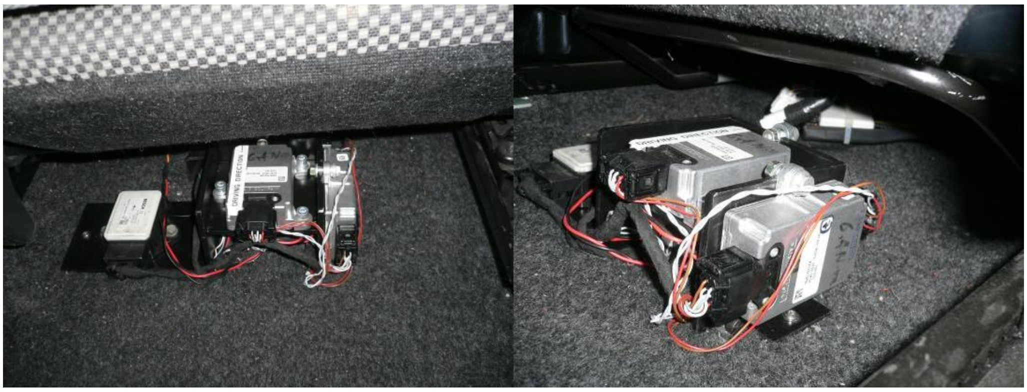


Figure 3 Installation of the IMU

3.2 Steering torque sensor

A steering torque sensor is embedded in the EPS unit that is standard equipment of the Fiat Stilo. The basic idea in the development of the demonstrator was to use the information from this sensor, but this was not possible in practice since the steering torque message is not available as a standard on the C-CAN, neither was possible to get an updated system by the EPS supplier. Additional sensors (force transducers on the steering tie rods) were added in order to calculate the steering torque signal.

3.3 Brake pressure sensors

Brake pressure sensors are mounted on the pipes, as near as possible to each caliper. The sensors are connected to their own power supply and conditioning boxes, and the voltage output is connected to the analog input port of the dSPACE ECU. These signal are available to the RPU, but are not actually used by the FRICTION estimation algorithm.

4 HMI Hardware

For the passenger car demonstrator the Info-Telematic devices of the existing vehicle are used for the implementation of the HMI. In particular, the normal production display of the navigation system, on the central console, is used to provide information about the FRICTION application and the APALACI application (Forward Collision Mitigation) as well.

Figure 4 The navigation system display used for the HMI

5 FRICTION estimation system

The FRICTION estimation system implemented in the Fiat Stilo is based on in-vehicle sensor information, related to vehicle dynamics and steering system. It runs in the dSPACE Rapid Prototyping Unit every 10 ms.

The following table lists the signal used in the FRICTION VFF application on the passenger car

Input sensor	Corresponding preprocessed signal	Unit	Comment
steering wheel angle sensor	SteeringWheelAngle	rad	
steering torque	SteeringTorque	Nm	
lateral acceleration sensor	LateralAcc	$m.s^{-2}$	
Siemens IMU	LateralAcc LongitudAcc VerticalAcc YawRate PitchRate RollRate	$m.s^{-2}$ rad/s	
yaw rate sensor	YawRate	rad/s	
wheel speed sensors (one for each wheel)	WheelSpeed	km/h	
brake pressure sensors (one for each wheel)	BrkPressij	bar	

PART 3 – Safety Application Description

6 PReVENT Applications within the Fiat Stilo

The passenger car demonstrator vehicle, Fiat Stilo, is equipped with ABS and ESP from production. It also supports the following additional ADAS applications developed in the APALACI and LATERAL SAFE projects (PReVENT subprojects):

- Forward Collision Mitigation
- Pre-Set
- Pre-Fire
- Lateral and Rear Monitoring System
- Lane Change Assistant
- Lateral Collision Warning

Several modifications and adaptations have been necessary in order to equip the vehicle with the sensors and actuators required for the PReVENT applications developed and demonstrated in the vehicle.
The Figure 5 presents a sketch of the hardware architecture of the PReVENT demonstrator.

