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Electrical Drives in Intelligent Vehicles: Basis for Active Driver Assistance Systems

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Abstract— **Drive-by-wire systems have been establishing the technological basis that is opening opportunities for the development of new driver assistance and safety systems, making it possible even for a computer to drive or park a car. Electrical drives represent the heart of such systems and are also becoming a trend in relation to distributed electrical traction systems in hybrid and electrical vehicles. This work presents an overview of electrical drives in intelligent vehicles. The article brings also a discussion about the reliability, production and maintenance costs of different types of electrical drives that can be used in such automotive applications.**

I. INTRODUCTION

The drive-by-wire technology leads to a new era, where many mechanical solutions will be substituted by electronic ones [1]. The possibility of driving a car just using electronic signals allows the use of a computer as co-pilot, helping the driver in dangerous situations. However, Active Driver Assistant Systems can only be effective when they are able to perform an intervention in the vehicle's behavior.

On the other hand, global primary energy resources are limited, and conventional fuels, like gasoline or diesel, are becoming each year more expensive. Even with the development of new fuel injection systems, like the flex-fuel technology implemented recently in Brazil, which allows the mixture of gasoline and alcohol in any percentage and contributes to reduce atmosphere pollution, air quality is still a problem in all metropolis and most cities in developing countries. Hydrogen based technologies seem to be an interesting alternative to fossil energy sources. Remarkable progress has been achieved in recent years with fuel cells, in which electrical energy is generated with efficiencies beyond 50%, producing neither CO_2 nor other toxic emissions [2]. Hybrid Electric Vehicles represent a transition to that stage, but this technology offers a great range of possibilities concerning electrical drives applications.

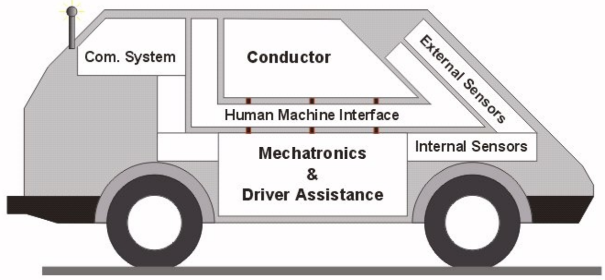

Figure 1. Intelligent Vehicle Platform

Therefore, electrical drives play a significant role in future cars, representing the basis for the development of new environmental friendly intelligent vehicles.

II. INTELLIGENT VEHICLES

The structure of a drive-by-wire intelligent vehicle is presented in Figure 1. It consists of a Mechatronics & Driver Assistance Unit that receives data from internal and external sensors, interacts with the conductor through a human-machine-interface (H.M.I.) and can also exchange information with the road and other vehicles by using inter-vehicle and vehicle-road communication systems.

The Mechatronics & Driver Assistance Unit can be divided in different layers, as presented in Figure 2. The first layers, situated in the base, are related to mechatronics applications, while upper control layers are responsible for driver assistance. The set points are firstly generated in the upper level and then are sent to the base level.

The lowest-level layer is responsible for traction, acceleration, brakes and steering control. In fact, electrical drives make here the interface between information and movement control and a failure can lead to a catastrophic consequence. Independent of the technological solution, the main concept here relies on electrical drives with torque, velocity or position control.

The second layer responds for the control of the vehicle dynamics, like ABS (anti blocking system), ABC (active body control), ACC (adaptive cruise control), ESP (electronic stability program) and TCS (traction control system)

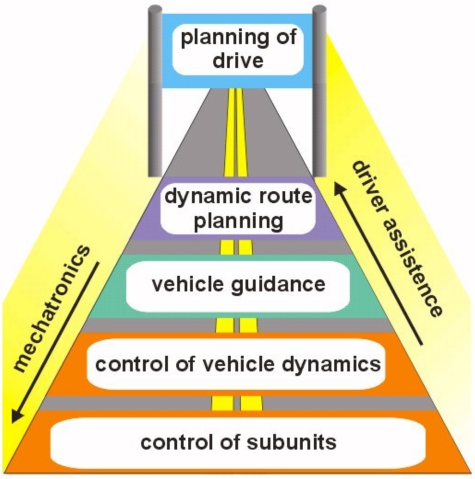

Figure 2. Control Layers

A human driver or a computer system can perform the third layer, which represents the vehicle guidance. Autonomous vehicles, guided by computers, can be used as AGVs (autonomous guided vehicles) in factories for material transport, or as part of a convoy in highways.

