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Assistance Controller for Driving Backwards and Parking an Articulated Vehicle

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***Abstract*— Driving backwards and parking articulated vehicles represent a hard procedure also for skilled drivers. If a vehicle is semi-automated in a way that a computer can command the steering wheel, a driver assistance system may help the conductor to perform such maneuvers easily. This work presents a solution for this problem. A self constructed prototype was developed to analyze the effectiveness of the proposed control strategies that include a stabilizing controller for the joint angle and a path tracking controller. The results show that the stabilizing controller permits an untrained driver to steer the vehicle backwards by setting up the joint angle reference signal with an external human machine interface while the path tracking controller allows the vehicle to follow a predetermined route autonomously.**

I. INTRODUCTION

Hands-on-teaching methodology allows students to learn by solving real problems. They are challenged to come up with the optimum solution while combining theory and praxis [1],[2],[3]. Themes involving intelligent vehicles and driver assistance systems represent excellent opportunities for control engineering students to learn and prove their skills [4],[5],[6]. One of them, for example, is associated with the problem of driving backwards articulated vehicles [7],[8]. The students of the 2007.2 Control System II class were challenged to solve this problem by developing a control system that allows any unskilled driver to drive backwards and park an articulated vehicle. Their solutions are presented in this article.

To test the proposed assistance controllers a small prototype, presented in Figure 1, was developed and constructed by the students themselves. The rest of this paper is divided as follows: The prototype description is presented in the next section, followed by the controller design that includes: the motor drive control, the obtained vehicle dynamic model and controller specifications. From sections 4 to 6 experimental results and considerations for full scale vehicles are presented.

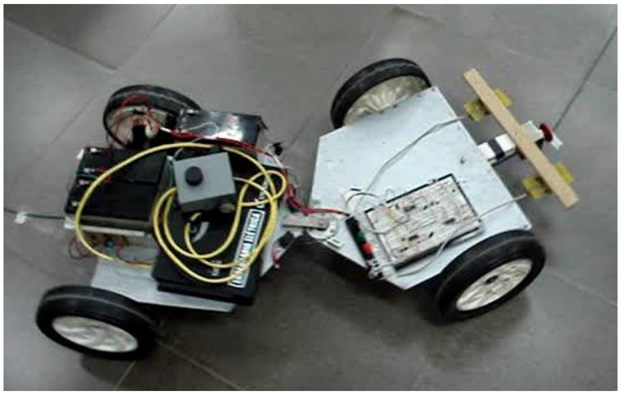

Figure 1: Articulated Vehicle Prototype

II. SYSTEM STRUCTURE

The vehicle prototype presented in Figure 1 is mainly composed of a traction platform, as it can be observed in the left side of the picture, and a passive one, as shown in the right side, both interlinked together with a moving joint. To simplify the construction of the traction platform a differential drive structure was chosen instead of an Ackerman steered solution. Here two 12V DC motor drives with gearboxes where used. As the main focus of the problem is related to the forces involved in the link between both vehicles parts this simplification, when imposed to some movement constrains, represents here an adequate solution. The system architecture is presented in Figure 2.

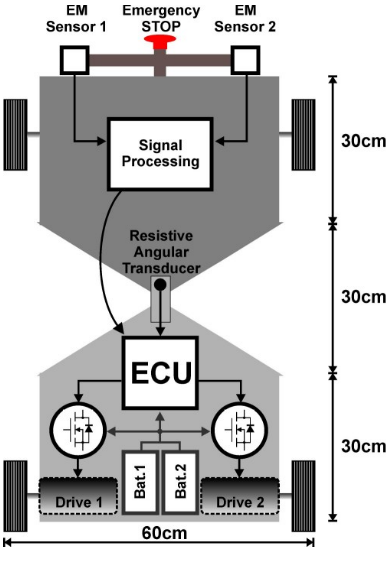

Figure 2: System Architecture

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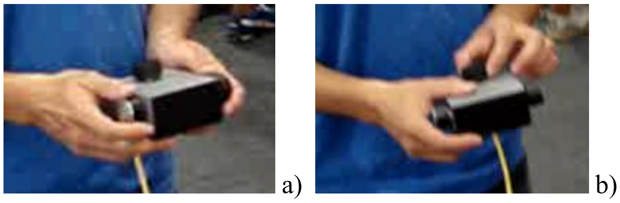