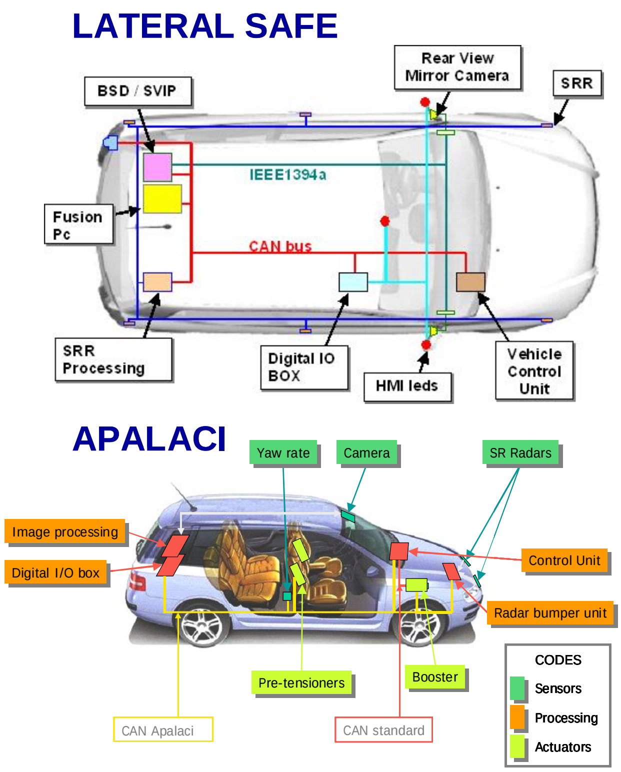


Figure 5 Scheme of the PReVENT physical architecture

The vehicle has been equipped with additional environmental sensors in order to support the applications mentioned above:

- 2 medium range forward looking radars
- 3 short range right side-looking radars
- 3 short range left side-looking radars
- 1 long range rear looking radar
- 2 cameras for the blind spot to the right and left of the car
- 1 forward looking camera
- 1 forward looking camera

Furthermore it is equipped with following actuation devices:

- active booster
- seat belt pre-tensioner

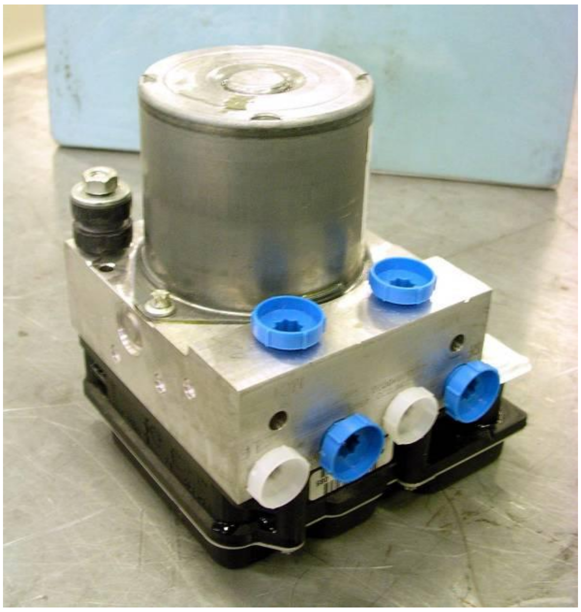


Figure 6 Active Booster

Figure 7 Seat Belt pre-tensioner during the installation

7 Fiat Stilo Demonstrator Safety Application

The chosen safety application for demonstration of the benefits of having information about the road friction is the CMbB safety function [deliverable D6], developed within the PReVENT sub-project APALACI
The APALACI sub-project developed a safety system for advanced pre-crash and collision mitigation, including innovative and robust sensor fusion techniques.
The objective of the APALACI was to enhance the driver's capability to mitigate collisions with forward vehicles, that is rear-end collision, or to avoid them according to circumstances, thus reducing or eliminating impact velocity and collision energy.

