Development and Testing of Assistant Rider Systems with the UNIPD Motorcycle Riding Simulator

Vittore Cossalter, Roberto Lot, Matteo Massaro, Roberto Sartori

Department of Innovation in Mechanics and Management, University of Padova, Italy
E-mail: vittore.cossalter@unipd.it, roberto.lot@unipd.it, matteo.massaro@unipd.it, roberto.sartori@unipd.it

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SUMMARY. The work illustrates the main features of the motorcycle riding simulator developed at the Dept. of Innovation in Mechanics and Management (DIMEG) of the University of Padova. The simulator consists of six subsystems: the sensors subsystem that monitors rider's control actions, the multibody model that simulates real-time motorcycle dynamics and includes a 3D road-tire model, the washout filter, the mock-up of the motorcycle that generates motion cues, the audio system and the visual system. The progress made so far within the two European Research Projects in which the riding simulator is involved will be discussed. In particular, the riding simulator is used for testing and developing ARAS devices such as Speed Alert, Curve Warning, Frontal Collision Warning (SAFERIDER Project) and to investigate the rider behaviour in both real and virtual environment (2-BE-SAFE Project). Additionally, the utilization of the UNIPD riding simulator for the development of traction control system, for the analysis of ABS systems as well as for the test of algorithms that predict motorcycle lateral fall (and which are intended to be used for the activation of an airbag integrated in the rider's suite) will be briefly presented.

1 INTRODUCTION

Motorcycle and moped fatalities account for 17.8 % of the total number of road accident fatalities in Europe and, compared to a passenger car occupant, a motorcycle rider is 26 times more likely to die in a crash, based on vehicle miles travelled [1]. This is the reason why the European Community is driving industries and research community to develop efficient and rider-friendly interfaces and interaction elements for riders' comfort and safety. In this context, a motorcycle riding simulator has been developed and built at the Dept. of Innovation in Mechanics and Management (DIMEG) of the University of Padova (UNIPD). The advantage of a riding simulator is that is possible to test Advanced Rider Assistance Systems (ARAS) on a virtual motorcycle but with a real rider in a controlled environment. This approach differs from classical control and multibody approaches where the real human behaviour is hard to simulate. Moreover, it is clear that a simulator can easily replicate accidents in a wide range of situations without any risk for the rider.

Motorcycle riding simulators are not as widespread as aircraft and car driving simulators, and therefore the current panorama is not very rich. Honda started to develop a series of motorcycle simulators in 1988: its first prototype consisted of a 5 DOF mock-up (lateral, yaw, roll, pitch and steer motions on a swinging system for the longitudinal acceleration restitution) and was based on a linear 4 DOF motorcycle dynamics model. In 1996, as a consequence of the change of the Japanese Road Traffic Act which required the use of simulators in riding schools lessons, Honda put a mass-produced model on the market. This second prototype had a simplified 3 DOF mock-up (roll, pitch and steer motions) and it was based on a properly tuned empirical motorcycle model. In 2002 Honda presented a third prototype which consisted of a 6 DOF plan manipulator for the mock-up motion, a head mounted display for visual projection, a 4 DOF model for the lateral motorcycle dynamics and 1 DOF model for the longitudinal dynamics, Ref. [2],[3]. In 2003 PERCRO laboratory presented its riding simulator with a real scooter mock-up mounted on a Steward platform (Ref. [4]) and in 2007 INRETS presented a riding simulator based on a 5 DOF platform and a linear 5 DOF motorcycle mathematical model, Ref. [5]. The University of Padova started the development of a riding simulator in 2000s and presented the first prototype in 2003, Ref. [6]. The simulator has experienced major improvements ever since, see e.g. Ref. [7],[8], and it is now used for the development and testing of several ARAS systems.

Of course riding a simulator does not give exactly the same feeling as riding a real bike, but the presented simulator is able to reproduce motorcycle counter-steering, capsize, weave and wobble instabilities, wheeling, skidding, etc. In order to have an effective riding feeling, it is not only necessary to use a reliable vehicle dynamics model, but also to transmit to the rider a consistent acceleration field and force/torque feedback in a realistic audio (engine, wind, gear change and other noisy sources) and visual (terrain, buildings, other vehicles, pedestrians, etc.) environment.

