Steering assistance for backing up articulated vehicles

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ABSTRACT

Articulated vehicles belong to the category of non-holonomous wheelers. Under the aspect of control theory they require a sophisticated handling. This corresponds to the experience of unexercised drivers, for instance maneuvering a car and its caravan into a parking box.

In this context some adequate advice for the right steering movements would give an appreciable assistance. Here a visual assistance is proposed and realized. The decisive advice for the driver is derived from kinematic modeling. The system is designed to be integrated into standard cars and trucks. For testing purposes the actual system has been incorporated into an existing backing up simulator.

Key words: driving assistance, backing up aid, kinematics of articulated vehicles, ergonomic visualization

1. INTRODUCTION

Bystanders admire the widespread skillfulness of truck drivers in operating their trailers at logistics centers or construction sites. Drivers who are less experienced with trailers are often overcharged when backing up a trailer straight backward or around a corner. Automobile associations know about this fact and offer special courses to get more acquainted with the behavior of trailers.

The kinematics of articulated vehicles is a lasting topic of scientific consideration. Besides approaches based on control theory, fuzzy logic and neural networks there have been research efforts on the derivation and exploitation of the curves which vehicle and its trailers are supposed to take. Particularly for vehicles with one-axle trailers there exists a closed formula describing the future motion of the trailer (see [3] and [5]). Furthermore it can be predicted when due to the angle between vehicle and trailer

- a straightening of the articulated vehicle gets impossible (point of impasse),
- a collision of vehicle and trailer will happen (point of collision).

The steering assistance which will be elaborated in the following sections is part of the project EZauto[1]. A major concern of this project is to develop and provide a system of class libraries at different levels of application (see figure 1).

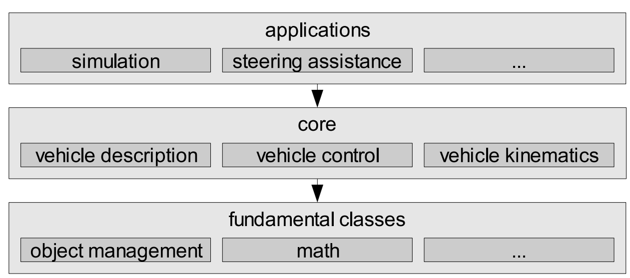


Figure 1: Layered software architecture of EZauto

Its key competence consists of the description and control of articulated vehicles. Based on respective class libraries are other application oriented class libraries for autonomous driving, simulation and visualization as well as driving assistance. Steering assistance as part of driving assistance and aims at the development of interfaces to be integrated into real vehicles. However, at the actual state of this part of

[1] *EZ* stands for the German word *Echtzeit* (real-time) and *auto* is an abbreviation for both *autonomous* and *automotive*.

the project the steering assistance is tested and evaluated in the context of a simulation and visualization environment.

2. CONCEPT OF STEERING ASSISTANCE

The concept of steering assistance has to be launched somewhere between the human perception and the technical constraints. With respect to the techniques of steering several solutions are thinkable. So, steering wheels of today's vehicles are still mechanically connected to the front wheels. In spite of the fact that a steer by wire technique would have offered a broader conceptual base, the project, so far, only supports mechanical steering. This implies that computer based assistance cannot directly manipulate the steering angle but indirectly via the human driver (see figure 2).

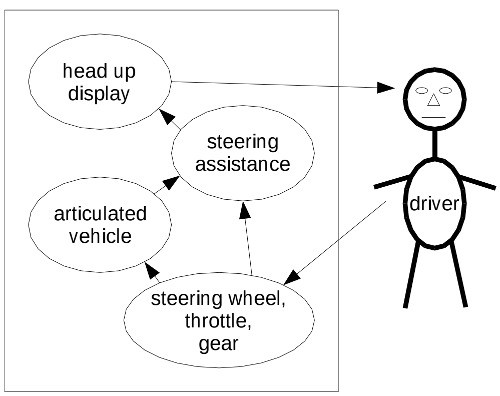


Figure 2: UML use-case diagram for the control loop of the embedded steering assistance

In this conceptual view the human driver plays as a consequence the role of an input and an output device operating at a rather high degree of reactivity. Therefore the intuitive perception of the actual state and the obvious reaction has to be supported. In principle the following senses of the driver are worthwhile considering:

- sense of sight
- sense of hearing
- sense of touch (via steering wheel)

With the option for a later extension to other senses the driving assistance in its first version is restricted to the sense of sight by a visual display, in out case a head up display projecting to the vehicle's windscreen. The choice of this kind of head up display does not change the body posture of the driver and minimally influences his habits:

- the head up display still permits a transparent view through the windscreen,
- moderate movements of the pupils are necessary to switch between the rear-view mirrors and the head up display.

