6
Conclusions

A fully non-linear and three-dimensional road vehicle model was derived employing a multibody approach and the Jourdain's principle. In addition, the kinematics of a double wishbone suspension system was also derived. For the tire-road interaction, the TMeasy tire model was employed. Then, using the road vehicle model, that includes all the subsystem mentioned before, a vehicle simulation package was implemented employing Python as a main programming language, this package was named in the scope of this thesis as PyCar. Numerical and well supported libraries were employed within the PyCar framework. This package also includes a visualization tool in order to analyze the motion of the global model. Lastly, the lateral dynamics of this multibody vehicle model was validated using a scaled car and PyCar, as presented in Section 3.

Common active safety system were designed and tested in order to prove their efficiency in critical driving scenarios. The Anti-lock braking system or ABS, was designed using a simple ON-OFF control strategy. This model also includes the hydraulic dynamics. Considering this hydraulic model, more realistic and practical results were obtained. It can be concluded that, the nature of the ABS system requires inherent dynamics that arise from its hydraulics components.

The Electronic stability program or ESP, improves the vehicle stability in critical scenarios as demonstrated in Section 4. The ESP model proposed in this thesis, uses the simple handling model, Section 2, as reference or desired vehicle behavior. By employing this system model, the yaw error between this linear model and the actual one is computed and used by the ESP in order to estimate the vehicle tendency and therefore, brake a selected wheel in order to restore the vehicle stability if necessary.

The Four-wheel steering system or 4WS, was designed in this thesis using a simple feedforward control strategy. The front steering wheel angle commands the rear wheel steering angle. In addition, a limit value for the rear steering angles is defined in order to avoid unexpected or unstable vehicle behavior. An avoidance maneuver proved the improvement of the vehicle lateral stability in a vehicle equipped with the 4WS model proposed in this thesis.

Using the extended simple handling model, Section 5, a rule to integrate the ESP and 4WS was defined. This rule uses the sideslip angle as input and dependent of its value activates or not the ESP. Only if large values of sideslip angle are detected a brake intervention is triggered, i.e. the ESP braking activations, in order to stabilize the vehicle. By employing the same critical maneuver of Section 4, the IC-ON demonstrated an improvement of the vehicle stability against the non-integrated approach or IC-OFF as can be seen in Section 5.

Finally, this thesis focuses on improving the stability of road vehicles embedded with common active safety systems, i.e. ABS, ESP and 4WS. The approach considered to accomplish this major objective is, to integrate the active systems and coordinate them in order to develop an integrated system. In the development of this project, different simulation environments were employed to support the design process regarding the integrated system's performance. A reliable road vehicle model was also an important part of this project and therefore, a consistent analysis of the main components of the road vehicle was performed in order to build a three-dimensional and fully non-linear vehicle model and then implement it in a package denominated here as PyCar. Moreover, this model was developed considering several assumptions and simplifications, and consequently, specialized studies such as crash simulation, vehicle's aerodynamics shapes or tires wear are not possible. This thesis describes the design and testing process of a robust integrated control system in a general manner with no intentions of developing or contributing in areas such energy consumption, noise, vibration and harshness (NVH) problems or improving comfort characteristics. Furthermore, due to the special importance of the tire-road interaction modeling, it is important to mention that the road vehicle model established in this thesis uses a well defined and commercial tire model called TMeasy [33].

6.1
Further work

The capabilities of PyCar can be extended in order to simulate, for instance, the truck dynamics. This would be particularly useful because the huge investments made in this type of vehicles in order to improve its stability in demanding driving situations. This extension of PyCar can involve, for instance, to find a Differential Algebraic Equations or DAEs solver for it because the constraint incorporated by the semitrailer needs to be considered.

More advanced control strategies can be considered for the design of the

ESP and 4WS. But only low-cost sensors need to be employed for the design of this safety systems. This is due to the cost restrictions in commercial vehicles. Furthermore, additional safety systems can be incorporated in the integrated structure presented in this thesis. For instance, the Active front steering system (AFS) [71] seems to be a good candidate to be integrated with commercial safety systems, like those presented in this thesis. This will be particularly a challenge due to the potential conflicts of the AFS with the ESP and the 4WS.