Figure 3: Human Machine Interface

The instrumentation is placed on the passive side of the vehicle. The joint angle is provided by a resistive angular transducer, while the path tracking information is given by the processed signal originated by two electromagnetic (EM) sensors. Since the reference route is marked with a guiding cable attached on the ground, the EM sensors are used to sense the magnetic field generated by the electrical current in this cable.

A human machine interface (HMI) shown in Figure 3 was also attached to the microcontroller based Electronic Controller Unit (ECU). Using the system in a non-autonomous mode the HMI permits the conductor to adjust either the traction forces of the driving motors independently or the joint reference value for the stabilizing controller.

III. CONTROLLER DESIGN

The control strategy is based on a cascade architecture, where the inner control loop represents the control of electric drives control and the outer cascaded controllers are used to interact with the vehicle dynamics [9]. Usually controllers of the PIDT family are used here. The set-points for the outer controllers, on the other hand, can either be delivered directly by the HMI, a conventional instrumentation solution (guiding cable, transponders, etc…) or be generated by another higher hierarchical computational controller based on artificial intelligence solutions [4]–[8]. The suitable solution depends on the complexity of the environment and the possibility to perform modifications and adjustments on it.

A. Traction Control

The traction force generated by each motor drive needs to be controlled to guarantee a high performance behavior of the complete system. Therefore, if both drives receive the same reference value and considering the vehicle on a regular surface the traction platform will not execute any rotatory movement.

The resulting torque in a DC motor shaft can be considered proportional to its armature current $i_{arm}(t)$ [10]. Therefore, each drive must have a current controller to adjust the armature voltage $U_{mot}(t)$ and impose the desired armature current. Referring to the gearboxes as torque amplifiers the traction force of each drive $F(t)$ can be considered proportional to the motor current:

$$F(t) = K_1 \cdot i_{arm}(t) \tag{1}$$

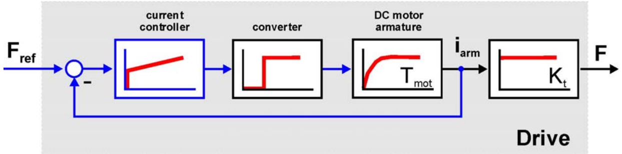

Figure 4: Controlled DC Drive

The armature dynamic model can be represented by a PT1 element defined in (2), where T_{mot} and V_{mot} are the armature time and amplification constants, respectively.

$$T_{mot}\frac{\partial i_{arm}(t)}{\partial t} + i_{arm}(t) = V_{mot} \cdot U_{arm}(t) \tag{2}$$

Figure 4 shows the control structure for both DC motor drives used to move and steer the vehicle. The most suitable controller for this kind of plant is a PI controller and the electronic converter was modeled as a small time delay. As a result each motor drive delivers the traction force defined in the set-point.

B. Vehicle Dynamic Model

When maneuvering an articulated vehicle backwards some considerations can be taken into account. Firstly, the vehicle is driven at lower speeds, what reduces the effect of the kinetic energy involved in the dynamic behavior. Secondly, also due to the speed limitation the velocity related non-linearities of a more detailed model can be neglected. Thus a lower order model considering the vehicle moving at a constant and low speed can be utilized.

The vehicle dynamic model can be separated into two sub-systems. When considering the objective of controlling the joint angle $\varepsilon_1(t)$ independently of any predefined path only the dynamic behavior of the traction platform is necessary, leading to the model presented in Figure 5a. On the other hand, if the objective is to have the vehicle tracking a specified route by canceling the angle between the passive platform and the predefined lane $\varepsilon_2(t)$ [11],[12] the dynamic model of the passive side is also requested, leading to the model presented in Figure 5b. In this case $\varepsilon_1(t)$ doesn't need to be controlled, but limited to a predefined range.

