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Entering an Automated Platoon

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Automated convoy driving is seen as a necessary ingredient of future intelligent transport systems. It means that individual vehicles will be controlled to move at small distances at acceptable speeds without significant loss in transport time and with guaranteed safety. It also means that intelligent vehicles have to move in and out of this platoon in a safe and efficient way. The merging (future) vehicle is assumed to be equipped with chassis control and monitoring devices to support the driver in his task of controlling the car.

The paper reports about the project DAVINCI (Design of an Automated Vehicle INtegrated Control Instrument), aimed at the derivation of tools and methodologies for the analysis of automated vehicles within a future intelligent transportation network. One of the objectives of DAVINCI is to find and analyse integrated control strategies for the merging manoeuvre. The merging vehicle is assumed to be fully automatic and equipped with local monitoring and (steering and braking) control devices. For that purpose, simulation studies and tests have been carried out for a realistic 1:5 scaled test vehicle within a laboratory. As a first step, tests have been carried for automatic lateral control for an arbitrary but predefined path and compared with simulation studies. Vehicle behaviour is captured using both vehicle-based sensors and laboratory based optical sensors in terms of position, vehicle orientation, velocities, yaw rate etc. The results are discussed and it is shown, that the results of measurements and simulations can be interpreted well in terms of most standard vehicles with a high degree of accuracy.

Keywords / Intelligent Transport Systems, Automated Highway System

1. INTRODUCTION

The paper reports about the project DAVINCI (Design of an Automated Vehicle INtegrated Control Instrument), aimed at the derivation of tools and methodologies for the analysis of automated vehicles within a future intelligent transportation network. One of the objectives of DAVINCI is to find and analyse integrated control strategies for the merging manoeuvre as mentioned above. The merging vehicle is assumed to be fully automatic and equipped with local monitoring and (steering and braking) control devices. For that purpose, simulation studies and tests have been carried out for a realistic 1:5 scaled test vehicle DAVICAR, specially designed for the project) within a laboratory, with DAVICAR merging into a platoon of scaled vehicles. As a first step, tests have been carried for automatic lateral control for an arbitrary but predefined path and compared with simulation studies. Vehicle behaviour is captured using both vehicle-based sensors and laboratory based optical sensors in terms of position, vehicle orientation, velocities, yaw rate etc. The results are discussed and it is shown, that the results of measurements and simulations can be interpreted well in terms of most standard vehicles with a high degree of accuracy.

2. MOTIVATION & OBJECTIVES

The research project entitled DAVINCI deals with the design of automated vehicles. The aim was to develop a control environment with reference to platoon performance and with focus on the in-vehicle and convoy management. The result of the project will be a generic tool for the design of such an environment.

Project is developing, for demonstration and validation, a scale-model research facility for evaluating technologies and techniques for advanced vehicular control systems.

The project initially employs a 1:5 scale model car and on-board sensors to demonstrate real-time longitudinal and lateral vehicle control. Davinci provides an effective way to obtain and replicate realism at reasonable cost and without excessive preparation time from the simulation phase to full-scale tests.

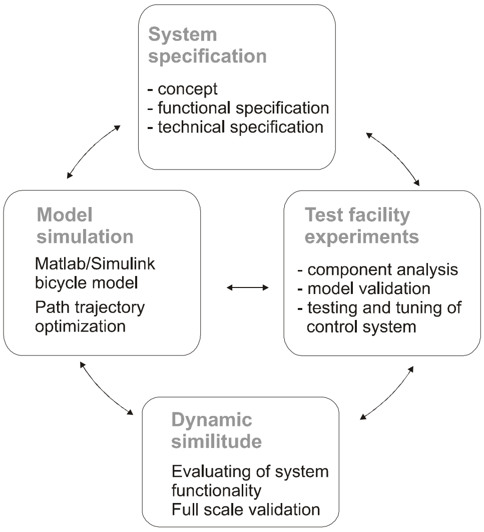


Fig. 1 Activity clusters

Experiments will be conducted that a scale model car using data provided by an advanced LPS (Local positioning system) technique for lateral and longitudinal control can follow the desired path.