The last layers are responsible for both journey and dynamic route planning. They set a reference corridor that can be dynamically adapted to avoid obstacles.

III. DISTRIBUTED TRACTION SYSTEM

Fuel Cell Vehicles will probably be the major vehicles by the end of this century. This trend begins with Hybrid Electric Vehicles, which are already available on the market. Nevertheless, the main point is the fact that the vehicle will have an electric traction system.

The main advantage of Electric Vehicles resides in the fast and precise torque generation of the electric motor [3][4]. This quick and accurate torque generation provides a good basis for the development of 4WD Electrical Vehicles with independent and optimal traction control for each wheel.

Considering first a rear wheel drive vehicle, the use of two electric motors, one for each wheel, allows also the elimination of the differential gearing, which represents a disturbance for the traction controller in conventional vehicles. This solution also eliminates the mechanical transmission, gearshift and gearbox [5]. Features like ABS and TCS can be also easily implemented without any extra mechanical structure or hydraulic circuit. Necessary data to detect the vehicles behavior in relation to different road conditions are the distances between axles l and between wheels on the same axle b, the steering angle, the curve ratio R and the wheel speeds v_1, v_2, v_3 and v_4 [6] as illustrated in Figure 3. Slip detection occurs by calculating the normalized speed difference on each side of the vehicle, as shown in (1). If the detected slip ($\lambda_{3,1}$ or $\lambda_{4,2}$) reaches a predefined condition the control system adjusts the torque provided by each drive [5].

$$\lambda_{3,1} = \frac{v_3 - v_1}{v_3}\ , \quad \lambda_{4,2} = \frac{v_4 - v_2}{v_4} \qquad (1)$$

For 4WD Electric Vehicles, however, the detection of road conditions, e.g. slip detection, is much more complex then just measuring the wheel speeds. For such vehicles the road conditions must be estimated and different approaches have been presented lately [3][4][7][8][9]. Optimal Slip Ratio Control and Advanced Adhesion Control [3] can than assure a robust EV motion control.

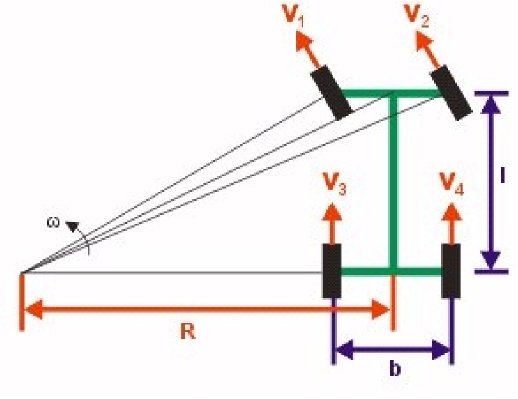

Figure 3. Distributed Electrical Traction System

Figure 4. Automated Mini-Baja

IV. DRIVE-BY-WIRE VEHICLE

In a previous work [13][14] our research group presented a Mini-Baja prototype that was automated and converted into a drive-by-wire vehicle, as shown in Figure 4. At that stage the drive-by-wire structure implemented in the vehicle was based on an ALTUS PLC network, with industrial PLCs interconnected to each other with an ALNET1-Bus. Each PLC is responsible for a sub-system as in a distributed control structure. The steering, traction and braking systems were analyzed separately and for each of them a specific controller was developed [10][11][12].

A. *Accelerator and Brakes Controller*

To substitute the vehicle pedals two electrical drives were implemented. To accelerate the vehicle a small DC motor pulls the carburetor fuel valve and a flexible wire replaces the accelerator cable. The carburetor opening is adjusted by controlling the rotor angular position. In a conventional vehicle, however, it is possible to send electronic information directly to the fuel injection electronics.

The brakes are activated by another DC motor mounted in a gearbox-lever structure. To obtain the necessary force to pull up the brake levers a gearbox originally used in an electric drill was integrated to the mechanical structure. By controlling the motor current it is possible to control indirectly the mechanical torque applied by the motor. So, it is possible to simulate the force that the driver would be implementing on the brake pedal [11][12].