For reasons of the special stress situation an unexperienced driver is in when driving backward the representation has to be condensed to the very essential without loosing its comprehensibility. It is easier for a human to quickly perceive simple graphical and analogous representations than to read text and numbers. Therefore the display should show only a simple graphical representation that acts as an advice for the right steering movements.

To lower the compexity of the backing up maneuver it can be split into four major cases:

(s) driving on a virtual straight line

(a) driving on a virtual arc

(a→s) straightening the articulated vehicle

(s→a) bending the articulated vehicle

There are a number of information that could be of interest for the driver when assisting him in each of these cases:

- the position of the truck
- the trajectory of the truck
- the position of the trailer
- the trajectory of the trailer
- the point of impasse
- the point of collision
- the steering angle
- the angle between truck and trailer
- the trajectory of the articulated vehicle
- steering hints
- the surrounding

Because the display should not be congested, only a selection of this information should be displayed to the driver.

3. TRAJECTORY ANALYSIS AND INTERPRETATION

For a truck with a one-axle trailer the decisive point of control is the center of the trailer's axle. The configuration of the articulated vehicle can be denoted in terms of the vector $(x_0, y_0, \Theta_0, \Theta_1, \phi)$ (see diagram 3). The angle ϕ corresponds to the drivers input via steering wheel. The curves described by the point of control (x_2, y_2) are variants of tractrix-curves (see [3] and [4]).

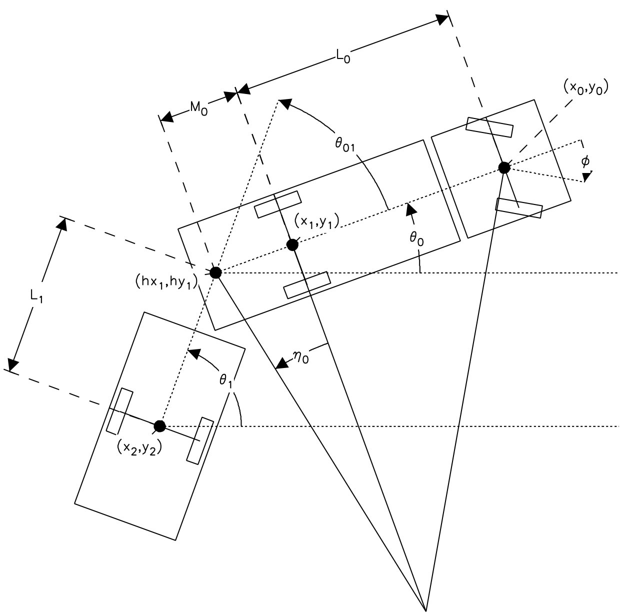


Figure 3: Kinematic model of an articulated vehicle

A simple but basic result of this approach is that for a given angle Θ_{01} between truck and trailer there exists a corresponding steering angle ϕ such that

- either for $\Theta_{01} = 0$ the entire vehicle moves on a straight line (with steering angle $\phi = 0$),
- or for $\Theta_{01} \neq 0$ all parts of the vehicle move on concentric circles.

In the latter case the steering angle computes due to the following formula:

$$\phi = arctan\left(\frac{L_0 \cdot sin(\Theta_{01})}{L_1 + M_0 \cdot cos(\Theta_{01})}\right)$$

The two steering angles above correspond to the cases (a) and (s) as discussed in the last section. The cases (s→a) and (a→s) are the maneuvers to increase or decrease the bending between truck and trailer and henceforth to change between (a) and (s). The resulting curves are tractrix-curves, for $\phi = 0$ the classical tractrix with the point of traction on an straight line and for $\phi \neq 0$ a bunch of curves with the traction point on an arc parameterized by ϕ. The two forms of tractrix curves are shown in figure 4. The diagram shows the movement of $(x_2, y_2) = T(hx_1, hy_1, \phi)$ depening on the traction point (hx_1, hy_1) either moving straight ahead or on a circular arc.

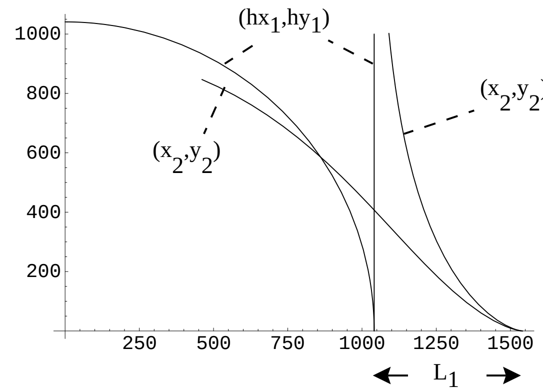


Figure 4: The curves depicted are for the model of a vehicle with $L_0 = 600mm$, $M_0 = 60mm$ and $L_1 = 500mm$. The steering angle ϕ of the truck is either 0° or 15°.