The model car determine its own position and orientation being calibrated by camera data, which are used to update manoeuvre necessary to follow the desired path at the desired velocity. The technique can be applied to a platoon of multiple following vehicles by each vehicle broadcasting the necessary data, and each following vehicle comparing its own data to that of the vehicles in front of it, obtained through the camera system.

Monitoring of position and orientation of the DAVICAR and communication between the infrastructure and the vehicle makes it possible to determine lateral speed, longitudinal speed and yaw rate (with sufficient accuracy) during a manoeuvre. This must happen on the basis of realistic vehicle behaviour. This means that the update-rate (data exchange updates) between the vehicles and the infrastructure must be sufficiently high to ensure sufficient accuracy.

The test facility is based on optical detection of retro-reflective markers. Therefore, a number of markers are attached to the top of the model car. The car is remotely tracked towards the area illuminated by a local positioning system (LPS) [1]. Within this area the car performs a lane change (double-lane change) manoeuvre, precisely controlled via a sensitive digital camera hanging above the testing area. From the coordinates captured by the camera we can create a high accuracy path description map and provide feedback and adjustments needed for the steering commands.

3. APPROACH

First a state of the art study was carried out and a first design for vehicle control and layout was prepared. Then studies involving lateral control, stability, and sensors placement for intelligent control and determining of position were examined at this stage of the project. As a third step, mathematical models were developed accounting all sub models including driver controller and tyres. From these models, based on the bicycle model and describing vehicle dynamics, differential equations of motion and the analytical expressions for the kinematics and dynamics have been derived. The analyses have been determined for each sub model. These models were prepared within a Simulink environment.

Based on the above-mentioned analysis a scaling factor 1:5 was selected for implementation and an experimental car was built.

A Local Positioning System based on optical detection of markers was used to calculate position and other values necessary for tracking along the wished path.

First tests have been carried out to show the feasibility of the test environment for automatic lateral control for an arbitrary but predefined path and compared with simulation results. Values and parameters (like mass, moment of inertia and centre of gravity) of the experimental car were experimentally assessed.

4. TEST ENVIRONMENT

In this chapter, the first part describes the principle of the test facility and additional hardware components used within the project.

Description of test facility

The test facility consists of two main parts: a real time high-resolution camera and of a scaled model car – Davicar. Monitoring of position and orientation of the test car as well as communication between infrastructure and vehicles makes it possible to determine lateral speed, longitudinal speed and yaw rate during a manoeuvre.

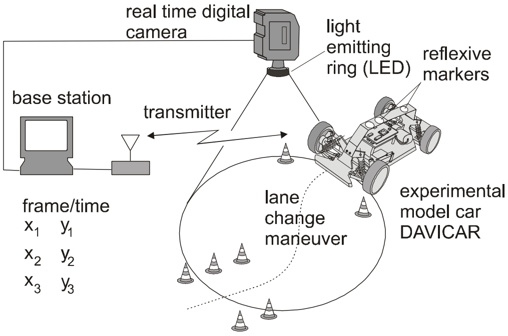


Fig. 2 Schematic depiction of test facility

The 15 Hz Adimex MX12P camera with high-resolution 1024 x 1024 pixels is used. The camera is equipped with 100 powerful narrow-beam green LED's, synchronized to the electronic shutter to maximize efficiency.