Since a differential drive solution was chosen for the traction platform, its steering depends on the difference of the traction forces generated by each motor drive.

$$\Delta F(t) = F_2(t) - F_1(t) \tag{3}$$

The angular velocity of the traction platform around the axles midpoint $\omega_1(t)$ in Figure 5a can be defined as the output of a PT1 element specified in (4). The differential force $\Delta F(t)$ is used as input variable, while T_1 and V_1 represent, respectively, the time and amplification constants that depend on the systems mechanical design.

$$T_1\frac{\partial \omega_1(t)}{\partial t} + \omega_1(t) = V_1 \cdot \Delta F(t) \tag{4}$$

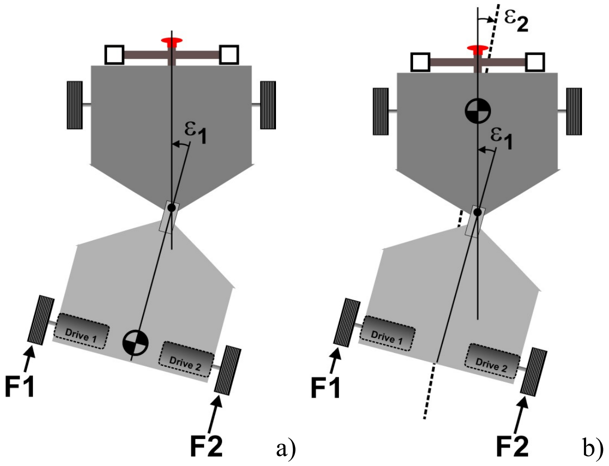

Figure 5: System Modeling

The relationship between $\omega_1(t)$ and the joint angle $\varepsilon_1(t)$ is presented in (5).

$$\frac{\partial \varepsilon_1(t)}{\partial t} = \omega_1(t) \tag{5}$$

The vehicles passive side has a behavior similar to the traditional inverted pendulum model. The differential force applied on the traction platform will generate a force component at the joint parallel to the passive side axle. This force component produces a torque around the axles midpoint indicated in Figure 5b that causes a rotational movement. The angular velocity of the passive platform around the axles midpoint $\omega_2(t)$ can also be defined as the output of a PT1 element defined in (6). T_2 and V_2 represent, respectively, the time and amplification constants that also depend on the systems mechanical design.

$$T_2 \frac{\partial \omega_2(t)}{\partial t} + \omega_2(t) = V_2 \cdot \cos(\varepsilon_1(t)) \cdot \Delta F(t) \tag{6}$$

Considering the axles midpoint over the desired route the deviation angle $\varepsilon_2(t)$ is defined in (7).

$$\frac{\partial \varepsilon_2(t)}{\partial t} = \omega_2(t) \tag{7}$$

Based on the mathematical dynamic model of the articulated vehicle defined in (3)–(7) and depending on the variable chosen to be controlled ($\varepsilon_1(t)$ or $\varepsilon_2(t)$) two different controllers can be implemented, as presented next.

C. *Stabilizing Controller*

The stabilizing controller is used to guarantee a smooth backward driving maneuver limiting the maximum value of $\varepsilon_1(t)$ and allowing the driver just to steer the vehicle by setting up the desired joint angle $\varepsilon_{1\_ref}(t)$. This controller is responsible for determining the optimum traction force difference $\Delta F(t)$ between both motor drives sending this information to each low level inner cascade drive controller.