The next section presents the main feature of the UNIPD riding simulator, whereas the next sections are devoted to the discussion of the most recent applications of the simulator in the development of ARAS systems.

2 THE RIDING SIMULATOR

The UNIPD simulator consists of 6 subsystems (see Figure 1): the sensors subsystem (managed by sensors.dll) which monitors rider's control actions, the multibody model (motorcycle.dll) which simulates real-time the vehicle dynamics, the washout filter (washout.dll) which converts the motorcycle motion into mock-up motion, the mock-up (controlled by motion.dll) that generates motion cues, the audio (sound.dll) and the visual system (graphics.dll).

2.1 *Sensors*

The rider behaviour is recognized by monitoring the steering angle and the steering torque, the throttle position, the pressure applied to the front brake lever and rear brake pedal, the clutch position and the gearshift lever position, the pressure applied to the footpegs as a consequence of

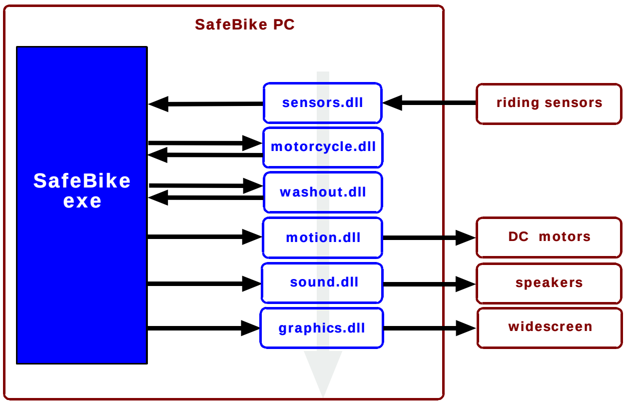


Figure 1: Simulator subsystems.

the rider lateral displacement with respect to the chassis, and the rider lean angle with respect to the chassis symmetry plane.

More in detail, the steering torque is measured by means of a transducer on the handlebar steering axis, the throttle position is measured with a linear position transducer (range 0-96 mm) connected to the accelerator cable, the front/rear brake actions and the clutch position are measured by means of pressure sensors (range 0-100 bar), the gearshift command is detected by inspecting the digital signals created by two micro-switches that are triggered when the top or the bottom end-of-stroke position is reached by the gearshift lever, and the footpegs are designed to measure the differential pressure applied by right and left foot. This differential pressure is assumed to be related to the lateral position of the rider's upper body with respect to the chassis. Notwithstanding the steering torque gives the main contribute to the out-of-plane motorcycle dynamics, it has been found that the rider's body movement significantly improves the virtual riding feeling.

2.2 *Multibody model*

The motorcycle multibody model is based on a validated code developed at DIMEG over the last years, Ref. [9],[10]. In particular, the modelling details have been reduced to capture the essential features to give a reliable and fast code suited for real-time simulation. The model has 14 DOF (see Figure 2), the position and orientation of the chassis (6 DOF), the steering angle (1 DOF), the front and rear suspension travels (2 DOF), the front and rear wheel rotations (2 DOF), the engine spin rate (1 DOF), the front frame lateral deflection (1 DOF) and the sprocket absorber deflection (1 DOF). Linear assumption has been made only for the steering angle, the suspension travels, the rider lateral displacement, the frame deflection and the sprocket absorber deflection. The resulting motorcycle mathematical model is therefore non-linear.

It is worth highlighting that the frame compliance has been added (by means of a lumped spring-damper element at the steering head) in order to have reliable vehicle dynamics as regards the wobble vibration mode behaviour (see e.g. [11]): indeed when neglecting this flexibility it is common to have strong high speed wobble instability thus making the simulator behaviour far from that of the real bike. The introduction of the sprocket absorber flexibility (which accounts for the elastic element between the chain sprocket and the rear wheel rim) is necessary for a proper modelling of the engine-to-slip dynamics which are essential when it comes to traction control design and test, Ref. [12]. Moreover this flexibility is related to the so called chatter instability that may appear in racing motorcycle during braking, Ref. [13].

As the road-tire model is concerned, the force generation is computed according to the *Magic Formula* (Ref. [14]), the tire transient behaviour related to the longitudinal and lateral carcass flexibility is managed by means of the well known relaxation equations and the road-tire 3D model is a simplified version of that presented in Ref. [15].