The system prevents low speed accidents involving pedestrians, by monitoring the frontal area close to the vehicle and, more generally, mitigates the severity of unavoidable collisions, by significantly reducing the kinetic impact energy and improving the control of restraint systems to enhance the protection of car passengers.

Therefore the system can be considered an extension of Collision Warning function to a braking manoeuvre, consequently it needs information about ranging to forward vehicles, motion of forward vehicles, motion of the host vehicle, road slipperiness, driver commands and driver actions.

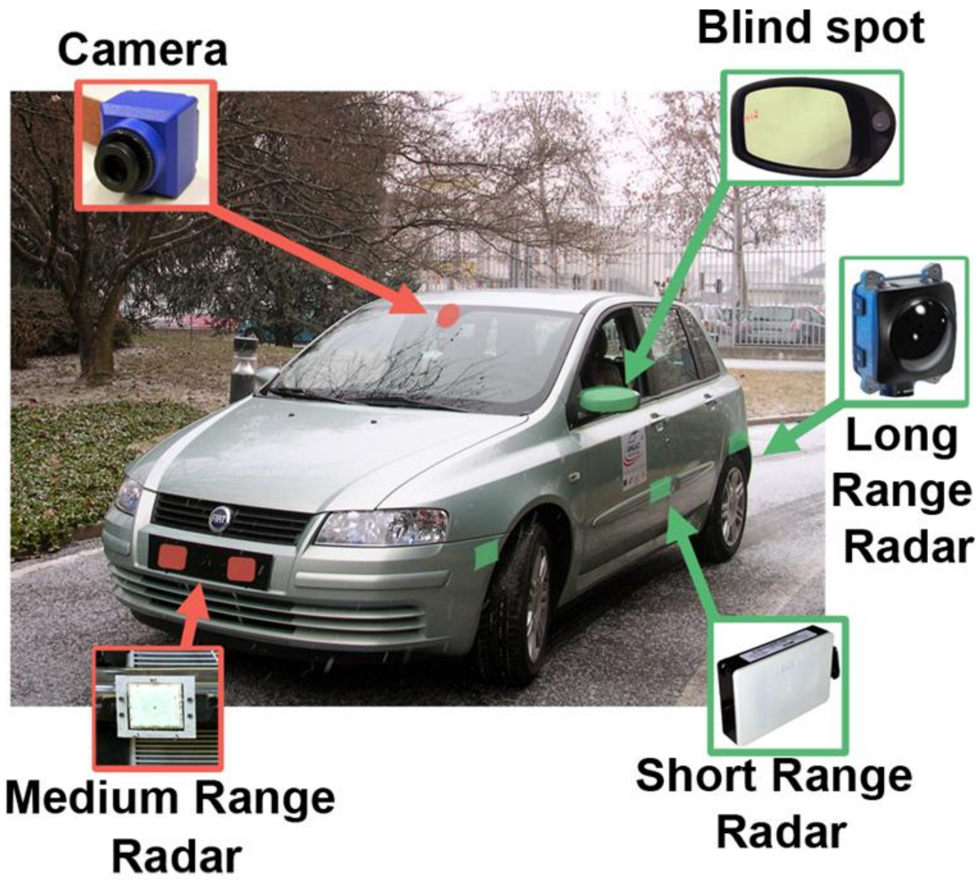


Figure 8 Fiat Stilo PReVENT demonstrator vehicle with sensor locations. Red are APALACI specific sensors and green are LATERAL SAFE specific sensors

For the CMbB function the following sensors are used to monitor the frontal area close to the vehicle:

- a digital monocular grey level CMOS camera installed in the driver compartment behind the central mirror in the windscreen (see Figure 9);

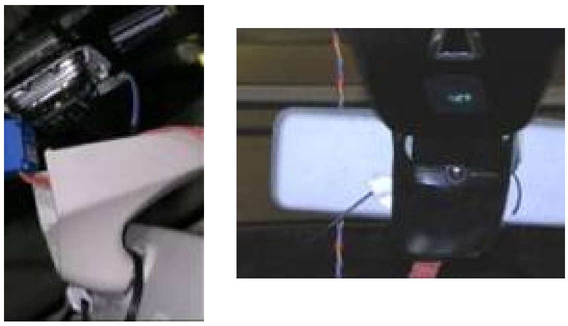


Figure 9 View of the camera behind the windscreen during installation

- two medium range radars positioned behind a bumper with low attenuation to microwaves in the radars operational frequency range (see Figure 10).