An important advice for the driver is the relative distance to the point of impasse. If the point of impasse once is overridden there is no other way to straighten the articulated vehicle as to interrupt the backward movement and to go ahead. For this is not the desired way to drive backward, the distance to the point of impasse interpreted in the right way can give adequate advice. Corresponding to the actual steering reaction the point of impasse comes near or moves away. The kinematic background for the computation of this point lies in the geometry of the articulated vehicle and the maximum steering angle ϕ_{max} depending on the mechanics of the truck. This angle corresponds to a maximal curvature of the point (x_2, y_2) which can be derived by the standard formula:

$$\frac{\dot{x}_2\ddot{y}_2 - \ddot{x}_2\dot{y}_2}{\left(\dot{x}_2^2 + \dot{y}_2^2\right)^{3/2}}$$

Furthermore of interest is the point of collision. This point however does not depend on the kinematic geometry alone. Here the breadth and supernatant of truck and trailer constitute further determining values. Based on this a minimal collision angle Θ_{01} can be derived. Hence, a trajectory emerging from the middle of the trailer's axle, running to the point of impasse and further to the point of collision can be computed arithmetically [4].

4. VISUALIZATION AND USAGE

In order that the driver can easily determine the actual state of the articulated vehicle the shapes of truck and trailer are drawn as simple outlines. Because the relative position of the truck to the driver never changes, the shape of the truck is displayed at a fix position on top of the display. The trailer is drawn with the correct bending angle.

The wheels and axles are also drawn for better recognition. The front wheels of the truck represent the actual steering angle.

The trailer is the relevant part when backing up. Therefore it is vital for the driver to know how the trailer will move in the future. Hence, the trajectory of the trailer based on both the steering and bending angle of the articulated vehicle is shown. It is drawn in a glaring green for good visibility. At the point of impasse the color of the trajectory changes to yellow. The point of collision ends the trajectory and is marked by a red dot. The trajectory will be calculated for the middle of the trailer axle, since this is the pivotal point of the trailer.

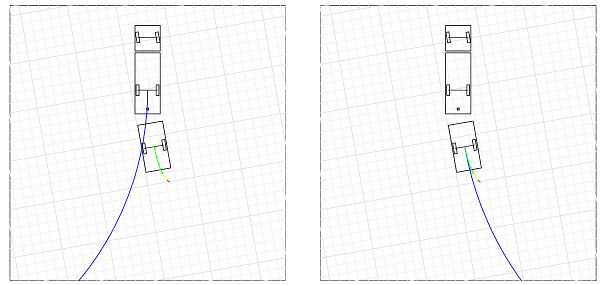
With the shape and the trailer's trajectory the driver can observe the actual state of the articulated vehicle and how the trailer will move in the future. But for assisting the driver during the backing up maneuver, some additional information is needed to decide for the correct steering movements. Alternatively the trajectory of the truck or of the entire vehicle could be used in combination with the trailer's trajectory for this.

version A: The truck's trajectory is dependent on the measures of the truck and the actual steering angle. It forms a straight line or a circle with its center at the intersection of the extension of the truck's axles. The trajectory will be calculated for the middle of the rear axle.

version B: The vehicle's trajectory is based on the measures of truck and trailer as well as the angle Θ_{01} between them. It forms either a straight line or a circle with its center at the intersection of the extensions of the truck rear axle and the trailer axle. The vehicle trajectory will be calculated for the middle of the trailer axle.

Figure 5 shows the display for the different versions.

In the sequel we explain how the driver should use the displayed information to maneuver the articulated vehicle. This is done for the four cases of backing up maneuvers and the two versions of display.



version A   version B

Figure 5: Display for bending the vehicle

(s) Superimpose the truck or trailer trajectory with the trailer trajectory on a straight line.

(a) Here we distinguish between the two versions:

version A: The trailer trajectory should form the desired arc. To follow the arc the truck's trajectory must have the same curvature. It is generally not possible to superimpose truck and trailer trajectories due to the different reference points and the influence of clutch positions.

version B: The vehicle's trajectory should form the desired arc. The steering wheel should be moved so that the trailer trajectory superimposes the vehicle's trajectory.

(a→s) Diverge the trailer trajectory with a curvature lesser than or opposite to the curvature of the truck's or vehicle's trajectory.