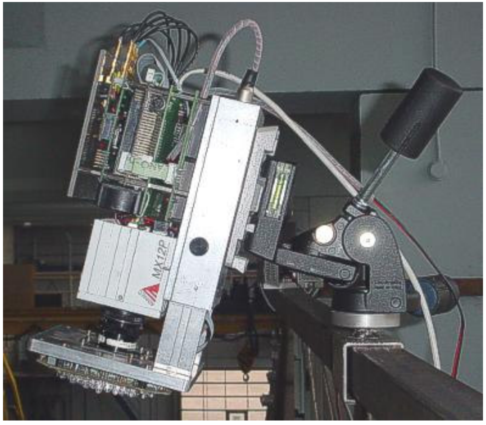


Fig. 3 Test facility high-resolution camera

Description of model car

The model car design that satisfies our requirements is an actively controlled, remotely tracked, scaled prototype vehicle, which serves as an experimental platform for systems and control engineering research in the DAVINCI project. The car is shown in Fig. 4. And consists of chassis equipped with combustion engine and two servos. One for steering of the vehicle and the function of second servo is doubled for throttle and braking.

Fig. 4 Experimental testing car DAVICAR

PC/104 and sensors

The whole system is controlled by an on-board advanced system for real-time control PC/104. This PC104-based has 16 megabytes of internal memory, 16 megabytes of flash disk-storage and an onboard VGA-chip. Staked onto PC104 ISA-bus is a PCMCIA – adapter board to provide the PCMCIA-slot for the wireless network card. Connect the wireless network the car should be able to operate within 100m-circle area, while continuously being connected to the network to communicate with supervisor. One more additional card provides a signal processing for servos. Car is equipped with sensors sensing speed of vehicle and heading of the vehicle with respect to the earth pole – a magneto resistive sensor [1].

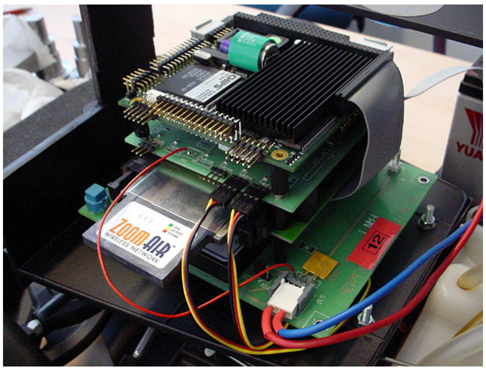


Fig. 5 Detailed depiction of PC/104 unit

5. TIRE TESTING

The tyre is the least understood component of a car. A good match between tyre and car is generally determined subjectively. Testing of tyres is mainly based on driver assessing handling. An alternative approach is to model a tyre and imitating manoeuvres in simulation. For modelling we were used two tire models: a linear tyre model and the Magic Formula tyre model. Final testing of the tires, focussing on estimation of the tire cornering stiffness, was carried out on the test stand shown in Fig. 4. This testing derived values of cornering stiffness necessary for further calculation. Lateral wheel forces, produced by the scaled vehicle tire holding the slip angle constant, were measured [2].

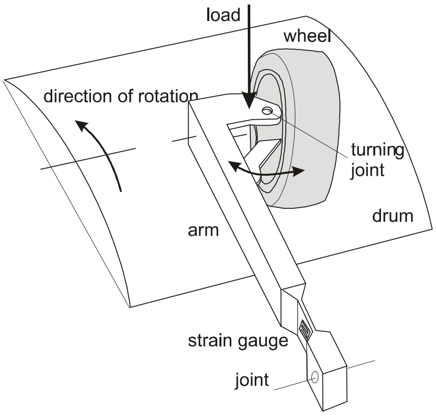


Fig. 6 Experimental testing rag for tire cornering measurement

Table 1 Measured Davicar parameters

Body mass	m	8.8	[kg]
Moment Inertia	I_Z	0.3	[kg.m^2]
Cornering stiffness	C_{a1},C_{a2}	1.6	[N/deg]
Length	L_1	0.262	[m]
Length	L_2	0.200	[m]

6. THEORY, SIMULATION AND EXPERIMENTAL RESULTS

Vehicle model

The vehicle model, which is used in the controller, is the well-known bicycle model. This model was taken as an initial estimate for the dynamics of the scaled DAVINCI car. The equations of motion of the model have been derived according to [6].