Figure 10 Front part of the vehicle during the set-up of the radar sensors and after the sensor installation

When the system, detecting the scenario in front of the vehicle, determines a possible hazardous condition and estimates that the driver hasn't an adequate opportunity to avoid the hazard and contemporarily appropriate criteria are met, the control algorithm assesses that a collision is imminent. Based upon this assessment, the control strategy activates vehicle brakes to mitigate its severity or to avoid a collision according to circumstances.

In order to give an appropriate support to the driver and actuate automatically or semi-automatically an appropriate braking pressure according to the risk situation, the Collision Mitigation function developed takes in consideration the following cinematic formula to calculate the system intervention distance:

$$d_{Inter} = d_{SAF} + \frac{1}{2} \cdot \frac{V_R^2}{a_{brake} - a_V} + t_{reaz} \cdot V_R$$

where:

– d_{Inter} = intervention distance;

– V_R = relative speed;

– d_{SAF} = stop-distance, that is the distance at which the vehicle should stop with respect to the obstacle;

– a_V = obstacle deceleration;

– $a_{brake} = a_{brake\ max} - a_{road} + a_V$;

– $a_{brake\ max}$= starting max deceleration;

– a_{road} = depending on the road surface (dry, slipper…);

– t_{reaz} is the reaction time of the system. This time includes the detection and processing time for the sensorial system and the reaction time for the vehicle control and actuation in case of the “autonomous activation” modality. On the contrary, in case of “semi-autonomous activation” modality, this time has to include also the driver reaction.

Analyzing this formula, could be highlighted how the d_{Inter} is directly connected to the maximum vehicle deceleration (a_{brake}), to the relative speed (V_R) and to the condition of the road surface (a_{road}). Therefore the Collision Mitigation application intervention range could be different depending on the maximum braking power of the equipped vehicle and on the weather conditions.

Then it’s clear that this functionality can be significantly improved by using friction information.

Having friction information it is possible to calculate the correct maximum vehicle deceleration, to evaluate properly vehicle braking system capabilities and consequently to modify the intervention of the system. In fact under low road friction conditions the space necessary to brake the vehicle increases, then the system intervention has to be appropriately anticipated: the driver should be alerted in advance, through a warning, for starting a braking manoeuvre in order to reduce the consequences of an unavoidable crash.

