Proceedings, Bicycle and Motorcycle Dynamics 2010
Symposium on the Dynamics and Control of Single Track Vehicles,
20 - 22 October 2010, Delft, The Netherlands

An intelligent Frontal Collision Warning system for Motorcycles

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ABSTRACT

This article introduces a novel Frontal Collision Warning system for motorcycles, which has been developed in the SAFERIDER project [1] of the 7th EU FP. The Frontal Collision Warning function (FCW) described here is based on a holistic approach, which localizes the motorcycle in the road geometry, estimates the motorcycle dynamics state and rider input and senses obstacles in the motorcycle lane. The warning strategy is based on the correction of longitudinal dynamics as suggested by an optimal previewed manoeuvre (reference manoeuvre), which is continuously computed from the actual state of the vehicle. The reference manoeuvre accounts for the riding styles and in normal driving conditions fairly matches with the rider's one. However, when the rider misses to spot a front obstacle or does not brake enough a large difference between actual and ideal acceleration is generated therefore the rider is warned to decelerate or brake. As soon as the correct value of deceleration is achieved the warning disappears improving the system acceptability. Warnings are given to the rider via a proper combination of haptic, visual and audio signals thanks to specific HMI device, which include an haptic handle among, a vibrating glove, a smart helmet, and a visual display.

Keywords: advanced rider assistance systems, frontal collision warning, optimal preview manoeuvre, motorcycle.

1 INTRODUCTION

Motorcyclists are among the most vulnerable groups of road users and current statistics show that they are involved in fatal crashes 20 times more than car users [2]. The MAIDS study [3] found out that Powered Two Wheelers (PTW) rider error is the primary accident contributing factor in 31% of all cases compared to 50% of other vehicle drivers. When the rider error is the case decision failure is a frequent factor (13% for PTW) and inattention contributed to accident causation in 10.6% of all cases. Also traffic scan errors are a cause in 28% of cases especially in urban area where three quarters of all collected accidents took place. In urban area the most frequent collision partner is a passenger car (63%) and the average speed is less than 50km/h. Those figures prove that collision between PTW and cars occur because the rider ad the driver has to face a complex situation and take the correct decision in short time. Additionally many times the PTW are not spotted by the car driver due to their low conspicuity. Moreover, accoring to MAIDS, if one look at the collision avoidance manoeuvre performed by the PTW rider he/she realizes that in 49% of cases braking was the preferred avoidance collision action and only in 16% of cases the rider attempted to avoid the accident by swerving. However in one third of all cases the rider did not take any action because he/she did not have time to decide what to do or failed to spot the dangerous obstacle.

The Frontal Collision (FC) function fits exactly this situation: it is intended as an application that draws the rider attention to the potential dangerous obstacles with a fair anticipation in order to give the rider the time to take a collision avoidance action. The FC function is one of the five functions developed in SAFERIDER project to assist the PTW riders. SAFERIDER is a project funded in the 7th EU Framework Program and aims at introducing advanced driver assistance systems specifically designed for motorcycles, called ”Advanced Rider Assistance Systems" (ARAS). The project schedule includes development of five rider assistance functions, embedded in a unified hardware and software framework, namely Speed Alert, Curve Warning, Frontal Collision Warning, Intersection Support and Lane Change Support. The development of such functions for PTW is not a trivial translation of the same ADAS developed for cars [8], since PTWs differ in many aspects. Motorcyclists are less willing to accept a system that interferes with motorbike dynamics and personal driving style. As PTWs are singletrack vehicles, they are intrinsically "unstable" systems; motorcyclists use more freely the free spece of the road and not necessarily sticke to available lanes. In addition, ARAS are technically challenging because, compared to cars, there is less space for sensors and less power available. Motorbikes also exhibit large roll angles, which makes it more difficult to estimate the vehicle position in the lane.

An initial analysis of past and on going projects and available devices on the market has shown that not much has been done for the development of such systems for PTWs except at informative level [6]. The forerunners of intelligent systems for motorcycles stem from the Japanese Advanced Safety Vehicle (ASV) initiative, concerned with development of technologies for accident avoidance and crash mitigation. A number of prototype in vehicle systems have been developed among which Yamaha ASV-2 that conveys warning information (e.g. forward collision, curve speed, speedometer, and navigation), on a visual display on the console and via an earpiece worn by the rider. Other relevant project such as SIM [5] and PISA [6] are devoted to the development of active electronic devices (e.g. enhanced anti-lock braking system, traction control and brake by wire) for PTWs and/or algorithms to activate passive safety devices such as protective inflatable bags worn by the rider or fitted to the vehicle (for lower limb protection).

The Frontal Collision Warning (FCW) function described in this paper addresses the above aspects with a novel, unique and holistic approach, which combines road geometry, motorcycle dynamics, riding styles and obstacle detection. The article has an initial section that introduces the concept of the Frontal Collision Warning. A section follows with an overview of the hardware and software architecture. Lastly a section is presented shows the system behaviour from a sample of data of an experimental test.

2 GENERAL INSTRUCTIONS

The aim of the Frontal Collision Warning is to support a rider to safely handle a situation where an unexpected, or unseen obstacle is present in front of the motorcycle.

