Dynamics of Towing for Trailer Path Tracking

Ünal Dana[1,2], Levent Çetin[2]

[1]Graduate School of Natural and Applied Sciences, Department of Robotics Engineering, İzmir Kâtip Çelebi University, Çiğli, 35620, İzmir, Turkey, {unal.dana@ikcu.edu.tr}
[2]Department of Mechatronics Engineering, İzmir Kâtip Çelebi University, Çiğli, 35620, İzmir, Turkey, {levent.cetin@ikcu.edu.tr}

ABSTRACT

1 Introduction

The demand for production efficiency has contributed to the increase of automation within the industry. In the past decade, the human labor started to be inefficent , leading to the promotion of Industry 3.0, which encourages the implementation of robotic systems for automation. Advancements in technology related to indoor robotics, along with a growing confidence in automation, have facilitated the integration of mobile robots in industrial facilities. These robots are mostly utilized for transportation (logistics) and assembly tasks [1] [2] . Common method of transport is usualy placing cargo directly on the robot's surface [3]. While mobile robots aim to optimize energy consumption through efficient path generation and tracking, the existing transportation methods tend to be simple and inefficent [4] [5] [6]. This research proposes a method of transportation with existing trailers to be towed by mobile robots to address these transportation inefficiencies. This study focuses on analyzing, controlling, and testing the dynamics of the trailer under external towing forces.

2 Problem Describtion

The focus of study presented in this research is to control a trailer path by applying external forces therefore dynamic analysis, path generation and path tracking are carried out . The test environment and mechanical system for this problem has some constraints and assumptions those are; the trailer has 3 degrees of freedom,trailer wheels are non holonomic,there is no slip between wheel and the ground ,the center of mass is between middle of the 2 wheels of trailer shown on the figure 1 (b) .Figure 1 (a) presents an established trailer.

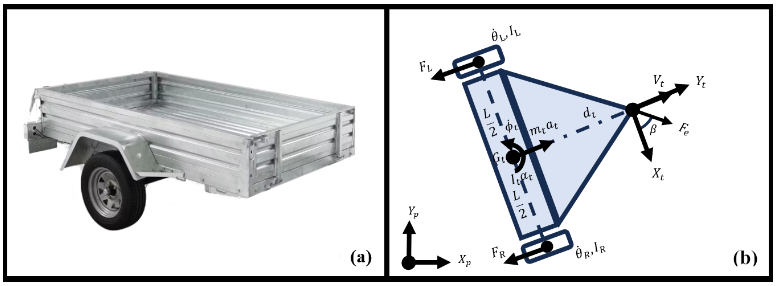

Figure 1: (a) Simple trailer , (b) forces acting on trailer

The relationship between external force and trailer velocities is analyzed in order to calculate corresponding external forces needed to control trailer velocities and path. The equation 1 is the inverse kinematic analysis and equation 2 is the dynamical analysis of towed trailer. This equations calculate output external forces acting on the connection joint of trailer to attain desired velocities.

$$\begin{bmatrix} \dot{\theta}_L \\ \dot{\theta}_R \end{bmatrix} = \frac{1}{2r_t} \begin{bmatrix} 2 & -L \\ 2 & L \end{bmatrix} \begin{bmatrix} V_t \\ \dot{\phi}_t \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} F_{ex} \\ F_{ey} \end{bmatrix} = \begin{bmatrix} \frac{I_L L}{2d_t r_t} + \frac{I_t r_t}{d_t L} & \frac{I_R L}{2d_t r_t} + \frac{I_t r_t}{d_t L} \\ \frac{I_L}{r_t} + \frac{m_t r_t}{2} & \frac{I_R}{r_t} + \frac{m_t r_t}{2} \end{bmatrix} \begin{bmatrix} \ddot{\theta}_L \\ \ddot{\theta}_R \end{bmatrix} \tag{2}$$

3 Path Planning and Tracking

In an ideal environment with no obstacles the easiest method to achieve desired pose is to move in the shortest linear path but this linear path is not feasable and inefficent because it causes rotations around center of mass of trailer therefore a path generation with a cubic Bezier curve (n=3) function is used for path planning.Equation 3 and 4 [4] defines the Bezier curve for any number of control points (n).

$$f(t) = \sum_{i=0}^{n} b_i B_i^n(t), \quad 0 \leq t \leq 1 \tag{3}$$

DOI: 10.17185/duepublico/82592

$$B_i(t) = \binom{n}{i} t^i (1-t)^{n-i}, \quad i = 0, \ldots, n \tag{4}$$

Path tracking is achieved by applying pure pursuit function [5] outputs as inputs to the dynamical equations (4).Pure pursuit function takes position errors to the next waypoint and outputs velocities.