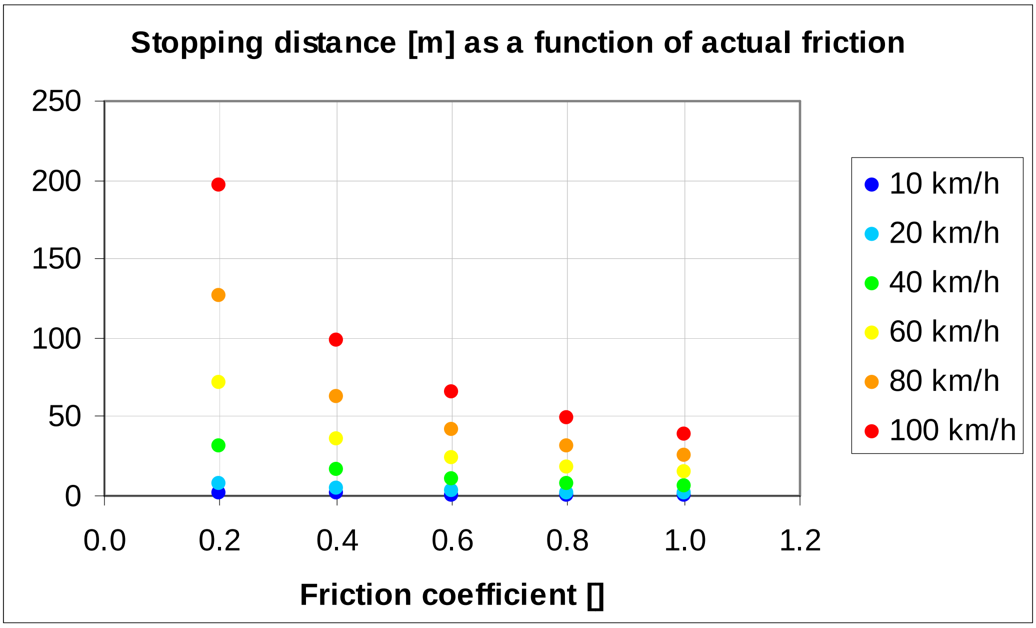


Figure 11 Stopping distance as a function of road friction coefficient for different values of vehicle speed

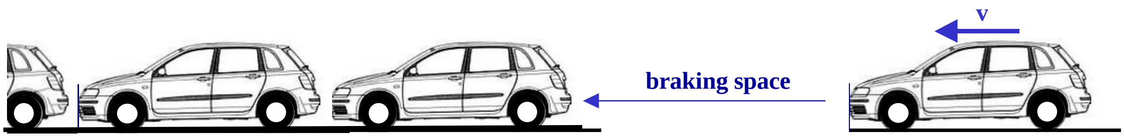


Figure 12 Forward Collision Mitigation system

Without information on friction forces available, the vehicle can not execute the calculated manoeuvres in an optimal way. When there is no information on friction, the system will act too late on wet or icy roads and it will not be able to reduce significantly the kinetic impact energy. Therefore to guarantee good performances of the Forward Collision Mitigation function the knowledge of the road friction becomes a factor of fundamental importance.

For a better integration, both the APALACI CMbB application and the FRICTION estimation algorithm (VFF) run on the same rapid prototyping ECU (dSPACE).
The FRICTION information about current *potential friction* estimation is provided to the APALACI application and, as explained above, influences the CMbM control strategy.

Figure 13 Rapid Prototyping ECU

8 HMI Application

The HMI application is implemented on the info-telematic device, which consists mainly of:

- a dedicated processor
- a B_CAN connection
- a CD rom unit
- a LCD display
- a series of buttons and selectors for navigation in the menu system

Although the info-telematic device is not the best solution for FRICTION HMI implementation due to its location (centralized: the driver has to divert attention from the road to get information), nevertheless it has been chosen for demonstration for the following reasons:

- fair display and graphic capability
- plenty of function keys for easy menu navigation
- normal production device integrated in the vehicle system

In particular the latest point allows for a physical evaluation of the bus load and communication aspects in relationship with the amount and modality of Friction visualizations.

The software of the HMI was adapted in order to allow the driver to select among the FRICTION applications:

- Ø FRICTION: this option enables the friction estimation application
- Ø APALACI: this option enables the APALACI front collision mitigation "stand alone" application, as it was developed in the EU project APALACI
- Ø FRICTION-APALACI: this option enables the "FRICTION enhanced" APALACI front collision mitigation application, developed within the FRICTION project.

Figure 14 Selection of the desired application

8.1 The FRICTION application

The FRICTION application provides information about the current estimated friction coefficient. The estimated values, for the Fiat Stilo demonstrator, are calculated by the VFF algorithm and made available on the vehicle network.