A typical scenario managed by the FCW function is shown in Figure 1 where a motorcycle is running on a straight road and a vehicle ahead suddenly brakes, or a new one cuts in on the lane. In both cases the remarkable speed difference between the motorcycle and the obstacle ahead is a potential danger. In this situation, the FCW aims at drawing the attention of the rider and suggesting the more appropriate action for the correct longitudinal control of the vehicle.

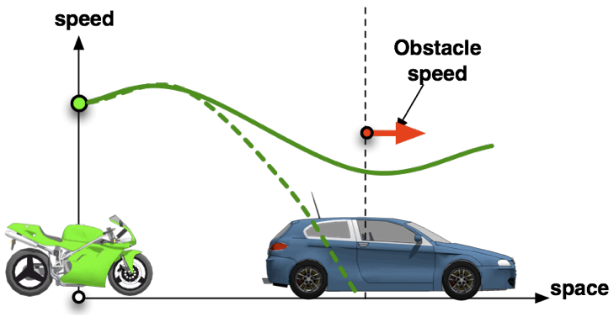


Figure 1 Typical scenario managed by the Frontal Collision Warning function

The proposed warning strategy is based on the correction of longitudinal dynamics derived from an optimal reference manoeuvre that previews the safest motion starting form the actual motorcycle state. The manoeuvre is continuously computed to account for changes in the actual state of the vehicle and surrounding scenario. The "optimal safe" manoeuvre is calculated based on a dynamic optimization approach which accounts for:

- an appropriate mathematical model of the motorcycle dynamics;
- an estimation of the actual dynamic state of the motorcycle;
- a model of the road geometry and attributes;
- the relative position and speed of the obstacle ahead
- riding safety, comfort and style
- the calculation of the riding risk

Since the reference manoeuvre includes the riding comfort style in normal driving conditions it is expected to fairly match with the rider's one. The same happens when the rider detects a dangerous obstacle in front and properly brakes: the optimal manoeuvre again fairly matches the actual motorcycle deceleration. Alternatively, if the rider does not brake enough or does not brake at all a large differences between actual and ideal acceleration is found and a warning is issued. As soon as the rider corrects the deceleration and achieves the suggested target optimal deceleration the warning disappears improving the system acceptability. Warnings are given to the rider via a proper combination of haptic, visual and audio signals thanks to specific HMI device, which include an haptic handle among, a vibrating glove, a smart helmet, and a visual display.

3 THE REFERENCE MANOUVRE: MATEHMATICAL FORMUALTION

The safe optimal preview manoeuvre is the core technology in the FCW application that assesses the risk level of the scenario. The preview manoeuvre is formulated as an optimal control problem that reads as follows: for a given state space model of the vehicle

$$\dot{\boldsymbol{x}} = \boldsymbol{F}(\boldsymbol{x},\boldsymbol{u}), \tag{1}$$

where $\boldsymbol{x}$ are the state variables and $\boldsymbol{u}$ are the vehicle controls, find the preview control history (e.g. brakes, throttle and steering) that minimises a given cost function J (e.g. a combination of riding comfort, distance travelled, etc.) for a given preview time T:

$$\min\int_0^T J(\boldsymbol{x},\boldsymbol{u})dt, \tag{2}$$

subject to imposed initial conditions on all state variables

$$\boldsymbol{x}(0) = \boldsymbol{x}_0 , \tag{3}$$

on final condition of selected state variable $\tilde{x} \in x$:

$$\tilde{\boldsymbol{x}}(T) = \tilde{\boldsymbol{x}}_T , \tag{4}$$

and inequality constraints (i.e. physical limits):

$$\boldsymbol{C}(x,u) \le 0 , \tag{5}$$

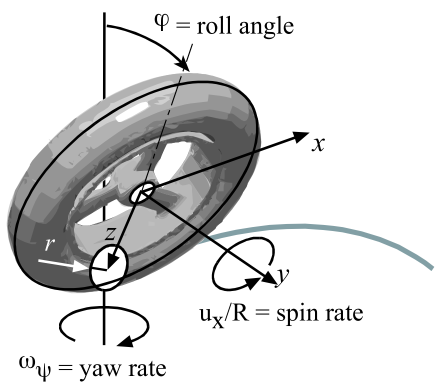
The solution of such a problem not only gives the control history $\boldsymbol{u}$ but also the whole preview motion $\boldsymbol{x}$ of the vehicle (i.e. trajectory, velocity, roll angle, etc.). The optimal motion predicts how to guide the vehicle smoothly from the current state $\boldsymbol{x}_0$ to a final steady state motion. The preview motion $\boldsymbol{x}$ also minimises the goal function and keeps, as much as possible, the vehicle state within the safety margin defined by the cost function and inequality constraints.

A specific dynamic optimization algorithm has been developed to solve numerically the resulting non linear system of equations in real time. More details on the adopted approach and numerical algorithm can be found in [11].

3.1 Dynamic model of the PTW vehicle

An optimized model of the motorcycle was developed to achieve real time solution of the optimal control problem at 10Hz rate on a pc104+. In this paragraph the model details are explained.