The vehicle body is assumed to be rigid. It is described by the mass m, the location of the centre of gravity and of the moment of inertia I_Z around the centre of gravity.

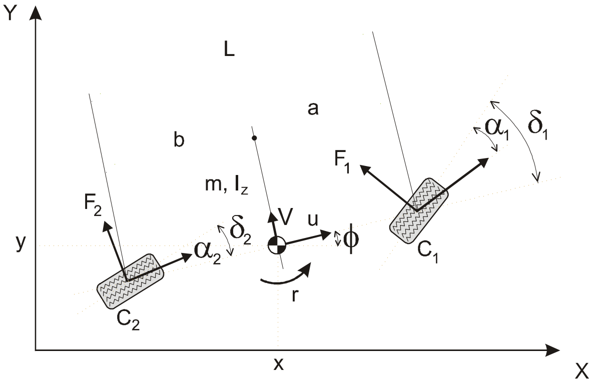


Fig. 7 Bicycle model

$$m(\dot{v}+Vr)+\frac{C}{V}v+\frac{C_S}{V}r=C_1\delta_1+C_2\delta_2$$

$$I_Z\dot{r}+\frac{C_{q^2}}{V}r+\frac{C_S}{V}v=C_1a\delta_1+C_2b\delta_2$$

$$C=C_1+C_2$$
$$Cs=C_1a+C_2b$$
$$Cq^2=C_1a^2+C_2b^2$$

In the prevailing front wheel steering system only the front wheels predetermine lateral motion and are actively involved in controlling the vehicle. To master this control task the bicycle model of the car was studied in detail. As an environment for modelling Matlab/Simulink program was used and several models were developed. These models were equipped with either linear or non-linear tyre characteristics.

Two elementary bicycle two-degree of freedom models were used for the definition of the specification of the steering strategy (with reference to a final merging strategy). The state-space model has linear tyre characteristics. This model is valid for small slip angles and lateral accelerations. The inputs of the bicycle model are the steering angle δ and the longitudinal velocity U.

The outputs are the followed path (x,y), the yaw angle Φ, the states longitudinal velocity U, lateral velocity V, yaw rate r and the lateral acceleration $\ddot{y}$.

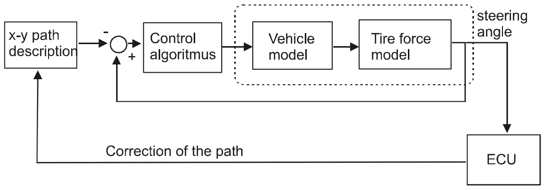


Fig. 8 Controller

Lane change manoeuvre with path planning

The wished path that the vehicle has to follow can be written by a function. For a single lane change it is possible to set for example 5 points between the lanes, which the vehicle has to pass. The path between these 5 points can be interpolated by Matlab® with the command "interp1". It is also possible to define the wished path by a continuous function.

A single lane change manoeuvre can be described by the following function for example:

$$y(x)=\frac{W}{L}\cdot\left[x-\left(\frac{L}{2\pi}\right)\cdot\sin\left(\frac{2\pi x}{L}\right)\right]\rightarrow for 0\le x\le L$$

with W is the lateral distance from lane to lane and L is the horizontal distance in which the lane change occurs.

The ISO/TR3888 double lane change is defined by 2 single lane changes and is shown in the following figure. The path width between the cones is 1.2 · (vehicle width) + 0.25 [m].

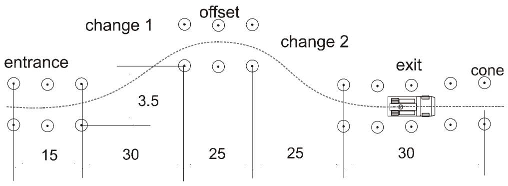


Fig. 9 The ISO/TR3888 double lane change definition

Virtual lever controller

A lateral controller can follow the predescribed path. The steering input δ is continuously controlled by a closed loop system observing the difference between the actual and wished position of the vehicle. This difference 'ε' can be calculated at the centre of gravity of the vehicle but it is also possible to do it in front of the vehicle, with help of a virtual lever. The last option for modelling is chosen: a virtual point in front of the car.