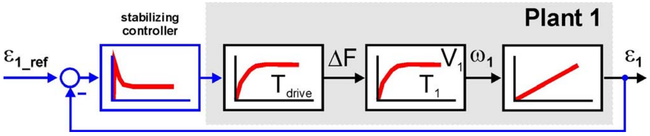

Figure 6: Joint Angle Control Loop

The resulting control loop is presented in Figure 6. To simplify the controller design the controlled motor drives representing the inner control loop shown previously in Figure 4 were converted into a PT1 element with an equivalent time constant T_{drive}. Since $T_{drive} << T_1$ the resulting plant can be considered an IT1 element, which can be easily controlled by a PDT1 controller. The parameters can be tuned by using for example the *root-locus* methodology.

D. *Path Tracking Controller*

The path tracking controller permits the vehicle to follow autonomously a predetermined route by minimizing deviation angle $\varepsilon_2(t)$. The measured joint angle $\varepsilon_1(t)$, however, is only used to limit the controller output. This procedure assures that the system will work around the operating point, where the plant can be linearized by considering a small and limited joint angle.

The resulting arrangement is presented in Figure 7. To specify the controller structure the plant can be considered linear around the operating point and the motor drive can be again converted into a PT1 element with equivalent time constant $T_{drive} << T_2$. Again an IT1 equivalent element is obtained and a PDT controller can be also used to control this plant. The parameters can be tuned in a similar way as before as done for the stabilizing controller.

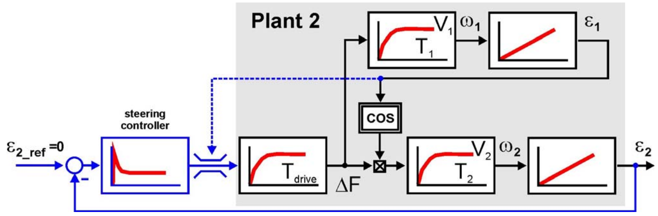

Figure 7: Guidance Controller

IV. EXPERIMENTAL RESULTS

To verify the performance of the traction controller the motor drive shafts were fixed steady and a 5A pulse was used as reference for the current control loop. The resulting armature current is presented in Figure 8.

The motor current and consequently the traction forces stabilize in about 250ms, which is fast enough to guide the vehicle at lower speeds. The resulting control loop presents a sufficient dampening factor i.e. there is no overshoot in the controlled system step response and a smooth movement is therefore possible.

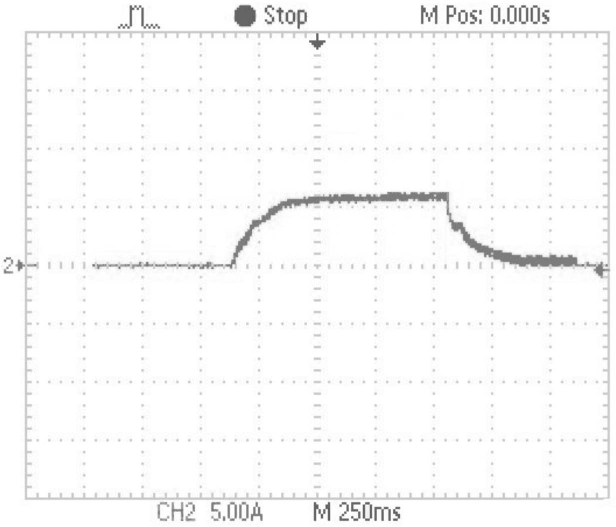

Figure 8: Traction Controller Step Response

The stabilizing and path tracking controllers were implemented on the embedded ECU of the prototype and tested in different occasions. To really feel and understand how helpful the stabilizing controller can be, we performed an experience inviting eighty people to drive the prototype and to evaluate its performance at the Unisinos stand during the 2007 Mostratec Technology Fair. Each driver had first of all to drive the vehicle manually by adjusting the traction forces of each motor drive independently, as illustrated in Figure 3a. Afterwards they could perform the same procedure using the assistance of the stabilizing controller, as illustrated in Figure 3b. While in the first case only three volunteers were able to drive the prototype for more than 5m, using the stabilizing controller 100% of the people could execute any desired maneuver.

