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# NUMERICAL SIMULATION OF A MOTORCYCLE-RIDER SYSTEM WITH LASER SENSOR FOR COLLISION AVOIDANCE

[1]T. Alessandro, [1]M. G., David*, [1]K. Jian
[1]LMS International, Belgium

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ABSTRACT - The paper illustrates the research outcomes of the integration of sensor system and control logic into a multibody simulation environment for motorcycle accidental dynamics analysis. One of the main objectives is to propose feasible scenarios for intelligent collision avoidance scheme for powered two wheeler (PTW) systems. A multibody model of a motorcycle that comprises a simplified model of the rider is studied with a conceptual virtual laser sensor placed on the front fork and beaming forward. The sensor is modelled as a device that is able to detect objects within its beam that is characterized by sweeping, beaming and sampling parameters. The virtual environment is populated with moving obstacles placed along the nominal trajectory of the motorcycle. Several control logics are then investigated, from a simple warning system that will result in an action taken by the rider, towards an automatic collision avoidance manoeuvre system that includes controlled steering and braking compatible with the model dynamics and limitations. It is necessary to take into account the fact that the active control system may introduce additional discomfort to the rider due to the sense of limiting his control of the vehicle. Through virtual prototyping techniques which involves a complex model of the motorcycle and the behaviour of the rider, a conceptual study is conducted in order to demonstrate that a proper sensor system together with an active control scheme could, in principle, help the rider to take appropriate actions to avoid the crash against an obstacle or reduce the energy of the impact. Moreover this method is used also to investigate realistic motorcycle manoeuvres especially when the accident is unavoidable leading to a pre-crash scenario that is suitable for a more viable crash and post-crash simulation. This work has been developed within the framework of the EC Marie Curie project MYMOSA which focuses on the research of the integration of active safety systems in motorcycles to reduce the fatalities and injuries on European roads.

## INTRODUCTION

Nowadays European roads are becoming busier and busier do to the increasing number of vehicles. This unfortunately leads to an increased number of accidents and fatalities that raised some concerns in the European Commission. Thus there is a strong commitment to increase the safety on European roads. According to recent report (13), in the last 10 years, more than 2 millions people died or was injured on our roads with an estimated cost for the community that can be assessed around 2% of the European GDP. It's also clear that pedestrians, cyclists and motorcycle riders are among the most exposed to injuries do to the lack of protection that is assured by the body of the car, bus or truck. Every year there are more than 4000 motorcycle fatalities and more than 250,000 injured riders. The European commission is sponsoring several projects in the field motorcycle safety, one example in the 6th Framework programme is the MYMOSA project (MRTN-CT-2006-035965) that aims to educate more than 15 young researchers in the field of motorcycle dynamics in order to provide effective tools to model the motorcycle and rider behaviour and design solution to improve safety (12). These objectives will be achieved through the cooperation between researchers working in different universities, research centres and companies in Europe in a multi-disciplinary project, spanning from accidents analysis to vehicle dynamics, biomechanics, safety equipment).

In this framework, the topic of the integration of advanced sensors in a motorcycle has been investigated and will be presented in this paper. In particular a conceptual implementation of a laser sensor will be illustrated. The laser sensor is a device that can scan the environment in front of the vehicle and detect objects in its beaming area. This information can be processed in order to give information to the rider or eventually can trigger an augmented safety control logic that can act on the vehicle itself to prevent a collision or to reduce the effect of an unavoidable impact. The model of the laser sensor has been "plugged" in different numerical models of a motorcycle to implement such control logic and explore possible usage scenarios. Some simulation results will be here presented and conclusion will be drawn in order to assess the feasibility of this study.

## MOTORCYCLE DYNAMICS

In the MYMOSA project there is a whole work package dedicated to motorcycle dynamics in which several models have been created starting from a simple kinematic model to a more complex multibody model including suspensions, tire models and a simplified rider. For the purpose of concept modelling and integration of a laser sensor in a motorcycle, it has been decided to start with the simple kinematic model and then apply the laser sensor tool to a more complex scenario.

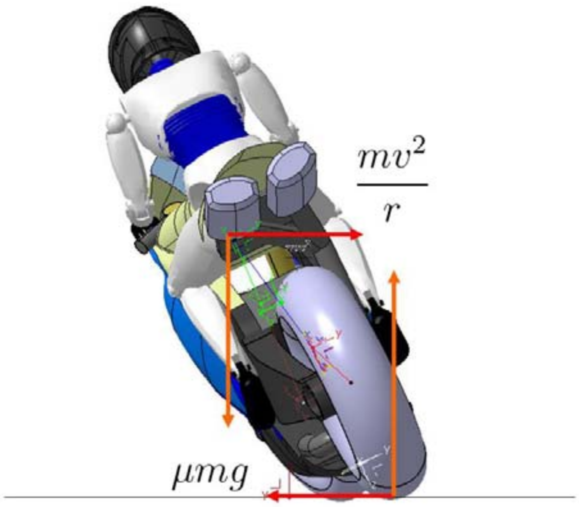

Figure 1. Lateral equilibrium of the motorcycle.