Even if the riding task is quite complex, the longitudinal and lateral dynamics of the vehicle may be considered uncoupled in a simplified description. The rider controls the longitudinal dynamics using throttle and brakes: the most relevant output is the vehicle speed. He controls the lateral dynamics using the handlebar (and secondarily by torso movements): the most relevant output is the vehicle heading. Based on these considerations, the simplest model that captures the essential motorcycle dynamics is a rigid body controlled in terms of speed and yaw rate and free to roll. In particular, if one imagines this model as a rolling wheel of proper size and inertia, the proposed basic model includes gyroscopic effects and tire shape features as average effect that are important in motorcycle dynamics, as is well known.



Model parameters

h	center of mass height
m	vehicle and rider mass
ρ_x	roll inertia radius
g	gravity acceleration
R	rolling radius
r	tire cross section
I_W	spin inertia of wheels
u_x	forward speed

Figure 2 free rolling wheel model

The state-space model of the rolling wheel is the following:

$$\begin{aligned}
\dot{\omega}_\varphi &= h \frac{\left(g \sin\varphi - \omega_\psi u_x \cos\varphi + \omega_\psi{}^2 \sin\varphi \cos\varphi\right)}{\rho_x{}^2 + h^2 + r h \cos\varphi} \\
&\quad + \frac{I_w}{m} \frac{\omega_\psi \cos\varphi\left(\omega_\psi \sin\varphi + u_x / R\right)}{\rho_x{}^2 + h^2 + r h \cos\varphi} \\
\dot{\varphi} &= \omega_\varphi
\end{aligned} \tag{6}$$

where the longitudinal speed u_x and the yaw rate ω_ψ are the model input and the roll angle φ and roll rate ω_φ are the state variables. Inspection of the first equation (1) reveals that the roll rate depends on gravity and centripetal acceleration (1st row), the gyroscopic effect (2nd row), and tire cross section (3rd row).

As discussed above, the basic PTW model can be controlled by the longitudinal speed and the yaw rate. However experimental evidence shows that humans plan trajectories minimizing the jerk to achieve a smoother motion [16][15][14][13], therefore it is convenient to control the vehicle through jerk (i.e. time derivative of acceleration) instead of speed. Therefore, four additional state variables and equations are introduced as follows:

$$\begin{aligned} \dot{u}_x &= a_x \\ \dot{a}_x &= j_x \\ \dot{\omega}_\psi &= a_\psi \\ \dot{a}_\psi &= j_\psi \end{aligned} \tag{7}$$

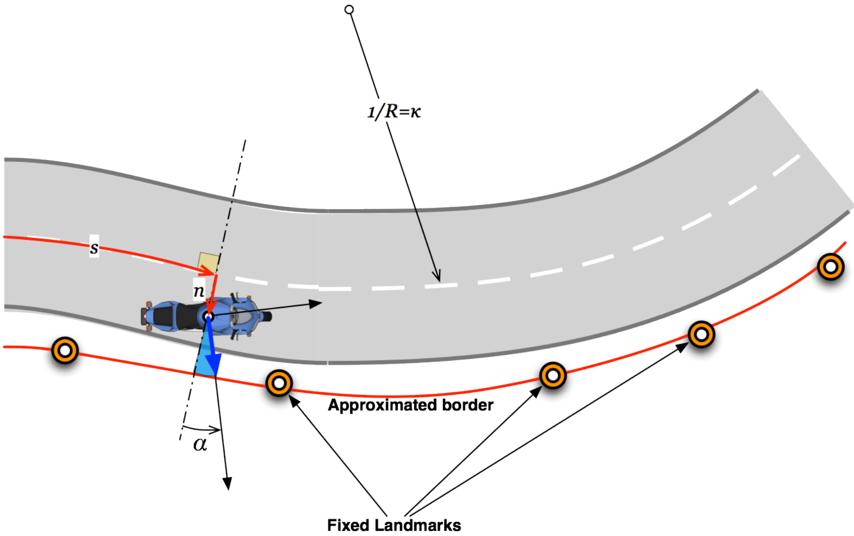


Figure 3 Curvilinear coordinates

The road geometry can be synthetically and effectively described using the curvilinear coordinates approach. As shown Figure 3, the road centreline may be completely defined by assigning the road curvature $\kappa(s)$ as a function of the road length $\boldsymbol{s}$, whereas the position and orientation of the vehicle can be defined using its position s along the route, the distance n from the road centre and orientation α relative to the road direction. This description leads to the following state space model:

$$\begin{aligned} \dot{s} &= \frac{u_x \cos\alpha}{n\kappa(s) - 1} \\ \dot{n} &= u_x \sin\alpha \\ \dot{\alpha} &= \frac{u_x \kappa(s) \cos\alpha}{n\kappa(s) - 1} + \omega_\psi \end{aligned} \tag{8}$$

Summarizing, the state space model of equation (1) is composed of equations (6), (7) and equation (8) for a total of nine state variables $\boldsymbol{x} = \{\omega_\varphi, \omega_\psi, \varphi, a_\psi, u, a_x, s, n, \alpha\}$ and two inputs $\boldsymbol{u} = \{j_\psi, j_x\}$.