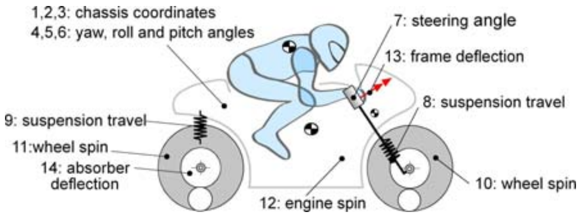


Figure 2: Motorcycle multibody model.

The model inputs are the measured steering torque, the engine torque which depends on throttle position and engine spin rate, the front and rear brake pressures, the clutch position, the gear ratio, and rider lateral position estimated from the differential footpegs pressure.

To the best of the author knowledge, there are no working riding simulators with such a detailed vehicle model.

2.3 *Washout*

The washout filter aims at converting the motion of the virtual multibody vehicle into the mock-up motion so that the rider's feeling on the simulator is as close as possible to his feeling on the real bike. It is worth pointing out that it is impossible to reproduce exactly the same accelerations the rider experiences on a real bike. Therefore the most important target is to make the rider's feedback reasonable.

Washout filter were developed for flight simulators and there are many examples in the literature, see e.g. Ref. [16],[17]. Most of them assume the pilot is stable with respect to the vehicle (and so the accelerations are approximately the same for both) but this is not true for motorcycles where it is not easy to establish correctly the rider's head position and movements. For these reasons we decided to approach the problem from an empirical point of view, considering the simple idea that the rider should feel the mock-up motorcycle reactions to be natural consequences of its behaviour. The washout filter has three stages (see Figure 3): in the first stage, inputs are filtered through a second order low-pass filter; in the second stage the washout outputs are computed as a linear combination of the filtered inputs, and as a third stage they are filtered again.

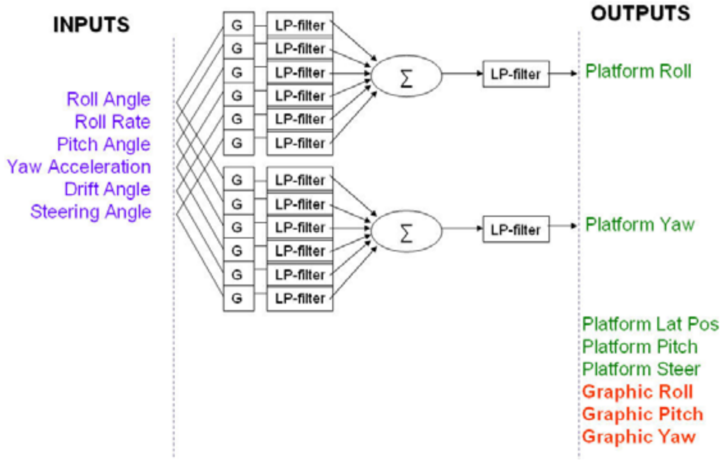


Figure 3: Simulator washout architecture (G: gain, LP: Low Pass).

2.4 *Motion system*

Figure 4 shows a scheme of the motorcycle mock-up whose serial kinematic chain is composed of four mobile members and a fixed frame. The first mobile member is the *yaw frame*, it is linked to the fixed frame by a pin-in-a-slot joint and has 2 DOF: the lateral displacement and the yaw rotation. The range of the lateral displacement is ± 0.3 m (± 0.3 m/s) and that of yaw rotation is ± 20° (±0.2°/s). In order to reduce the load on the pin-in-a-slot joint the yaw frame is suspended by means of four long steel cables attached to the roof. Two servo-motors equipped with ball screws (A2 and A3) drive the yaw rotation and the lateral displacement: when the two servomotors rotate in the same direction the lateral motion is generated; when the two servomotors rotate in opposite directions the yaw rotation is generated. The second mobile member is the *roll frame*. It is linked to the yaw frame by means of two revolute joints which define the roll axis of the roll frame with respect to the yaw frame. The roll range is ± 20° (± 60°/s), and it is driven by a servomotor (R1) equipped with a 50:1 speed reducer. The third mobile member is the *pitch frame*, which is mounted on the roll frame with another revolute joint. It makes it possible the rotation about the pitch axis and is driven by a servomotor equipped with a ball screw (A4). The pitch range is ± 10° (± 50°/s). Finally, the *handlebar frame* is moved by a servomotor (R5) mounted on the pitch frame and is equipped with a 10:1 speed reducer, the steering range is ± 10° (± 50°/s). Each axes of the simulator is equipped with brush-less servomotor and position loop control.