The kinematic model consists in a material point moving along a trajectory with a given initial speed and a maximum acceleration/deceleration that can be experienced in an average ride. The lateral equilibrium is enforced through the following equations whose symbols are indicated in figure 1.

$$\theta = \arctan\left(\frac{v^2}{gr}\right)$$

In the equation $v$ is the speed along the trajectory, while $r$ is the cornering radius and $g$ is the acceleration of gravity. From the equilibrium of forces, the side force is balanced by the friction generated between the road and the tire.

$$\frac{mv^2}{r} = \mu mg$$

Where $m$ is the motorcycle and rider mass and $\mu$ is the friction coefficient. Combining the two equations together it’s possible to derive a direct relationship between the radius and the speed, having as a fixed parameter the friction coefficient. This assumption is rather rough since in a real driving situation, the motorcycle can end up on dirty parts of the road reducing dramatically the factor $\mu$.

$$r_{\min} = \frac{v^2}{\mu g}$$

This can be taken into account in a sensitivity analysis or in a design of experiment optimization loop. For the simulation that have been carried out and that will be here described, this parameter has been kept constant.

In a more advanced simulation, a symbolic multibody model of the motorcycle has been developed as an S-function in Simulink. The model is composed of six rigid bodies: the front wheel, the lower part of the fork, the upper part of the fork (including the handlebars), the front frame (including the engine and the fuel tank), the swinging arm and the rear wheel (1-10).

This system has a total of eleven degrees of freedom that can be decomposed in the following way: six from the front frame (3 coordinates of the centre of mass together with the roll, pitch and yaw angles), one from the steering angle, two corresponding to the rotation of the wheels and another two from the suspensions.

The motorcycle is controlled by a virtual rider formulated according to the Model Predictive Control theory (11). The aim of this control algorithm is to make the motorcycle follow a predefined trajectory with a known speed profile by acting on the steering torque and the thrust/braking torques. The block scheme is depicted in figure 2.

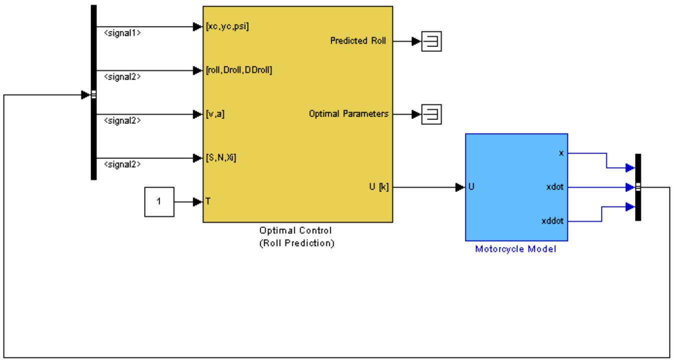

Figure 2. Schematic of the controller.

## LASER SENSOR

The laser sensor is a device that is mounted on the front part of the vehicle and has a laser able to scan the environment in front of it to detect objects. The commercially available devices are able to create a beam spanning up to 100 degrees field with a range up to 200

meters (an example is in figure 3). Some of them have also multiple beam planes in order to cope with uneven and non flat roads. In fact when a vehicle is riding on a flat road and suddenly hits a ditch, the laser beam will point directly to the ground giving a false reading, detecting an object that rapidly came closer.
This effect is common in all vehicles, while for motorcycles there is also an effect related to the lean angle. While cornering, the motorcycle leans towards the corner centre with an angle that can get up to 40 degrees or more. In this situation the outer part of the laser beam will detect again an incoming object. To solve this problem several solutions have been proposed. The most expensive one considers a tilting mechanism that allows the sensor to remain horizontal all the times, while a cheaper one includes a software procedure to take into account the motorcycle attitude and consequently the proximity of the road. In the work here described, this effect is neglected and the sensor has been considered always parallel to the road.

## NUMERICAL SIMULATIONS

All the simulations have been carried out in Matlab/Simulink. The simulation consists in a time domain simulation of the motorcycle trajectory in a virtual scenario (either a road or a flat plane with some obstacles) composed by entities that have been spatially discretized according to the laser sensor accuracy. It has been assumed that the sensor is scanning the horizon with 0.1 degrees angular spacing. This means that, using a range of 70 meters, the smallest detectable object at that distance has to be larger than 0.122 m. In figure () there is an example of these scenarios with some basic shapes as obstacles. A closer look to one of them reveals the discretization.