3.2 Constraints: moving obstacles

From the rider's point of view a safe-optimal preview manoeuvre has to satisfy several requirements such as being consistent with vehicle dynamics, satisfy tire adherence limits, stay within the road lane. The vehicle dynamics is imposed by the equation (6), (7) and (8) and through initial conditions, which are forced to be equal to vehicle actual state with equation (3). Other constraints such as the road limits and tire adherence or comfort criteria are enforced with inequality equations. However, in order to cope with possible inaccuracies of the knowledge of the limit exact values, a fair margin is kept by converting the inequalities into penalty functions as explained in [11]. The penalty functions are normalized that is having unit cost at limit value and decreasing to zero in the tolerance interval. The gradient of the penalty function is designed in order to guarantee good convergence rate. Moreover the tolerance interval has the meaning of available margin before the physical limit: an cost is put to the variable if it is in this interval which increases as the variable approaches the limit. More details on their mathematical formulation are given in [20].

The Frontal Collision Warning additionally has to keep a relative speed and/or distance from the front obstacle that guarantees to the rider a) not to hit the front preceding vehicle and b) enough time to react and brake if it suddenly decelerates. The first condition is achieved when the motorcycle's future target speed will be less equal than the front obstacle speed v_o: the rider will follow the preceding vehicle at the same speed. This condition is deterministic: if the motorcycle has an higher speed it will for sure collide into the obstacle if it does not decelerate to reach the target speed. The second condition b) is probabilistic: if the motorcycle is following very close to the obstacle at the same speed it might collide with it only if it suddenly brakes. On the contrary if the obstacle keeps its motion unchanged nothing would happen. However, to take into account the fact the obstacle may brake the motorcycle has to keep a distance from the preceding vehicle that guarantees the rider to brake in time in order not to crash into the obstacle. This safety distance is said SafeDistance and is calculated as follows. It is assumed that an obstacle running at speed v_o suddenly decelerates with a_b deceleration and the rider does not react immediately but after τ seconds. During this period, delay time, the motorcycle keeps it motion due to velocity v_{m0} and uniform acceleration a_{m0}. At the end of the dead time the rider brakes with a deceleration of ηa_b where $\eta \in [0,1]$ is the motorcycle deceleration efficiency with respect to the obstacle's one. When both vehicles reach zero speed the motorcycle distance has to be greater than zero otherwise it has crashed into the obstacle. Therefore imposing the kinematic equations of the above described situation the minimum distance that the motorcycle has to keep in order not to crash into the obstacle is the following:

$$s_D = v_{m0}\tau + \frac{1}{2a_b}\left(\frac{v_{m0}{}^2}{\eta} - v_o{}^2\right) + a_{m0}\tau\left(\frac{v_{m0}{}^2}{a_b\eta} + \frac{a_{m0}\tau}{2a_b\eta} + \frac{\tau}{2}\right) \tag{9}$$

In the optimal control formulation the following constraint is imposed for each obstacle:

$$s_o + v_o t - s - s_D \geq 0 \tag{10}$$

where s_o is the initial obstacle position in curvilinear coordinates at the start of preview maneuver calculation and $s_o + v_o t$ is its time evolution. The inequality is implemented as timedependent moving barrier penalty function. As explained above the penalty function has a threshold that is the SafeDistance s_D as shown in Figure 4. The reader may note that the condition a) above (i.e. target motorcycle speed less equal than obstacle speed) is automatically enforced by the more stringent inequality (10).