The application provides the following information to the driver, on the LCD (according to the definitions established in deliverable D5 and requirements established in deliverable D4):

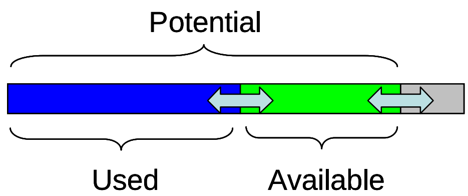
- Ø the estimated FRICTION USED, overall: a unique value for the whole vehicle, not for each wheel.
- Ø the estimated FRICTION POTENTIAL, based on the VFF subcluster

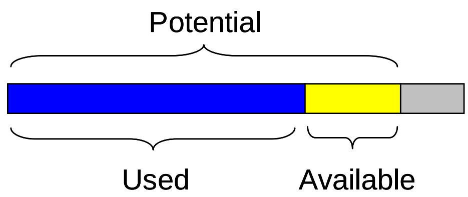
Ø the estimated FRICTION available, i.e. the difference between the estimated FRICTION POTENTIAL and the current FRICTION USED.

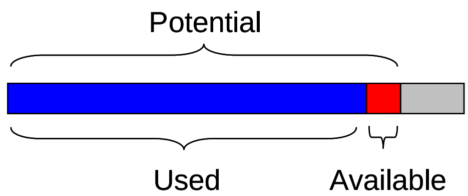
The basic approach for Friction visualization has been to synthesize information in a single graphical device whose peculiar characteristics may be summarized as follows:

- both informative and warning purposes
- colour code based “at a glance” information

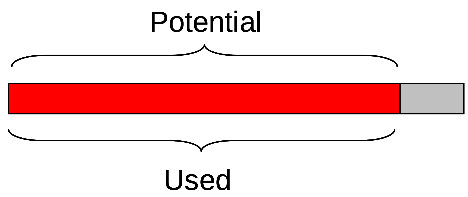
A variable length bar is made up of two parts, each with variable length and colour properties: the first one (usually blue) representing the FRICTION USED and the second one (green yellow or red according to warning strategies) representing the FRICTION AVAILABLE. The right end of the latter represents the FRICTION POTENTIAL
This provides the driver a straightforward graphical information about how much friction the car is using and relevant margin, as described in the picture below.



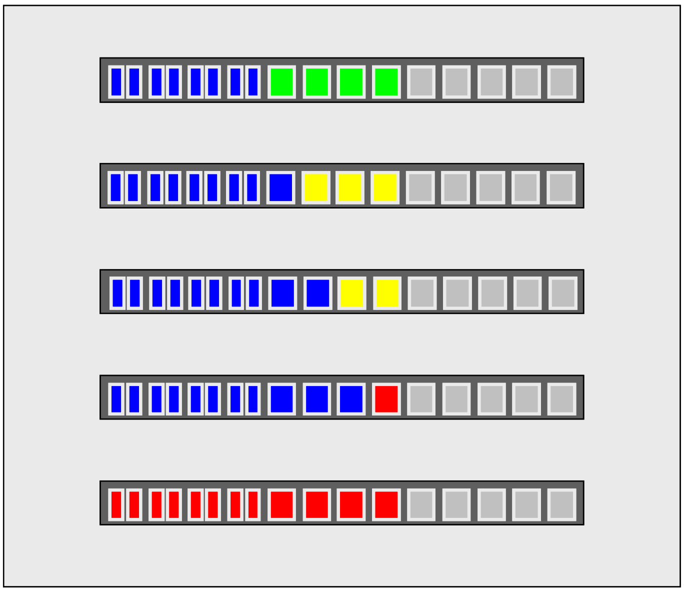




When the FRICTION AVAILABLE gets close to zero, the USED FRICTION bar becomes red (slipping situation).



Full scale has been set to μ=1.3 and resolution is 0.05 up to μ=0.4 and 0.1 over this value. Here are two examples showing evolution of the bar for an increasing of FRICTION USED (and a stable FRICTION POTENTIAL) and, vice versa, a decreasing of FRICTION POTENTIAL (with a stable FRICTION USED):