At each time step the algorithm evaluates whether or not there are some obstacles within the laser beam using the distance and angle in a local reference frame that has been fixed on the motorcycle and is oriented as the local tangent to the trajectory. Then the algorithm, based on the relative position between the motorcycle and the detected object, decides which direction it needs to steer the motorcycle in order to avoid it. Then a cornering manoeuvre is initiated at the minimum possible cornering radius according to the actual speed and friction coefficient

Starting with the simple motorcycle model, several virtual scenarios have been created. The first one consists in a bi-dimensional environment with several obstacles. The user can choose the initial position of the motorcycle, the initial trajectory (a straight line) and the initial velocity. Based on these data, the algorithm performs the time domain simulation and takes action when an obstacle is detected. When the obstacle is getting too close, it is also possible to apply a braking action to slow down the bike and make a sharper corner. When the obstacle has been safely avoided the motorcycle goes back to its initial velocity. It is also possible to assign a velocity to each object to increase the complexity of the scenario. The results here presented will include only the steady obstacles case do to the complexity of representation of the second case. However it has been demonstrated that the algorithm works fine in both cases.

In a second scenario, the user can draw a road (its middle line). The code will generate the left a right lanes and discretize them according to the sensor resolution. The user can choose again the initial position, velocity and direction and the algorithm evolves in time to stay within the prescribed limits. Also in this case an obstacle can be introduced along the track to simulate the presence of another vehicle on the road.

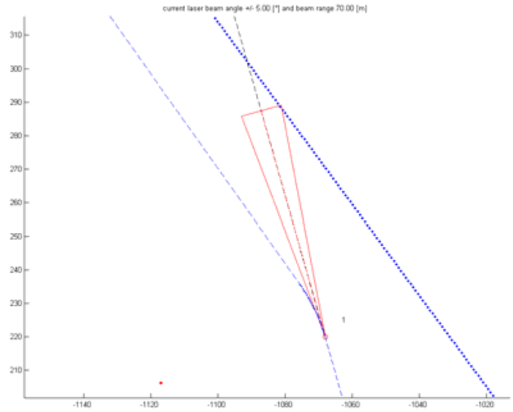

Figure 3. Representation of the laser sensor

## RESULTS

In the following figures, there will be shown the results of the simulation with the simple motorcycle model in the obstacle avoidance scenario. In figure 4, the scenario is composed by several obstacles. The user can select an initial straight trajectory and then the simulation starts. When the obstacle is detected the trajectory is modified to avoid it.

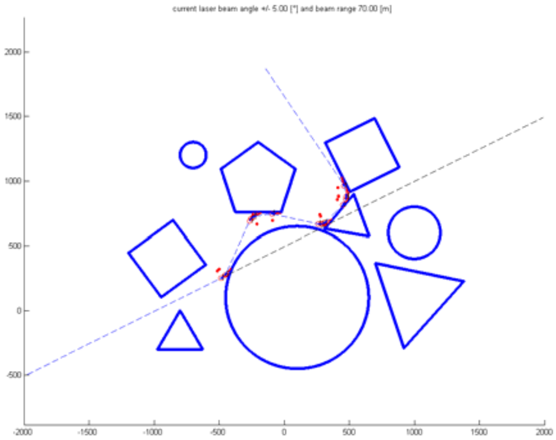

Figure 4. Trajectory modified by the algorithm to avoid the obstacles

In the second example a road follower is implemented. In figure 5 there is an example describing how the algorithm decides the trajectory to follow in order to stay within the two side-lines. The corner is pretty sharp for the initial speed than there is the need to slow down and turn with a smaller radius. In figure 5 the red dots indicate the centre of the current turn together with the speed.

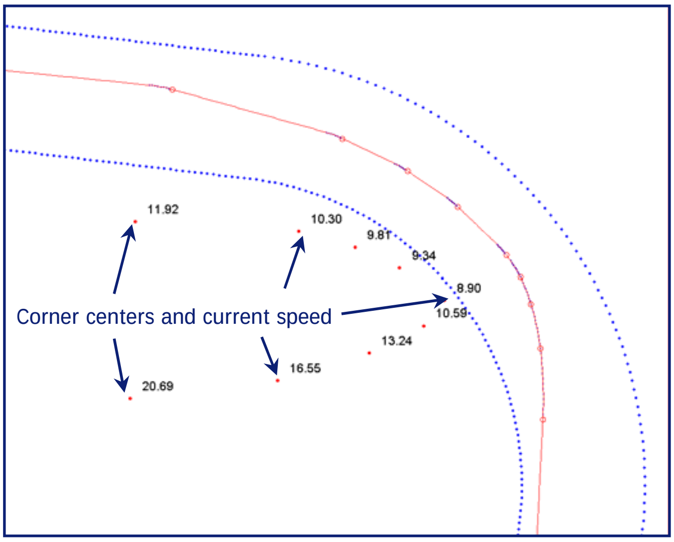

Figure 5. Example of the motorcycle entering the corner at 20 m/s, slowing down progressively to adapt to the sharp corner radius and then speed up again