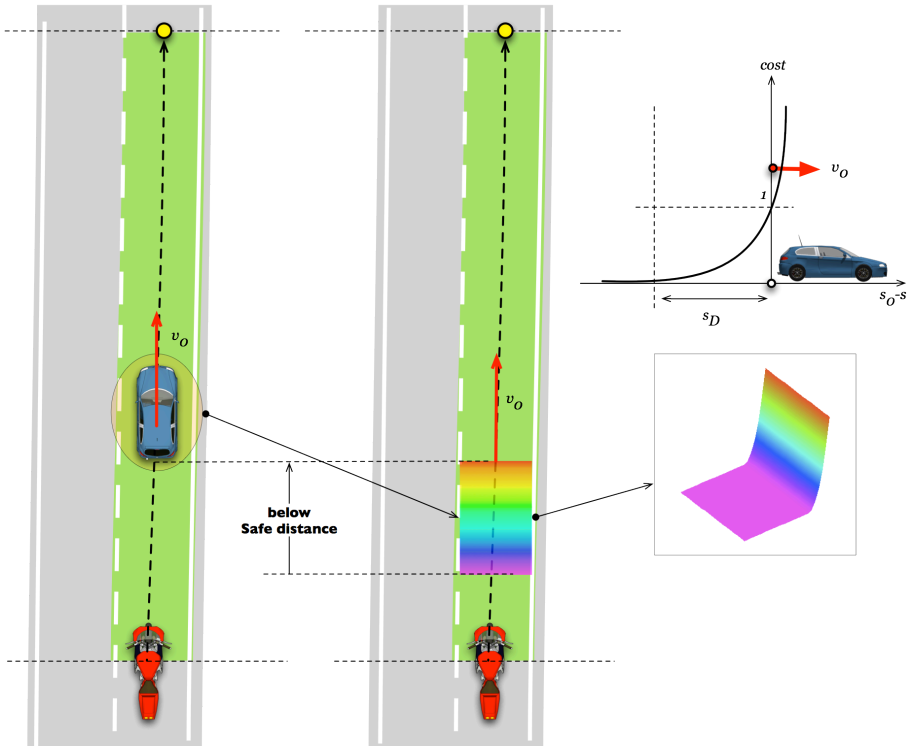


Figure 4 Cost function to implement moving obstacle an the SafeDistance concept

4 FRONTAL COLLISION WARNING IMPLEMENTATION

The FCW software and hardware architectures follow the "sensethinkact" paradigm. It is a three-layer structure where the *sense* layer processes the sensors data to reconstruct the vehicle state and surrounding environment; the *decision* layer assesses the manoeuvre's risk level and the *act* layer activates the proper HMI element. Figure 5 summarizes the hardware elements that fits into the three layers (perception, decision and action) that the FCW function shares with other SAFERIDER functions.

The perception layer includes sensors for the measurement of vehicle state such as a GPS device, an Inertial Measurement Unit (IMU), a Laser Scanner and a Vehicle Interface module (VIF), which links vehicle built-in sensors like speedometer, brake pressures and others to the SAFERIDER CAN bus. The decision layer consists in the ARAS Control Module (ACM), which manages ARAS software and interacts with the other SAFERIDER systems. It is hosted by a PC/104+ with a 1.4GHz CPU running Linux OS. Finally the action layer includes the HMI manager and a set of HMI elements: the visual display and three haptic devices: handle, glove and helmet. The HMI manager processes the warning provided by the ACM and properly activates the various HMI elements.

The FCW logic is hosted in the ACM together with other sub functional modules each of which implements a specific task, as depicted in Figure 7. The Main Application (MA) is the program in charge of the whole interoperation between modules. The MA implements the high-level ACM logic coordinating the data exchanged between modules and also synchronization of module operation.

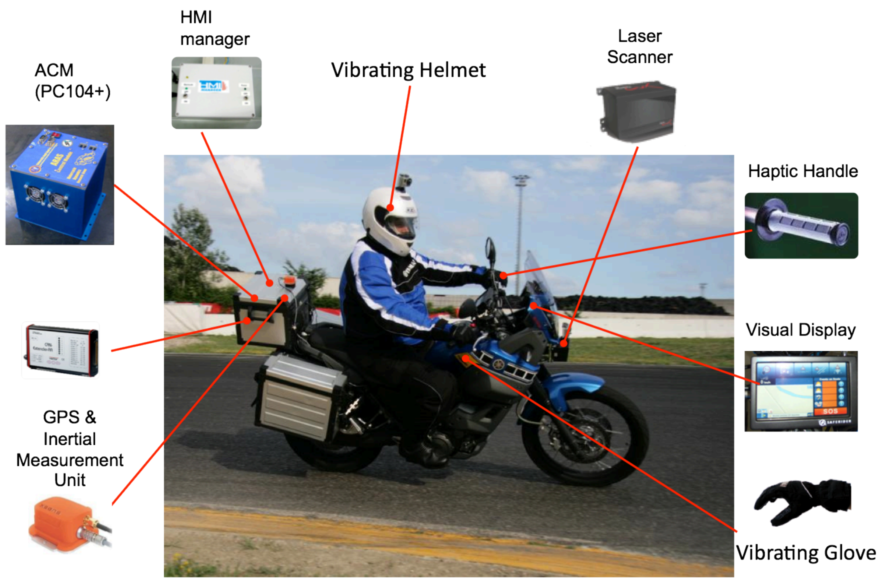


Figure 5: FCW hardware architecture

The CAN Manager module receives and stores sensor data from the dedicated Can bus; then the MA passes this data to the Scenario Reconstruction (SR) module, which fuses the heterogeneous sensor data to produce a consistent estimate of the vehicle's state of motion and position with respect the road, based on a digital road model provided by the Digital Road (DR) module. In the reconstructed road scenario are also placed the obstacles detected by the laser scanner. The laser device uses four laser beams to scan an area 100° wide in front to the vehicle with a time frame of 80ms. The collect points are internally processed and clustered and to each known cluster (e.g. vehicle, truck, etc.) size, position and speed are assigned and it is tracked. Obstacle absolute speed is reconstructed using the IMU and GPS data to correctly include the motorcycle dynamic evolution during each scan. An example of what it is reconstructed by the laser device is shown in Figure 6.