4 Results and Discussion

Path generation with cubic Bezier curves and path tracking algorithm works as intended. The simulation results show .The final position is reached within the range of ± 0.01 m.The desired final angle is reached without rotations around center of mass. Simulation path is almost identical to the desired path with RMS error of 0.0297 m .The desired path is % 0.62 longer than the simulated path.The simulated linear velocity settles to desired simulation velocity in 12 seconds.Desired angular velocity changes rapidly therefore the simulated angular velocity doesn't have time to settle or make smooth transitions.

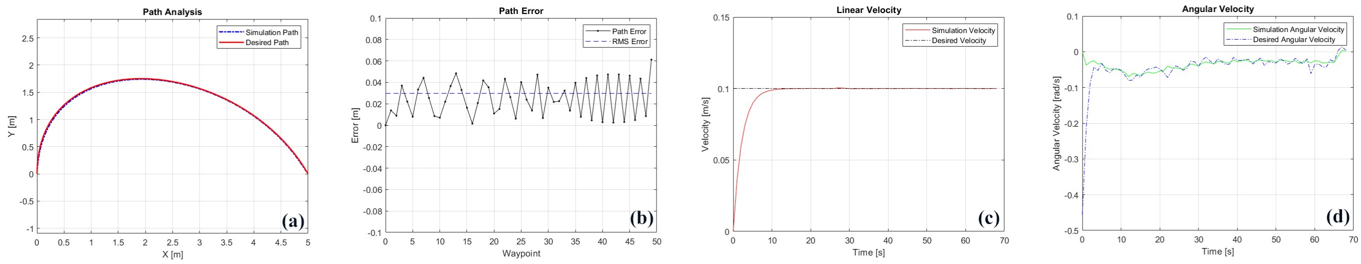

Figure 2: Simscape simulation results:(a) Path analysis, (b) path error, (c) linear velocity, (d) angular velocity.

The simulation result on figure 2 shows the trailer controlled by external forces on the joint tracking the generated path. Results in figure 2 (c) shows that the control of trailers linear velocity is successfull and can be achieved using mobile robot connected to the trailer. The angular velocity changes would be hard to achieve using mobile robot connected to the trailer, therefore a smoother curve in desired angular velocity in figure 2 (d) is essential. Overall system works however improvements on the settling time of linear velocity and smoother transitioning angular velocity should be done in the future.

Acknowledgments

This work has been financially supported by İzmir Kâtip Çelebi University (project no: 2024-TYL-FEBE-0008).

References

[1] R. Raj and A. Kos, "A Comprehensive Study of Mobile Robot: History, Developments, Applications, and Future Research Perspectives," Jul. 01, 2022, MDPI. doi: 10.3390/app12146951.

[2] J. Sinnemann, M. Boshoff, R. Dyrska, S. Leonow, M. Mönnigmann, and B. Kuhlenkötter, "Systematic literature review of applications and usage potentials for the combination of unmanned aerial vehicles and mobile robot manipulators in production systems," *Production Engineering*, vol. 16, no. 5, pp. 579–596, Oct. 2022, doi: 10.1007/s11740-022-01109-y.

[3] A. Yudiansyah, D. S. Ayu, and Y. Keke, "CAN THE MOBILE ROBOT BE A FUTURE ORDER-PICKING SOLUTION?: A CASE STUDY AT AMAZON FULFILLMENT CENTER."

[4] G. Tian, F. Zhou, and B. Song, "Bézier curve based smooth path planning for mobile robot," 2011. [Online]. Available: http://www.joics.com.

[5] C. Coulter, "Implementation of the Pure Pursuit Path Tracking Algorithm," 1992.

[6] M. Abdelwahab, V. Parque, A. M. R. Fath Elbab, A. A. Abouelsoud, and S. Sugano, "Trajectory tracking of wheeled mobile robots using Z-Number based fuzzy logic," *IEEE Access*, vol. 8, pp. 18426–18441, 2020, doi: 10.1109/ACCESS.2020.2968421.

DOI: 10.17185/duepublico/82592
URN: urn:nbn:de:hbz:465-20241118-120631-1

1st IFToMM Young Faculty Group Symposium on Emerging Fields in Mechanism and Machine Science 2024: 19.11. - 21.11.2024, Online Symposium