2.5 *Audiovisual systems*

There are three LCD placed on a shelf at 2 m of height and about 1.5 m behind the rider projecting images on three 2x2 m panels. The reason for the two side panels, angled of 45° with respect to the front one, is a proper speed sensation. Indeed the perception of speed is captured by the eyes' side portions: in other words without the lateral panels rider feels he is going slower than he is actually going in the virtual world of the riding simulator. Figure 5 shows the way the virtual

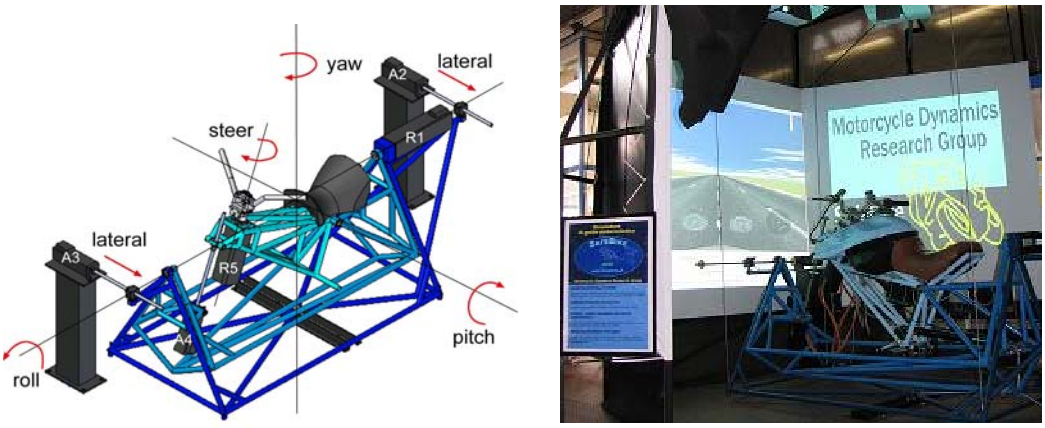


Figure 4: Simulator mock-up and motion system.

Figure 5: Simulator point of view.

world is rendered on the three screens. Actually the whole field of view is set to 240° (it should be 180°, but it has been found that the speed feeling is improved with such a choice).

A 5.1 surround system provides the generation of the environment sounds all around the rider.

The audiovisual software is able to reproduce a set of different simulation conditions: the road track (see Figure 5), the city with traffic and pedestrian (Figure 6 left), the rural panorama (Figure 6 right) and some other situations designed to execute more specific tests like slalom, lane change, steady-cornering, etc.

Figure 6: Simulator city scenario (left) and rural scenario (right).

3 RIDING SIMULATOR APPLICATIONS

The UNIPD riding simulator is being used in several research projects which aim at developing and testing Advanced Rider Assistance Systems (ARAS). The following sections briefly summarize the most important ones.

3.1 *2-BE-SAFE project*

Many large-scale research programs have been undertaken to understand the behavioural and ergonomic factors that contribute to crashes involving 4-wheeled vehicles. These have been effective in informing countermeasure development, which has led to significant reductions in crashes. No comparable human factors and behavioural research programs have been initiated in the 2-wheeled vehicle domain, in Europe or elsewhere. The 2-Be Safe (2-wheeler behaviour and safety, 7th Framework Programme) project, which involves partners from Europe, Israel and Australia, directly targets those behavioural and ergonomic factors. Among the objectives of this research, there is the improvement of the rendering of the UNIPD riding simulator, with a focus on rider feeling. This will make it possible to use the simulator in rider behavioural studies in addition to road tests.