In the last example the simple model of the motorcycle is replaced with the symbolic multibody model. The scenario is similar to the one proposed in figure 5 but with an extra obstacle. Also in this case the algorithm detects the object and changes the trajectory to avoid it and then to keep the motorcycle within the track

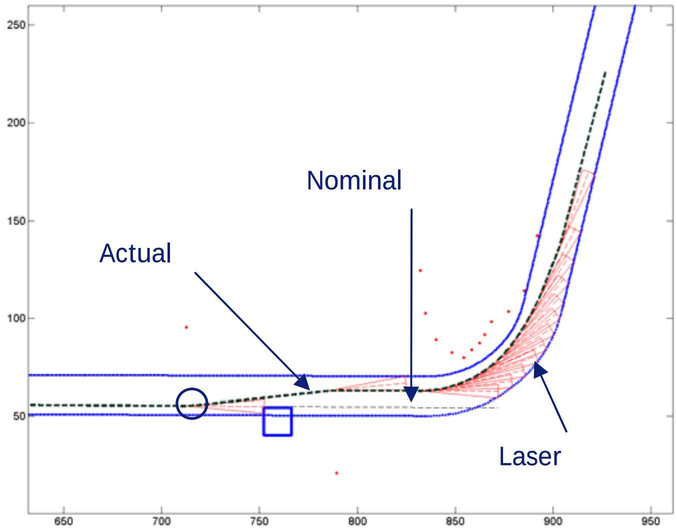

Figure 6. Example of obstacle avoidance and cornering with the multibody model of the motorcycle

In the next 2 figures are also shown the lean and steering angle needed to perform the manoeuvre and in particular the initial point of the trajectory modification is indicated in the three figures with a blue circle.

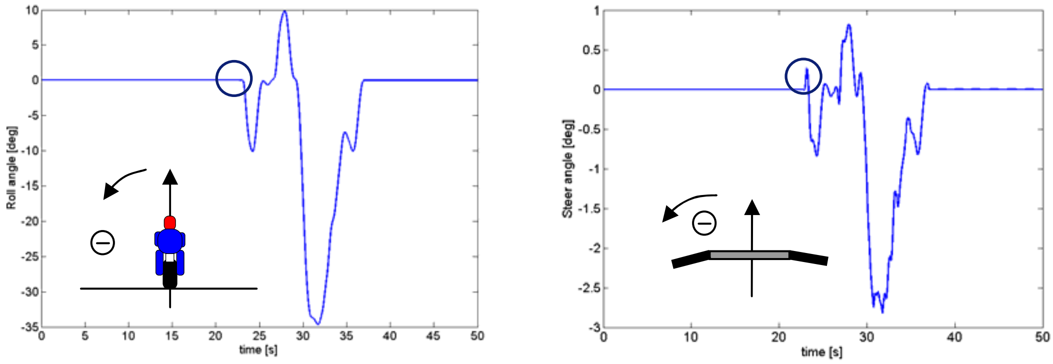

Figure 7. Lean angle and steering angle for the manoeuvre in figure 6

## CONCLUSIONS

In this paper has been demonstrated how to implement a laser sensor on a motorcycle in order to detect incoming obstacles. The detection can be used to warn the rider or to perform more effective actions in order to avoid the collision. It has to be noticed that in other types of vehicles such as car, busses and trucks, these kind of systems or similar, have already been implemented (for example the automatic braking system). The introduction of these safety devices is becoming acceptable to drivers nowadays. It is known that, when electronic systems have been introduced in vehicles, they were not too popular. In fact drivers where feeling that electronic systems were taking decision beyond their own wisdom. As the time passed, system such ABS, ESP and so on where accepted and the perception of drivers changed. Now they are viewed as aiding devices. This is not completely true in the motorcycle rider's community where also the ABS is considered to decrease their control over the vehicle. Then it is impossible to propose to them to use such an extremely active device such as the laser sensor with a collision avoidance system. Nevertheless these simulations show that it is possible to avoid a crash or reduce its consequences when some actions are taken. The examination of crash reports show that in most cases the rider does not take any action to avoid the collision. Thus, such tool, can be used to educate the riders and show them which is the most appropriate manoeuvre to avoid the obstacle. On the other hand the laser sensor, together with appropriate control logics can warn the rider sufficiently ahead.

## ACKNOWLEDGMENTS

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