MODELING, SIMULATION, AND CONTROL OF AUTONOMOUS TRACTOR-TRAILER ROBOT

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Introduction

This paper presents simulation and test results that demonstrate the navigation of Autonomous Tractor-Trailer mobile robot vehicle in reverse motion. Autonomous Tractor-Trailer system can be equipped in many practical situations from material handling in the factory environment to the agricultural field.

Numerous papers treat this problem with tools spanning from neural network, fuzzy control, learning and genetic algorithm, and nonlinear controls. A feedback linearization controller is derived in Sampei's paper for a trailer hitched at the axel while a back-stepping approach is used in Yuan's paper for a trailer hitched off the axel. A complicated hybrid controller is used in Claudio's paper to switch between a backward driving and a forward driving controller. The backward driving controller is a locally stabilizing controller with a small region of attraction and the switching between forward and backward motion ensures that the system is driven sufficiently close to equilibrium.

In this paper we design a controller for the reverse tractor trailer based on the input output linearization method of Sampei's paper. The method relies on transforming trajectory following problem in the time domain to that of a path following problem in the arc length domain. Thus the controller is expected to be insensitive to slipping of wheels. We derive the controller of Sampei's paper, modify it to the case of differential wheeled tractor system and simulate the performance and implement it on two types of tractor trailer systems; differential wheeled and non differential wheeled. The controller derivation assumes no slip tire rotation. Simulation results, which do not incorporate slip, demonstrate that the controllers have a very wide region of attraction. The two experimental setups show that the controllers perform quite satisfactorily even in the presence of considerable slip.

Mathematical Model

Figure (1) shows the basic geometry of the tractor trailer model. A trailer is steered by the angle of the tractor (θ). Here Point P_I is the midpoint on the trailer axle. We will seek to control the path of this point.

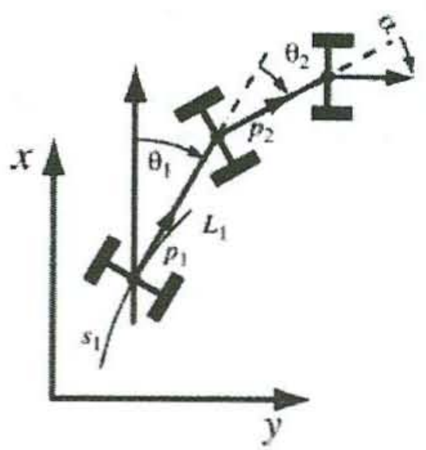


Figure 1. Basic geometry of the tractor trailer model

Line Tracking

The simplest approach to nonlinear control is typically local linearization.

A controller with a larger region of validity can be obtained through feedback linearization. Here we apply feedback linearization. In the approach to trajectory tracking, the independent variable is chosen to be the arc length along the desired path, and the controlled output is chosen as the orthogonal distance to that path.

-x-Axis Tracking

To prepare for the tracking problem we choose x_1 as the independent variable. Using feedback linearization technique, the total controller can be obtain as given in equation (1), here values of (k_1, k_2, k_3) can be chosen to give desired closed-loop dynamics.

$$\tan\alpha = \left(\frac{L_2}{L_1}\right)\cos\theta_2\left(\tan\theta_2 - 3\tan\theta_1\sin^2\theta_2\right) - \left(L_1L_2\cos^4\theta_1\cos^3\theta_2\right)\left(-k_1y_1 + k_2\tan\theta_1 - k_3\frac{\tan\theta_2}{L_1\cos^3\theta_1}\right) \quad (1)$$

Simulation Results

Figure (2) shows the performance of the total controller for reverse motion of the tractor trailer system. Simulation results show that the controller has large region of attraction unless the system was jack knife completely and if sensors can see the path as shown in the figure (2).

Experimental Setup

The vital fact we present here is that we have experimentally proved that the mathematical model that have been derived above are accurate enough for controller with feedback linearization to drive the system properly.

Figure (3) shows the experimental prototype which was used to implement the controllers. The prototype was successful maneuvering in the autonomous mode.

In the prototype we tested both four-bar mechanism (Fig.3.a) and differential system (Fig.3.b) for steering and observed that with differential system responsive region of controller is greater than with four-bar mechanism. Also the controller performed quite satisfactorily even in the presence of considerable slip since the controller development based in the arc length domain.

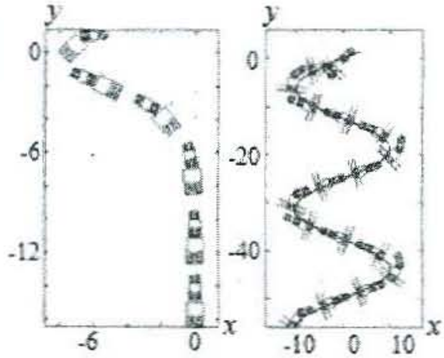
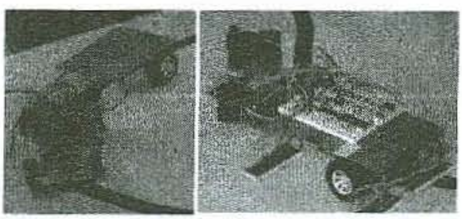


Figure 2. MatLab simulation. Left: tracking the –x-axis with initial angle is $\pi/4$ and initial y-offset is -7.5. Right: tracking the sinusoidal path with initial angle is $\pi/4$ and initial (x, y)-offset is (-2,-2).



(a) (b)

Figure 3. The experimental prototypes

For trajectory sensing we have used IR sensors. It could be done using vision system more accurately. The system is controlled by Microchip PIC microcontroller. Interface circuitry was carefully chosen to guarantee noise free reliable operation. Video of testing can be found at www. youtube.com/watch?v=CjecUJjhcDo

Discussion

This study poses several challenges with respect to control design and implementation as the Tractor-Trailer mobile robot is an under actuated naturally unstable non linear system in its reverse movement. The developed controller is working fine with an arbitrary trajectory as well. During testing of the prototype, it was noted that the feedback linearization technique has resulted in enhanced performance in both forward and reverse movements.

Conclusion

The controller obtained for line tracking of the tractor-trailer mobile robot in equations (1) using feedback linearization technique shows larger region of attraction and hence it can be identified as one of the best method for similar kind of design.

References

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