To improve the riding feeling the following two procedure have been iteratively applied: A) the fine-tuning of the motion, sound and visual rendering devices, which has been done by a selected group of high skilled riders, B) the simulator validation, carried out by comparing the behaviours, performances and self-reported impressions of a wider group of riders having different ages, experience and skill. The validation is based on two complementary concepts: objective validation and subjective validation. The objective evaluation consists in the comparison between the behaviour of the real and virtual motorcycle in presence of the same riding actions. Since there exist many riding conditions with several uncontrolled parameters, a selection of three typical manoeuvres has been selected as following: I) Slalom (three different cone distance), II) Lane change (two different lane geometry), III) Steady turning (three radii). It is worth pointing out that the selected riding situation are known as representative of the handling characteristic of a motorcycle, Ref. [19], indeed they actually are a subset of the test manoeuvres commonly used by motorcycle manufactures to develop their own vehicles. Test have been carried out by skilled riders.

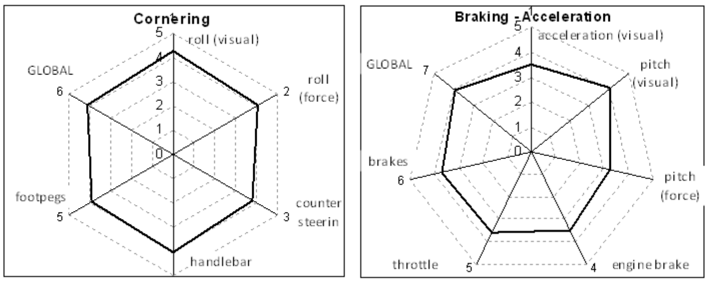
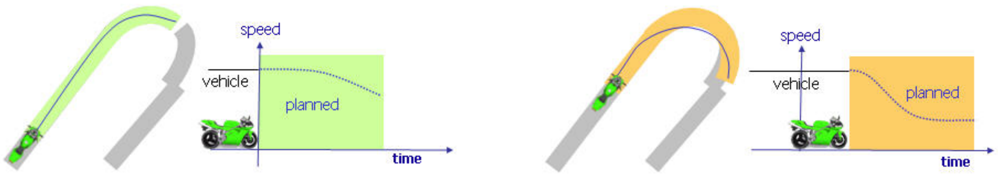


Figure 7: Example of Users' riding feeling rating.

The target of the subjective evaluation is the enhancement of the riding sensations in term of visual, acoustic and motion cues. The riding sensations of test riders are being collected by means of a questionnaire, which include both technical questions and questions about perception and cognitive processes, as shown in Figure 7. Hints for the improvement of simulator tuning are being derived and new simulator tests are being carried out. At the end of the iterations the simulator will be finely tuned.

3.2 *SAFERIDER project*

Saferider (advanced telematics for enhancing the safety and comfort of motorcycle riders, 7th Framework Programme, Intelligent Vehicles and Mobility Services) project aims at studying the potential of ARAS/IVIS (Advanced Rider Assistance Systems/In-Vehicle Information Systems) integration on motorcycles for the most crucial functionalities and developing efficient and rider-friendly interfaces (HMI: Human Machine Interfaces) and interaction elements for riders comfort and safety. However, such technologies should be designed and developed in a way that does not interfere with riding and/or annoy the rider. The UNIPD riding simulator is being used to investigate the most effective ARAS/HMI combinations in order to reduce the number of road tests which characterize the final part of the project. More in detail, three ARAS (Speed Alert,



LOW RISK SITUATION

The vehicle is still far from the curve. The planned manoeuvre suggests a mild deceleration. The rider runs at constant speed: his behaviour is consistent: no warning is delivered

HIGH RISK SITUATION

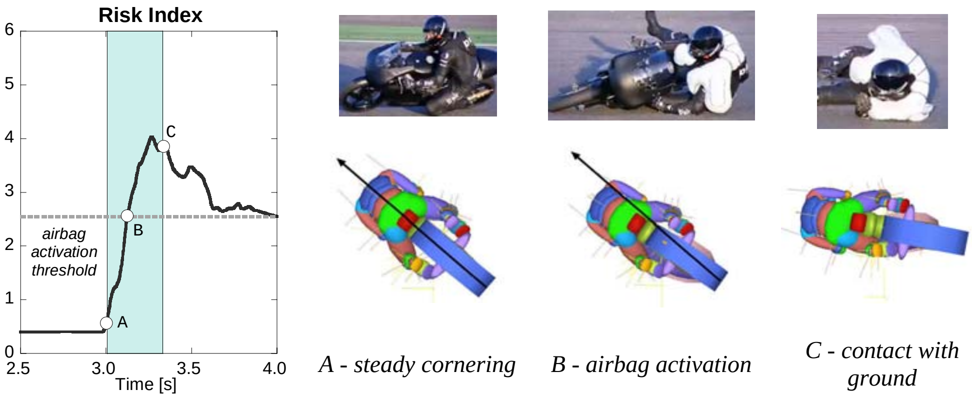
The vehicle is almost entering the curve. The planned manoeuvre suggests an hard deceleration. On the contrary, the rider accelerates: a warning is delivered

Figure 8: Curve Warning concept.