B. *Steering Angle Controller*

To automate the steering wheel movements, a DC motor was used as a drive. The mechanical linkage was arranged using two chain sprockets wrapped by a chain. To control the steering wheel angular position, a cascaded position-speed-current control loop was implemented.

In conventional vehicles the adaptation is much simpler if the vehicle is provided with an EPS (electric power steering) mechanism. In that case only a software modification is necessary.

C. *Human-Machine-Interface*

The possibility of driving a vehicle with electronic commands leads also to the development of new human machine interfaces, like a joystick, as shown in Figure 5, or even a cell-phone as for remote control [13][14].

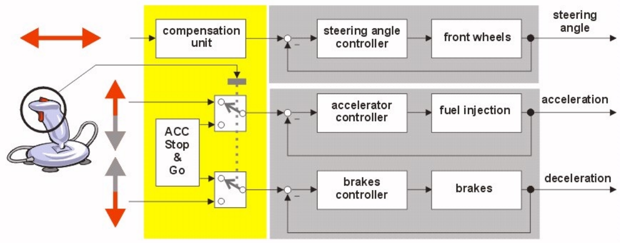

Figure 5. Joystick as H.M.I.

Nowadays there is no common consent about a revolutionary and ergonomic H.M.I. that could substitute in the future the steering wheel or a similar solution. However, for some physically handicapped people, a specific electronic interface could be developed and they would be able to drive any standard drive-by-wire vehicle. No special car would be needed, just a special human machine interface.

By using a joystick as H.M.I. and sending the reference values directly to the steering angle, accelerator and brakes control loops the vehicle can become unstable at higher speed [13]. To assist the driver and to keep the vehicle lateral stability, an Active Steering Compensation Unit and an Adaptive Cruise Control system are necessary between the joystick and the sub-units controllers [13], as presented in Figure 5.

The ACC system was separated in two branches, one for accelerating and the other for braking the car, as shown in Figure 6. Each branch presents some particularities, which were integrated in the vehicle's mathematical model.

The speed controller has to accelerate, decelerate and brake the vehicle, switching between both accelerating and braking branches. Due to the fact that one branch must not interfere in the other, a particular algorithm is needed to operate the switch.

The use of an electrical drive for vehicle traction would drastically simplify such an ACC unit. Electrical drives can be used to accelerate and decelerate a vehicle and only one cascaded speed-current control loop would be necessary.

If it is possible to drive the car using just electronic signals, another interesting H.M.I. can be, for example, a common cell-phone, as illustrated in Figure 7 and presented in [14]. In a rainy day the driver could phone the car and bring it back by just sending commands remotely through the cell-phone keypad.

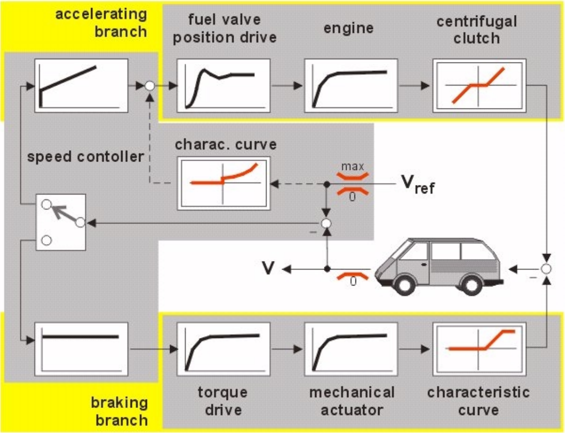

Figure 6. Adaptive Cruise Control with Stop & Go feature

Figure 7. Cell-Phone as H.M.I.

V. DRIVER ASSISTANCE SYSTEMS

As presented in Figure 2, Driver Assistance Systems are placed in the higher levels of the control layers. They are responsible for generating the references for the electrical drives placed in the base of the structure. Those applications are based on applied computing, in particular on artificial intelligence. Some applications are described bellow.

A. *Automated Parallel Parking Maneuver*

One possible application is related to parallel parking maneuvers. Different approaches and solutions have been investigated: from the simple installation of a camera in the rear end of the vehicle to fully automated systems [15][16].

After installing a rear end camera and showing its image on display placed on the instrument panel, the driver can be assisted by guiding lines projected on the image. No automation procedure is needed in this case and the driver is fully responsible for the conduction of the vehicle.