To keep the maneuver short the steering angle should be maximized.

version A: The steering angle will not change often during the maneuver. Because the truck's trajectory depends mostly on the steering angle it will not reflect the straightening of the vehicle. This degrades the usefulness of the trajectory as reference in this maneuver.

version B: Since the vehicle's trajectory is dependant on the angle Θ_{01} between truck and trailer it directly reflects the straightening of the vehicle. The trajectory of the vehicle forms a straight line if the angle reaches zero.

(s→a) Diverge the trailer trajectory with a curvature greater than the curvature of the truck's or vehicle's trajectory.

To keep the maneuver short the steering angle should be maximized.

version A: Similar to the preceding case the truck's trajectory is not useful as a reference. The desired movement of the vehicle can only be estimated by the angle between truck and trailer.

version B: The vehicle's trajectory forms an arc which will decrease in diameter during the maneuver. The maneuver can be stopped if the desired bending is reached.

These rules show that version B gives the driver more assistance than version A. This results from the fact that the truck's trajectory is not dependent on the angle between truck and trailer and hence is not directly correlated to the desired trajectory of the vehicle. It also changes quickly when the driver corrects the steering, which makes it difficult to use it as an reference. The vehicle's trajectory instead will show the driver what he wants to know: how the whole vehicle is going to move. He can instantly see if he is driving in the desired direction. And using identical reference points for vehicle and trailer trajectories demands less abstract thinking from the driver.

To further improve the feeling of driving an unobtrusive grid is used as background. It will move and rotate relative to the position of the truck. Together with the size of the truck it can be used to estimate angles and the radii of trajectory curves.

The transparent depiction of the actual state of the vehicle should not derange or overstrain the driver. Therefore it is projected at eye-level for the short phase of backing up (see figure 6 and figure 7).

5. REALIZATION

The design has to consider two different use cases. The prototypical use case of a driving assistance operating as part of a simulation and visualization environment has been realized prototypically (see [2]). However, the long-term purpose is the embedding of the steering assistance into real vehicles.

As a conceptual consequence the steering assistance was designed to work independent from the input and output devices. This is achieved by using simple interfaces for input and rendering (see figure 8). Only the steering angle, bending angle and speed of the truck are used for input, either generated by sensors of the real vehicle or by a simulated one. For rendering the output abstract drawing functions are used.

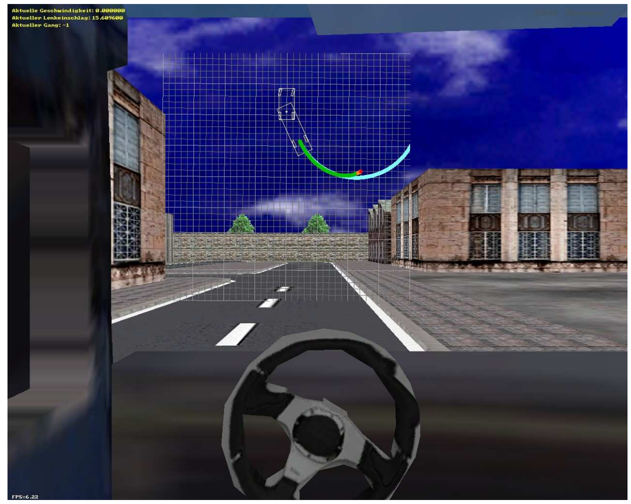


Figure 6: Integration into the backing up simulator

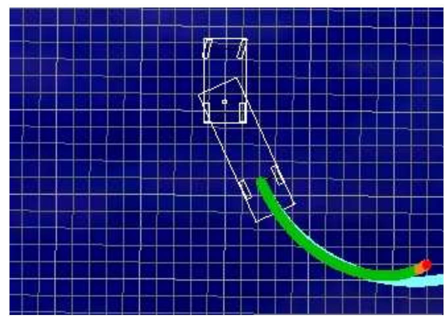


Figure 7: Display of the integrated assistance

The steering assistance itself decomposes into three parts (see figure 9):

- The trajectory computation which uses the steering and hitch angles along with the vehicle descriptions to compute the trajectories and the points of impasse and collision.

- The position calculation which uses the same input information to calculate the truck position relative to the starting point.

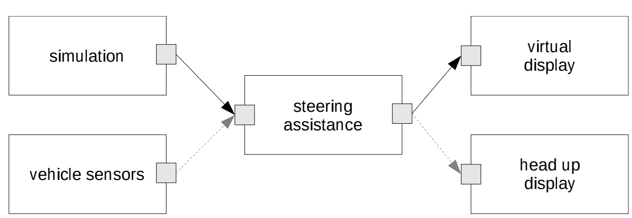


Figure 8: Compound diagram for the steering assistance

- The visualisation. The truck position is used to draw a grid that moves relative to the truck. A description of the vehicle's appearance is used along with the steering and bending angles to render the shape of the vehicle. Finally the trajectories are drawn.