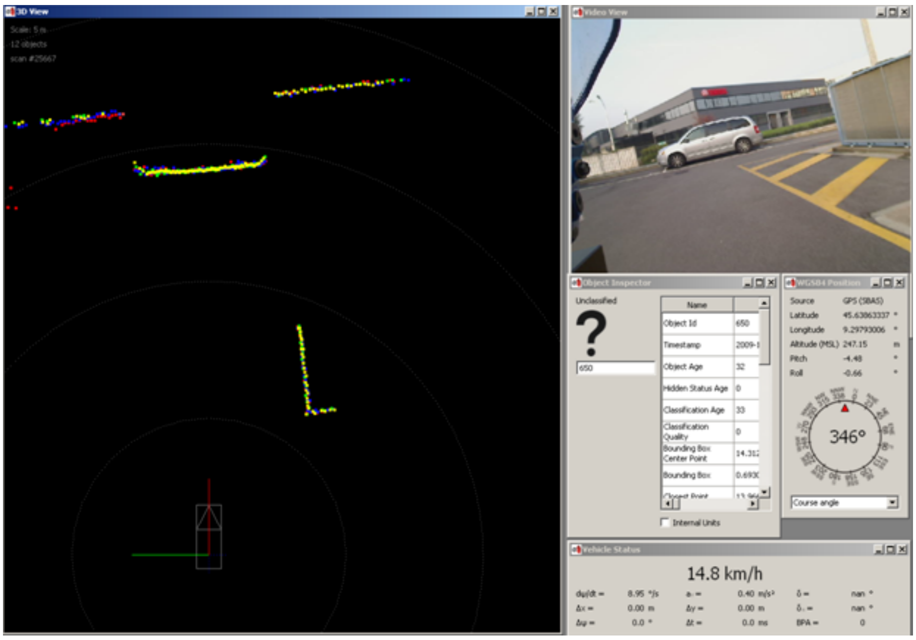


Figure 6 Example of laser scanner obstacle detection output: a car and walls are detected.

The reconstructed scenario is passed by the MA to the FCW module. Once the warning is generated it is sent back by the MA through the CAN bus at the first opportunity. While running, the logging module allows the MA program to trace the data exchanged between modules and the state of execution of the whole program. This allows postprocess analysis of the entire system behaviour.

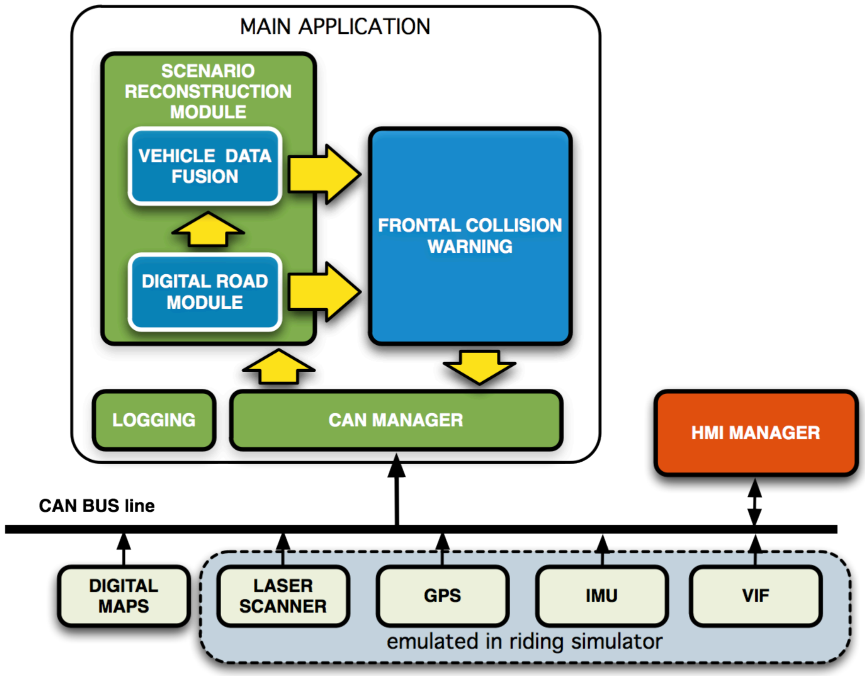


Figure 7: ACM software architecture

4.1 Risk level evaluation and warning level generation

The risk level assessment of an actual manoeuvre is derived based on the required rate of change of the forward acceleration. In other words the longitudinal jerk is used to estimate the level of severity of the corrective action required to steer the motorcycle into a safe state (as described above). The use of the longitudinal jerk as a risk level estimator is effective, since it corresponds to the main effect of the rider's brake command. Moreover it is expected to be more understandable from the rider's point of view since it is coherent with the effect of braking or throttle release actions.

The FCW module computes minimum jerk reference manoeuvres that smoothly adapt to front obstacles speed and distance within the envelope of comfort accelerations (as explained in [20]). If it is not possible to smoothly plan a manoeuvre inside the envelope of comfort accelerations an emergency manoeuvre will be planned that means without comfort acceleration constraints but complying only to physical limits of accelerations. Therefore the cost related to exceeding the capability envelope soon becomes the dominant term, and the criterion gradually shifts to minimizing tyre forces and avoiding to hit the front obstacle. If the motorcycle actual velocity and acceleration is not adequate to the situation a high negative jerk will be planned meaning longitudinal speed has to be reduced immediately. The correction demanded to the driver corresponds to the jerk j_x value at the beginning of the reference manoeuvre: $j_x \approx \Delta a_x / \Delta t$ accounts for the amount of acceleration change Δa_x for a given period of time Δt. If it exceeds a given threshold (human riders use limited jerk even in emergency situations) it is assumed that the rider is not likely to follow the reference manoeuvre, or at least that he/she has to execute a faster action than usual. At this point a first level warning is issued. A second threshold is set when emergency jerk limits are crossed. Summing up three level of warning are defined for FCW:

0 – Off/idle = jerk value positive or less than first threshold

1 – Safety = jerk value negative between the two thresholds

3 – Critical = jerk value negative over the second threshold

The thresholds are tuned during track test.