A semi-automated system uses distance sensors around the car to identify the parking space and drives the vehicle into it by turning automatically the steering wheel. The driver just needs to push the gas and brakes pedals. In fully automated systems no driver intervention is necessary.

To simulate such a system a three-dimensional virtual environment, shown in Figure 8, was created [16]. With this simulator it is possible to determine the best sensors configuration and to test different parking algorithms based on artificial intelligence.

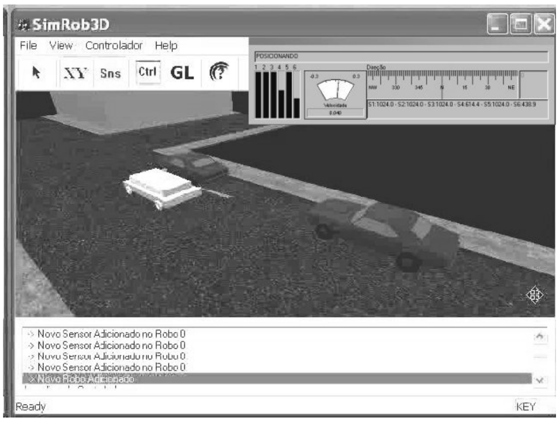

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Figure 8. Autonomous Parking Simulator

Figure 9. Lane Detection / Following

B. *Lane Departure Warning / Lane Keeping Assistance*

Researchers in the areas of computer vision and intelligent vehicles have been devoting great efforts to develop machine vision systems. Cameras installed inside a vehicle can be used for constant monitoring of the road, detecting in advance tendencies of lane departure or collision with other vehicles.

Many methods for road segmentation and lane detection / following have been proposed in the past years. Our research group developed a robust linear-parabolic method, presented in [17] and shown in Figure 9.

Based on the detected lane borders it is possible to predict involuntary lane departure [18]. To warn the driver the EPS system can, for example, generate a high frequency pulsating torque on the steering wheel.

Lane Keeping Assistance systems are based on the same principle. To relieve the conductor's effort, when he is driving in a highway, the system is responsible for generating 80% of the assistant torque necessary to turn the steering wheel and maintaining the vehicle in the road center [19].

VI. AUTONOMOUS DRIVING

A fully automated vehicle in a partially controlled environment can be easily conducted by a computer [20][21][22]. In highways, for example, similar to Lane Keeping Assistance systems, the vehicle lateral guidance can be based on the lane borders previously identified by a computer vision system [21].

Due to the non-linear behavior of the vehicle / road model, shown in Figure 10, different controller structures have been investigated in the last years [20][22]. The inputs of the complete system are χ, the road curvature and v, the vehicle speed, which act as a non-linear disturb. The output is represented by α, the lateral deviation to the road center and κ represents the course angle deviation.

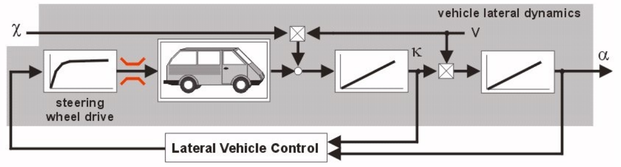

Figure 10. Lateral Vehicle Guidance

Figure 11. Identification of Colored Marks on the Front Car

Another possibility is to integrate autonomous vehicles in a convoy. A human driver drives the first vehicle, while all others are "electronically connected" and composing the convoy.

Computer vision can also be used here to identify the distance and the lateral displacement to the front vehicle [23]. By placing colored marks on the rear end of the front vehicle a color segmentation algorithm can easily identify them, as shown in Figure 11. By knowing the pattern formed by the marks the necessary distance and displacement data can be obtained. After filtering the resultant signals they are transferred to the lateral and displacement controllers.

The distance controller, illustrated in Figure 12, is placed in a cascaded structure with the ACC system and generates its reference. The performance of the distance controller depends on the convoy speed and the available data.

By knowing just the distance to the next car the controller shows a reasonable performance and the convoy is limited to few vehicles. To increase the number of vehicles in the convoy, i.e. to increase the distance controller performance, a greater number of data is necessary, like the acceleration and the speed of each car in the convoy. In that case an inter-vehicle communication system is inevitable and its configuration and implementation need to be investigated first.