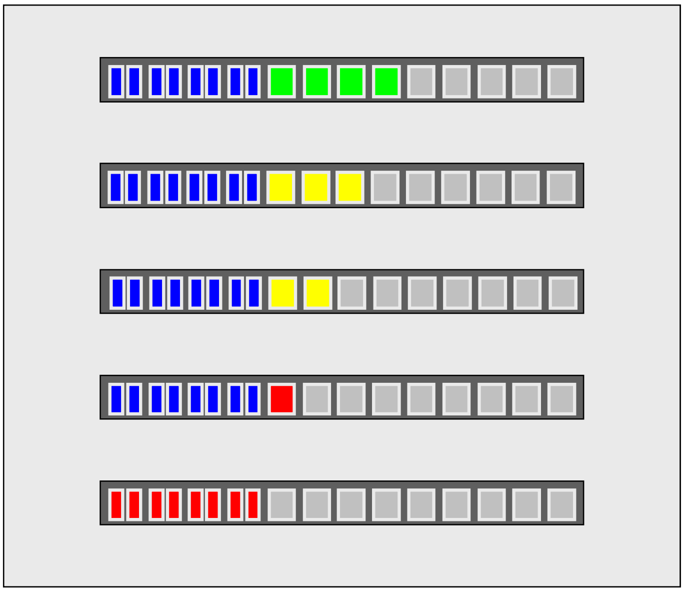


Figure 15 FRICTION information display

8.2 The APALACI application

The APALACI application provides driver assistance with the Collision mitigation system by braking.
APALACI provides a WARNING to the driver, by a BUZZER, when a dangerous situation is detected that requires a braking manoeuvre.
After the interventio of the collision mitigation system, the following informations are displayed on the LCD:

- the actual impact speed
- the impact speed of an average driver without the APALACI system
- speed, distance to the obstacle and time to collision at the warning
- Crash energy reduction with APALACI respect to the average driver

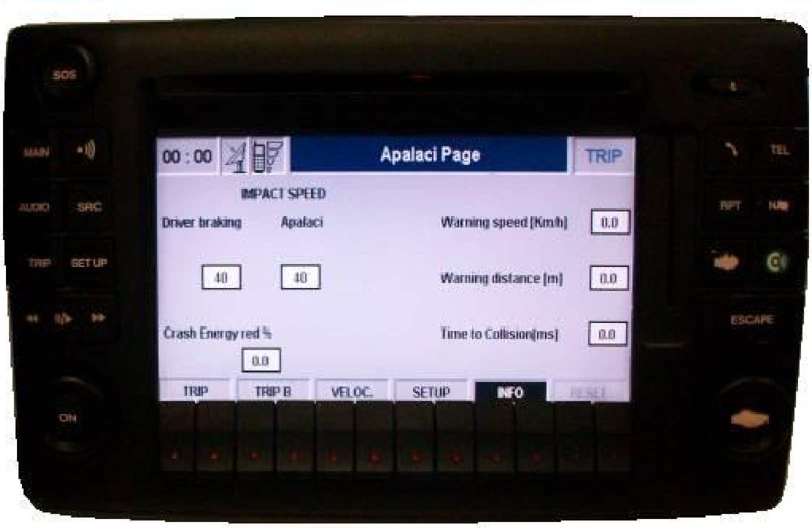


Figure 16 APALACI information display

8.3 The FRICTION-APALACI application

The FRICTION-APALACI application provides driver assistance with the Collision mitigation system by braking, enhanced with the FRICTION information.
The system works in the same way as APALACI, but with an adaptive strategy, optimized according to the friction level.
APALACI provides a WARNING to the driver, by a BUZZER, when a dangerous situation is detected that requires a braking manoeuvre.
After the interventio of the collision mitigation system, the following informations are displayed on the LCD:

- the actual impact speed
- the impact speed of the APALACI "stand alone" system
- the impact speed of an average driver without the APALACI system
- speed, distance to the obstacle and time to collision at the warning
- Crash energy reduction with APALACI and with FRICTION-APALACI respect to the average driver

Figure 17 FRICTION- APALACI information display

PART 4 – Appendices

References

CAN Specification, Version 2.0, Bosch

FRICTION Deliverable D5 (Specifications and System Architecture)

PReVENT – APALACI Deliverable D50.