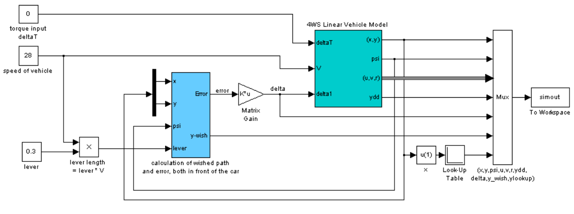


Fig. 11 Path following model

This vehicle model was developed to be included in the controller. Such model based control design methods are very powerful and can incorporate more system requirements in the design process.

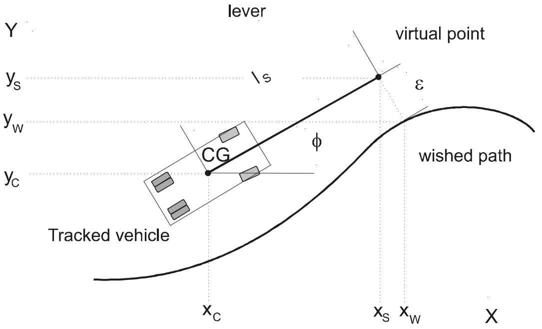


Fig. 11 Virtual lever controller

$$\begin{cases} y_s = y_c + l_s \cdot \sin(\phi) \\ x_s = x_c + l_s \cdot \cos(\phi) \end{cases}$$

$$\begin{cases} y_w = y_s + \varepsilon \cdot \cos(\phi) \\ x_w = x_s - \varepsilon \cdot \sin(\phi) \end{cases}$$

$$\Rightarrow \begin{cases} y_w = f(x_w) = y_c + l_s \cdot \sin(\phi) + \varepsilon \cdot \cos(\phi) \\ x_w = x_c + l_s \cdot \cos(\phi) - \varepsilon \cdot \sin(\phi) \end{cases}$$

This means 2 equations with the 2 unknown variables ε and x_w.

The error ε is needed for controlling the steer angle δ.

With the function of the wished path (a single lane change in this example):

$$y(x) = \frac{W}{L} \cdot \left[x - \left(\frac{L}{2\pi} \right) \cdot \sin\left(\frac{2\pi x}{L} \right) \right] \qquad 0 \le x \le L$$

and the definition of the error $\varepsilon = \sqrt{(y_w - y_s)^2 + (x_s - x_w)^2}$ the following equations are developed:

$$\begin{cases} y_w = y_c + l_s \cdot \sin(\phi) + \varepsilon \cdot \cos(\phi) \\ y_w = f(x_w) = \end{cases}$$

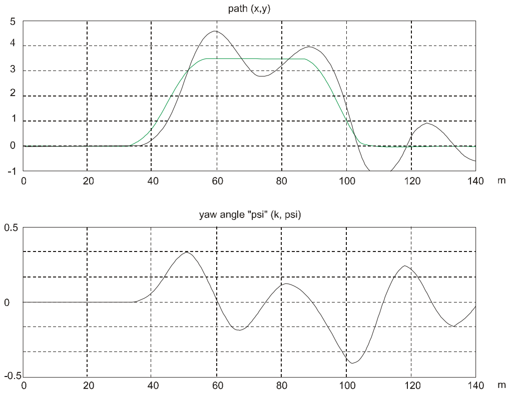
$$\frac{W}{L} \cdot [(x_c + l_s \cdot \cos(\phi) - \varepsilon \cdot \sin(\phi)) -$$

$$-\left(\frac{L}{2\pi} \right) \cdot \sin\left(\frac{2\pi}{L} \cdot (x_c + l_s \cdot \cos(\phi) - \varepsilon \cdot \sin(\phi)) \right)]$$