VII. CHOOSING THE BEST ELECTRICAL DRIVE

Manufactures are always concerned to offer their clients what they so call "the best solution". Many aspects as quality, robustness, reliability, simplicity and production costs are considered when choosing an electrical drive. Nevertheless, other boundary conditions also have to be taken into account and they can vary drastically from one region to other. Hence, the "best" solution in Europe not necessarily represents the optimum choice for Latin America.

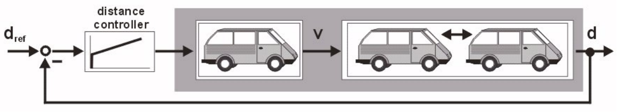

Figure 12. Distance Controller

An example can be found in EPS systems. Two possibilities are available nowadays on the market: one uses an electrical drive with a permanent magnet synchronous machine while the other uses a conventional DC motor. Which represents the "best" choice ?

Electrical drives are the basis of future intelligent drive-by-wire vehicles and three different solutions with similar performance can be used: DC motor, induction motor and PM synchronous motor. To control the sub-units of a vehicle, as presented in Figure 2, either torque, speed or position control is needed.

Direct current motors have been dominating the field of adjustable speed drives for over a century and are the most common choice if a controlled electrical drive has to operate over a wide speed range [24]. They have excellent operational properties and control characteristics and the only disadvantage is the mechanical commutator. On the other hand the electronic device is also extremely simple and the control can be done using a microcontroller or even with operational amplifiers.

Induction motors are the most widely used electrical drive motors with the advantage of the elimination of all sliding contacts, resulting en an exceedingly simple and rugged construction [24]. The use of static converters and field oriented vector control makes the induction machine the most promising adjustable speed drive for many applications. The elimination of the mechanical commutator resulted in higher power density per volume or mass, when compared to the DC motor. On the other hand the electronic device requires a digital signal processor with much more processing power and much more software programming.

Permanently excited synchronous motors are an attractive solution for servo drives in the kW-range [24]. Synchronous motors with rare earth magnets have higher power density then induction motors, due to the fact that there is no need for rotor currents producing torque. On the other hand, they are also more expensive. They also have a much larger impulse torque than a DC motor and have become the preferred solution for positioning drives on machine tools and robots [24]. In terms of complexity of the electronic device its complexity stays between the other two presented drives.

To achieve the "best" choice, however, other factors have to be taken into account. One of them is related to maintenance costs. It is commonly said that DC motors have high maintenance costs due to its brushes that need to be changed constantly. In many industrial applications, however, "constantly" means once a year and the service takes just a few minutes. Much more time is required when the bearings need to be changed. In those cases there is no difference between the service time either for a DC or an induction motor. Nevertheless, changing the bearings of a PM synchronous machine requires special procedures and knowledge. If an unadvised person tries inadvertently to disassemble the machine the risk of damaging it or demagnetizing the magnets is extremely high. For any maintenance procedure the machine is normally sent to the manufacture's representant and some days are necessary before having the drive back online.

The drive's reliability must also be considered. More important than the average time the drive stays online before presenting any problem is the time the system stays offline waiting for part reposition. Are the components available on the local market ? Must a new electronic device be imported ? Most elder DC motor drives, for example, use tyristor based converters and analog electronic components. In most cases they can be repaired in few days. Induction motor and PM synchronous motor drives are more complex. IGBTs can be easily replaced, but sometimes all the electronic processing unit must be changed. Depending on the needed part and where on the world it is needed the reposition can take up to several months.

VIII. CONCLUSIONS

Electrical drives represent the core of the drive-by-wire technology. Automated vehicles using such technology are the basis for the development of active driver assistance systems based on applied computing.

Electrical Vehicles with a distributed traction system, where each wheel is connected to an independent electrical motor, can offer increased vehicle dynamics. Due to the rapidly torque generation by an electrical motor the driver can be assisted by high efficient ABS and TCS features. ACC Stop&Go feature is also possible and does not require any other mechanical components.

If a car can be guided by electrical signals, different and innovative human-machine-interfaces can be created, especially for handicapped persons.

If an electrical drive controls the steering wheel angular position, then Lane Keeping Assistance and Autonomous Convoy Driving features can be implemented.

However, a special attention is needed when choosing the electrical drive for such applications. The newest and more modern technology is not necessarily the best choice. The bounding conditions of the problem must be well specified and need to consider the local reality.

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