The path tracking controller was tested at the Unisinos campus on different ground conditions. The first tests were carried out inside the laboratory having ideal floor conditions. However, to evaluate the controller performance in extreme off-road conditions, the subsequent tests were conducted outside the laboratory buildings.

Figure 9: Autonomous Backward Driving

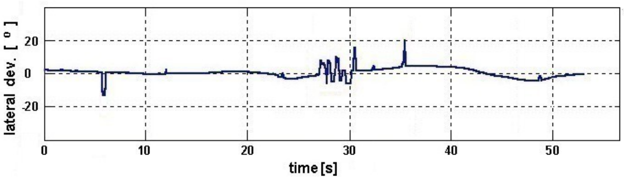

Figure 10: Lateral Deviation

Figure 9 shows the vehicle driving backwards autonomously tracking the guiding cable and passing through a grass-sidewalk transition and the lateral deviation angle $\varepsilon_2(t)$ during this procedure is displayed in Figure 10. The small spikes presented in the signal represent small disturbs originated by irregularities on the ground. The variations presented near the 30sec time mark indicates the grass-sidewalk transition of the vehicles passive side as it can be observed in Figure 9. The robustness of the path tracking controller guarantees the route following maneuver after defeating of such an obstacle.

V. EXTENDING THE PROCEDURE FOR PARKING MANEUVERS

The assistance controllers presented in this work can be extended to help drivers to park articulated trucks in loading docks, as illustrated in Figure 11. The implementation of a stabilizing controller doesn't need any changes in the environment and represents a useful solution, where only the truck must be automated. The driver could than easily park the vehicle by setting up the joint angle through a separated HMI, while the positioning of the steering wheel is executed by a servomotor. However, the measurement of the joint angle in real trucks seems not to be as easy as it was in the presented prototype.

A semi-automated solution could be reached by extending the use of the path tracking controller. The desired route to the loading dock can be pointed out in different ways. Here, due to its robustness in relation to an optical strip tracker solution [13] a guiding cable was used. However, other technologies using computer vision are also available [9],[14],[15]. On the other hand, since mainly the lateral deviation angle $\varepsilon_2(t)$ is needed, a particular mark could be placed at the loading dock, as indicated in Figure 11 and a camera at the rear end of the vehicle aligned to its longitudinal axis could be used to track this mark [9], [16]

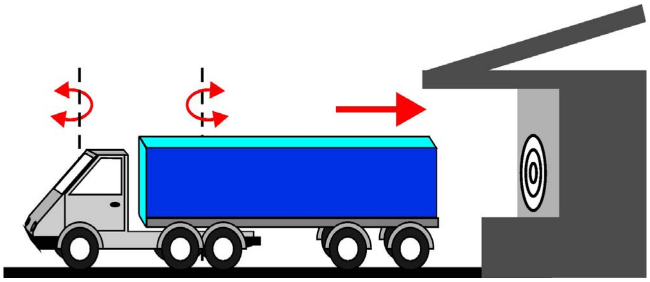

Figure 11: Parking an Articulated Truck

and get the deviation angle. If the driver supervises the joint angle while the controller is performing the parking maneuver its measurement could be quite unnecessary.

To test these procedures and other control algorithm based on Model Based Predictive Control [17],[18] an articulated truck is being implemented in a 3D simulator specially developed to simulate automated vehicles and mobile robots [19].

VI. CONCLUSIONS

In this article two control structures for driving backwards an articulated vehicle prototype were presented.

A stabilizing controller can easily control the joint angle allowing any unskilled driver to steer the vehicle backwards. The driver needs only to set up the joint angle reference with an external human machine interface.

A path tracking controller allows the vehicle to follow a predetermined route backwards in an autonomous mode. The joint angle is only needed to define the limits for the controller output variable.

To extend and apply these controllers in full scale articulated vehicles in order to assist the drivers in parking maneuvers, some technical considerations concerning the joint angle measurement and interventions in the environment must be taken into account to predefine and mark routes to the loading docks.

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