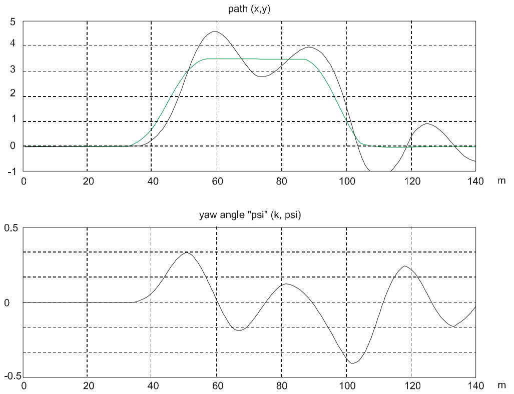
These equations with the unknown y_w and ε can be solved in Simulink by Algebraic Constraint blocks.

The feedback model can also be equipped with a PID controller in place of just a proportional gain. The path following model was build.

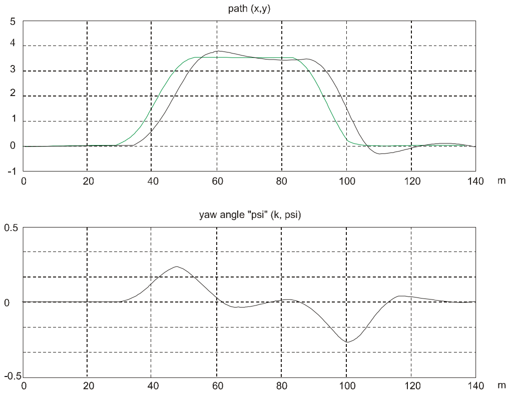
The ISO/TR3888 double lane change for path following control model with different values for lateral controller Gain and Virtual Lever length:



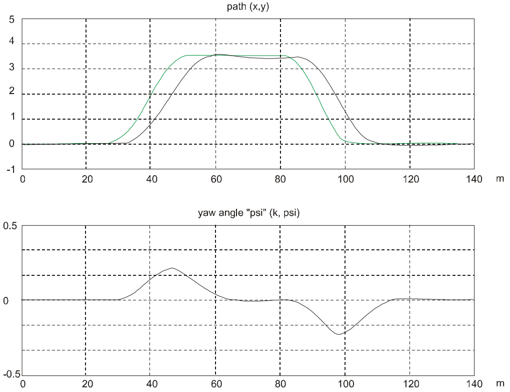
Lever length = 0.1 [m]



Lever length = 0.4 [m]



Lever length = 0.7 [m]



Lever length = 1.2 [m]

Fig. 12 Lane change simulation results

From these plots it becomes clear that if the virtual lever length is too small, a delay in steer input action is unavoidable. Although the effect can be reduced highly by choosing the value of gain Kp.

It also becomes clear that if the virtual lever length is too large, a lead in steer input action is unavoidable. Reducing the gain Kp cannot completely compensate this [8].

7. CONCLUSION AND FURTHER RESERACH

In conclusion, the use of scaled vehicles has provided a unique opportunity to study widely used highway automation manoeuvres. And with help of a feedback-based controller optimise the path with respect to changes in curvature. All this may be successfully applied to improve the vehicle performance for both normal as and critical driving situations. Simulation with a virtual point controller in front of the vehicle makes the behaviour more smooth and stable.

In this paper an enhanced path-planning algorithm has also been demonstrated. The method used permits inclusion of vehicle dynamics aspects into the autonomous vehicles path planning process. The advantages of including vehicle dynamics aspects can mainly be seen in the a priori estimation of driving manoeuvres. Due to this estimation, path planning methods for autonomous vehicle guidance increases not only the safety of the vehicle, but also be used to influence comfort related aspects and therefore increase acceptance of autonomous driving systems.

Further research has to be done on the determining of parameters of vehicle, on the continuum of testing within LPS with scaled vehicle, and on verifying of simulated results.

8. REFERENCES

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