5 PRELIMINARY RESULTS

To better understand the FCW concept let us describe how it works in a typical rearend collision scenario as illustrated in Figure 8. A sample of data from a preliminary experimental test is used.

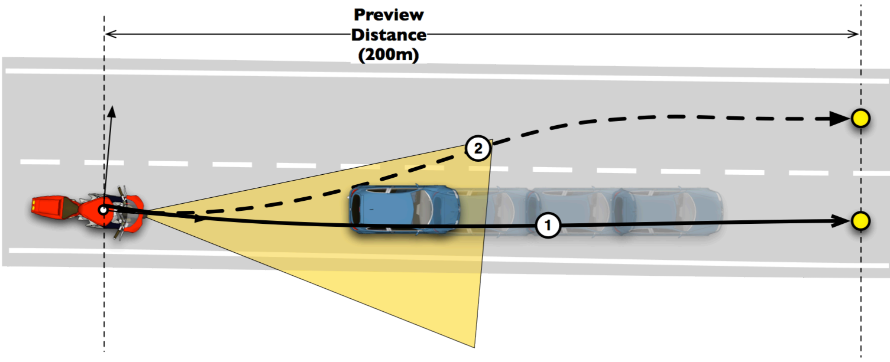


Figure 8. The car in front of the PTW has a speed remarkably slower than the ego vehicle**.**

It is worth pointing out that, in the situation represented in Figure 8, the rider may choose between two opposite alternatives: i.e. follow the vehicle ahead or overtake it. The second alternative is not included in the current version of FCW function due to the presence of technological limitations: indeed the risk calculation for manoeuvre 2 would require a precise estimation of the position and orientation of the ego vehicle with respect the road, which is not currently available in the project demonstrator (even if possible in principle).

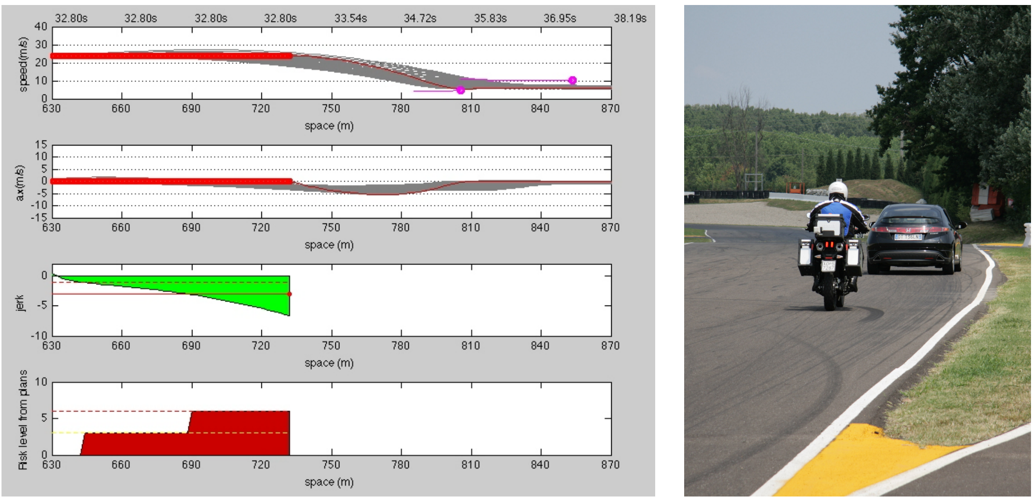


Figure 9. Sequence of preview speed plans and risk evaluation for a typical scenario

Therefore, it has been decided to refer to the manoeuvre 1 only, which is the more conservative and safer one. For the rearend collision scenario left plot of Figure 9 shows a sequence of preview manoeuvres in term of speed, longitudinal acceleration and the related jerk value and warning level. On the right side of Figure 9 a photo of the scenario is reported. In the speed diagram there are represented both the ego vehicle speed (red dots) and the car ahead speed (small dot), which is slower than the motorcycle. In addition, gray lines represents the sequence of preview manoeuvres for speed and roll angles, which are continuously recomputed. A deviation from the rider behaviour is visible only when the motorcycle is at about 30m: the reference manoeuvre plans suggest a speed reduction of about 10m/s. The jerk diagram of Figure 9 should be analyzed differently form speed and acceleration ones, since it only represents the initial value of jerk for any preview manoeuvre, and the risk level is evaluated according two jerk threshold, respectively (-1 m/s^2 for cautionary warning and -2 m/s^2 for imminent warning). Indeed, as the jerk becomes more negative, the urgency of reducing acceleration (or decelerating even more) increases, therefore two jerk thresholds have been selected for safety and critical warning. As essence of preview concept, first instants of the manoeuvre are strongly influenced from what is next, therefore it is sufficient to examine first values of jerk to suggest the rider what to do now for being in safe condition later. So, a major benefit of this approach for risk evaluation is the possibility of providing warnings in advance and leaving the rider the time to react and correct its behaviour.