Curve Warning and Frontal Collision Warning) and three HMI (haptic throttle, haptic handle and haptic glove) are being tested. More in detail, *Speed Alert* system compares the actual and legal speed and provides a warning message when the rider is speeding, *Curve Warning* system estimates a safe manoeuvre for the forthcoming curve basing on the actual vehicle motion and deliver a warning if the rider behaviour is unsafe (see Figure 8), *Frontal Collision Warning* detects objects in front of the vehicle and provides a warning message whenever the situation is considered dangerous. The rider is warned either by an *haptic throttle*, which makes harder the feedback on the throttle, or an *haptic handle,* which exerts a pressure on the rider's hand, or an *haptic glove*, which vibrates.

3.3 *Air-bag activation for a side fall*

The Riding Simulator has been used for testing algorithms which aim at predicting motorcycle lateral fall. Basically there is a risk function which is computed by combining vehicle acceleration and velocities. When this function is greater than a selected threshold, it is assumed that the vehicle is going to fall. This condition triggers the activation of an airbag jacket which aims at preventing rider's injury, see Figure 9. The simulator has been used to simulate several crash events to check if the risk function properly triggers an air-bag activation or not. It is clear that such investigation is almost impossible to carry out on real vehicles with real riders. For additional details see [20],[21].



A - steady cornering

B - airbag activation

C - contact with ground

Figure 9: Risk function and air-bag activation.

3.4 *Traction Control (TC)*

The Riding Simulator implements several Traction Control (TC) logics, that on real motorcycle will drive devices designed to prevent loss of traction of the driven rear wheel. TC on motorcycle is challenging when the vehicle is leaned, i.e. in cornering. Indeed most of the commercial TC systems work only in straight motion condition. The advantage of the riding simulator is that it is possible to test efficiently many different TC logics in a safe environment with a real rider. Several road-tire adherence curves have been tested (with friction coefficients ranging from 0.5 to 1.0) and the behaviour of different TC logics has been investigated. Several acceleration tests have been carried out by three riders with different riding experience (not expert, expert, very expert).

3.5 *Anti-lock Braking System (ABS)*

Even if ABS for car is a widespread device, ABS for motorcycle has some peculiarities that makes it development quite demanding. Two-wheeled vehicles have stability problem, particularly when cornering, and the independent braking ratio which characterizes motorcycle does not make things easier. Therefore the Riding Simulator has been used for the analysis of the performance of an ABS system, whose logic is quite similar to that of the widespread Bosch system. Basically it is a finite state machine whose target is to keep the tire working around the peak of the slip curve. Several road-tire adherence curves have been tested and the effect of several ABS parameters (cycle frequency, size of the switching windows, etc.) has been investigated by running braking tests. It is currently in progress an algorithm for the automatic real-time detection of the slip curve.

4 CONCLUSIONS

The main features of the UNIPD riding simulator have been illustrated. The riding simulator consists of six subsystems (sensors, multibody model, washout filter, mock-up, audio system, visual system) which have been detailed. The main research projects in which the riding simulator is involved have been presented with a focus on the two projects within the 7th European Framework Programme which aim at improving the riding cues and developing Advanced Rider Assistance Systems (ARAS) and Human Machine Interfaces (HMI). In particular, *2-BE-SAFE* project aims at investigating the behavioural and ergonomic factors that contribute to crashes involving 2-wheeled vehicles, and the *SAFERIDER* project aims at studying the potential of ARAS/IVIS integration on motorcycles and developing efficient and rider-friendly HMI for riders comfort and safety. Additionally, the riding simulator is involved in the test of algorithms for the prediction of vehicle lateral fall, and in the development of motorcycle ABS and traction control logics.

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