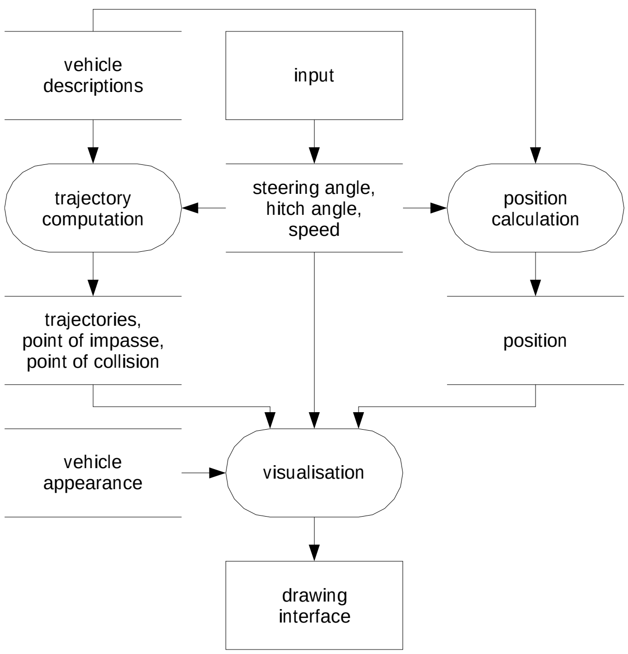


Figure 9: Data flow diagram for the steering assistance

Major efforts have been made to achieve timeliness and instantaneousness. The requirements for timeliness primarily emerge from display refresh time which was set to a tolerable bound of $20Hz$. The implementation is based on a time- triggered strategy with a major cycle of $50ms$. Thereof it follows that the maximal time gap between turning the steering wheel and displaying the corresponding trajectories is at most $100ms$ [1]. This still gives a good impression of instantaneous reaction of the trajectory to steering operations.

6. SUMMERY AND OUTLOOK

First tests based on the prototypical system already reveal that this kind of driving assistance leads to a smoother steering behavior and an increase of predictability of steering actions. However, the degree of stress, when backing up an articulated vehicle seems to be the same. Probably the concentration to visual perception is too tensing. On the other hand the sense of hearing is idle. Therefore it is reasonable to think about audible information, e.g. for the degree the coincidence between the trajectories of vehicle and trailer. A series of experiments and evaluations of test persons is necessary to find out which is the adequate audible message to be given to the driver.

The next step of this project is to embed the driving assistance into a real vehicle. Its realization can build upon the experiments and evaluations of the prototypical system. Additionally durig this step a cheap and robust sensor system for measuring the angle at the hitch between vehicle and trailer has to bed developed. Furthermore a synergistic integration with the driving assistance already available in vehicles, e.g. various forms of obstacle recognition, is the next step in the future.

References

[1] W. Albrecht and D. Zöbel. Hard real-time scheduling for age constraint computations in monitoring and control. In *Proceedings of the 2nd IFAC Workshop on New Trends in Design of Control Systems*, Smolenice, Slovak Republic, September 1997. Elsevier Science Ltd.

[2] Hanno Binder, Jérôme Diebold, Tobias Feldmann, Andreas Kern, David Polock, Dennis Reif, Stephan Schmidt, Frank Schmitt, and Dieter Zöbel. Fahrassistenzsystem zur Unterstützung beim Rückwärtsfahren mit einachsigen Gespannen. Fachberichte Informatik 100-2002, Universität Koblenz-Landau, 2002.

[3] Petr Švestka and Jules Vleugels. Exact motion planning for tractor-trailer robots. In *Proc. IEEE Int. Conf. on Robots and Automation*, pages 2445–2450, Nagoya, Japan, 1995.

[4] D. Zöbel and E. Balcerak. Präzise Fahrmanöver für Fahrzeuge im Gespann. In R. Dillmann, H.Wörn, and M. von Ehr, editors, *Autonome Mobile Systeme (AMS2000)*, volume 16. Fachgespräch of *Informatik aktuell*, pages 148–156, Karlsruhe, November 2000. Springer-Verlag.

[5] Dieter Zöbel. Trajectory segmentation for the autonomous control of backward motion for truck and trailer. In *(ITSC'2002)*, pages 188–193, Singapore, 3-6 September 2002. IEEE 5th International Conference on Intelligent Transportation System Council.