It is worth pointing out that the warning strategy based on jerk evaluation do not only recognize a possible danger situation, but in addition it evaluates the mismatch between rider actions and system plans in order to produce warning only when both there is a potential danger and the rider has not perceived it yet. Indeed, in a reference scenario where the rider is running at a certain speed and there is an obstacle ahead, if the vehicle acceleration is null (or even positive), most likely the rider should be warned, on the contrary if the vehicle is already decelerating most likely the rider should not be warned because he is aware of the situation and he is already reducing the speed and therefore redundant messages will bother him. The FCW is capable of distinguish between these situations: in the first case a negative, possibly high, jerk arises in the preview manoeuvre and a warning is delivered, on the contrary in the second situation the preview manoeuvre will be much smoother, with no so negative jerk and hence no warning.

6 CONCLUSIONS

The Frontal Collision function is an important rider support application since it draws human attention to potential dangerous obstacle reducing reaction time and improving the rider's perception of the road scenario. Within SAFERIDER project a FCW function was developed based on the continuous computation of a reference safe manoeuvre formulated as an optimal control problem, which makes use of a vehicle model, road geometry description and obstacles in the motorcycle front view. The longitudinal jerk is the optimal input that is also used to build the warning strategies since it expresses the amount of acceleration rate of change that has to be used by the rider to steer the motorcycle into a safe state given the actual situation. The application architecture follows the "sensethinkact" paradigm and was implemented on a Yamaha Teneré demonstrator. The rear end collision scenario was used to test the FCW functionality and the preliminary results were shown in this paper.

7 ACKNOWLEDGMENT

The authors wish to thank the EU for funding this project within the 7th Framework Program (SAFERIDER grant agreement FP7-ICT1-216355) and also all other partners involved in the project

REFERENCES

[1] www.saferider-eu.org

[2] http://ec.europa.eu/transport/publications/statistics/doc/2009_energy_transport_figures.pdf

[3] MAIDS final report2.0.pdf. Available at: http://www.maids-study.eu/

[4] SAFETY IN MOTION (SIM) European project : http://www.sim-eu.org/

[5] PISa European project: http://www.pisa-project.eu/

[6] Bayly M., Hosking S., Regan M., "I*ntelligent Transport Systems And Motorcycle Safety*", Paper number 07-0301, http://www.monash.edu.au/muarc/reports/muarc260.html

[7] Bryson A.E. (Jr). (1999) Dynamic Optimization. Addison-Wesley. ISBN 0-201-59790-X.

[8] Amditis A., Bertolazzi E., Bimpas M., Biral F., Bosetti P., Da Lio M., Danielsson L., Gallione A., Lind H., Saroldi A., Sjögren, "*A Holistic Approach to the Integration of Safety Applications: the INSAFES Subproject within the European Framework Program 6 Integrated Project PReVENT*", IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, 2010, ISSN: 1524-9050.

[9] Bertolazzi E., Biral F., Da Lio M., Saroldi A., Tango F. , "*Supporting Drivers in Keeping Safe Speed and Safe Distance: the SASPENCE Subproject within the European Framework Program 6 Integrating Project PReVENT*". IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, 2010, ISSN: 1524-9050

[10] Bertolazzi E., Biral F., Da Lio M., "*Real-time motion planning for multibody systems*". MULTIBODY SYSTEM DYNAMICS, **17**; p. 119-139, 2007, ISSN: 1384-5640, DOI: 10.1007/s11044-007-9037-7.

[11] Biral F., Lot R., "*An interpretative model of g-g diagrams of racing motorcycle*", in: Proceedings of the 3rd ICMEM International Conference on Mechanical Engineering and Mechanics. Beijing, Repubblica Popolare Cinese, Ottobre 21−23, **2**, 2009.

[12] Biral F., Bortoluzzi D., Cossalter V., Da Lio M. "*Experimental Study of Motorcycle Transfer Functions for Evaluating Handling*". VEHICLE SYSTEM DYNAMICS, 2002, ISSN: 0042-3114

[13] Yamakado M., Abe M. ," *Examination Of Voluntary Driving Operational Timing By Using Information Obtained With The Developed Jerk Sensor*", World Automotive Conference FISITA2006, paper number F2006V137, 2006.

[14] T. Hiraoka, T. Kunimatsu, O. Nishihara, H. Kumamoto, "*Modeling of driver following behavior based on minimum-jerk theory*", Proc. of 12th World Congress on Intelligent Transport Systems, CD-ROM (2005.11)

[15] Biral F., Da Lio M., Bertolazzi E., "*Combining safety margins and user preferences into a driving criterion for optimal control-based computation of reference maneuvers for an ADAS of the next generation*". In: IEEE Intelligent Vehicle Symposium, June 6 – 8, 2005.

[16] Biral F., Da Lio M., Lot R., Sartori R. (accepted). "*An Intelligent Curve Warning System For Powered Two Wheel Vehicles"*. EUROPEAN TRANSPORT RESEARCH RE-VIEW, ISSN: 1866-8887A