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Online Torque Optimization of Wheeled Robots based on a Multi Objective Algorithm

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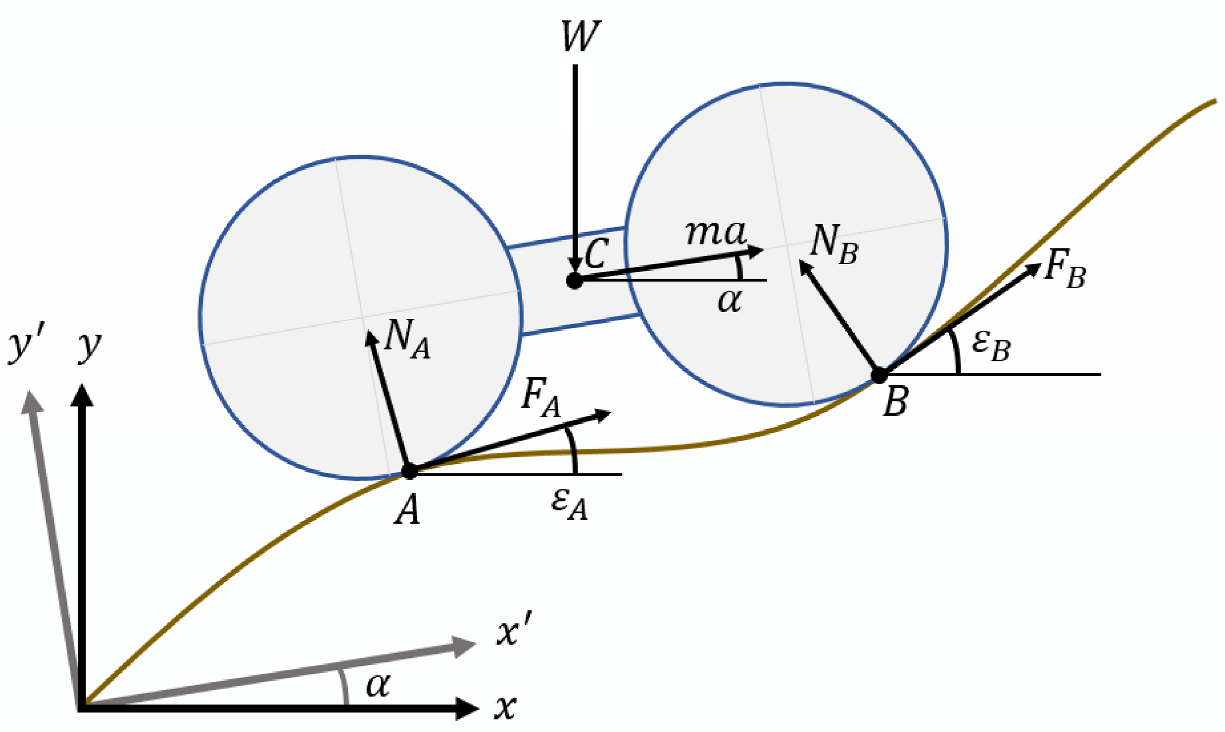
Introduction

- This work deals with motion of wheeled robots with skid-steering drive systems and without suspensions, with applications in highly sloped terrains and step climbing.
- No previous knowledge of the terrain is assumed, while unpredicted obstacles or high inclinations should be overcome.
- To perform safe maneuvers, optimal torque distribution is required for maximum stability and minimal slippage.

Methodology

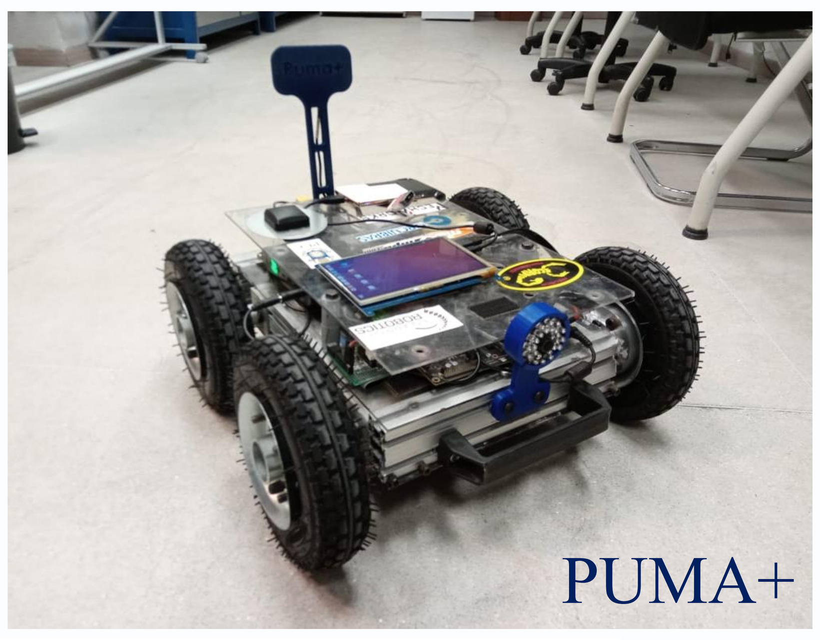
A simplified 2D dynamical model of the system is considered. The robot is assumed to perform stable trajectories if a minimum stability margin is guaranteed. The relation between normal and frictional forces is then controlled, to avoid slippage.



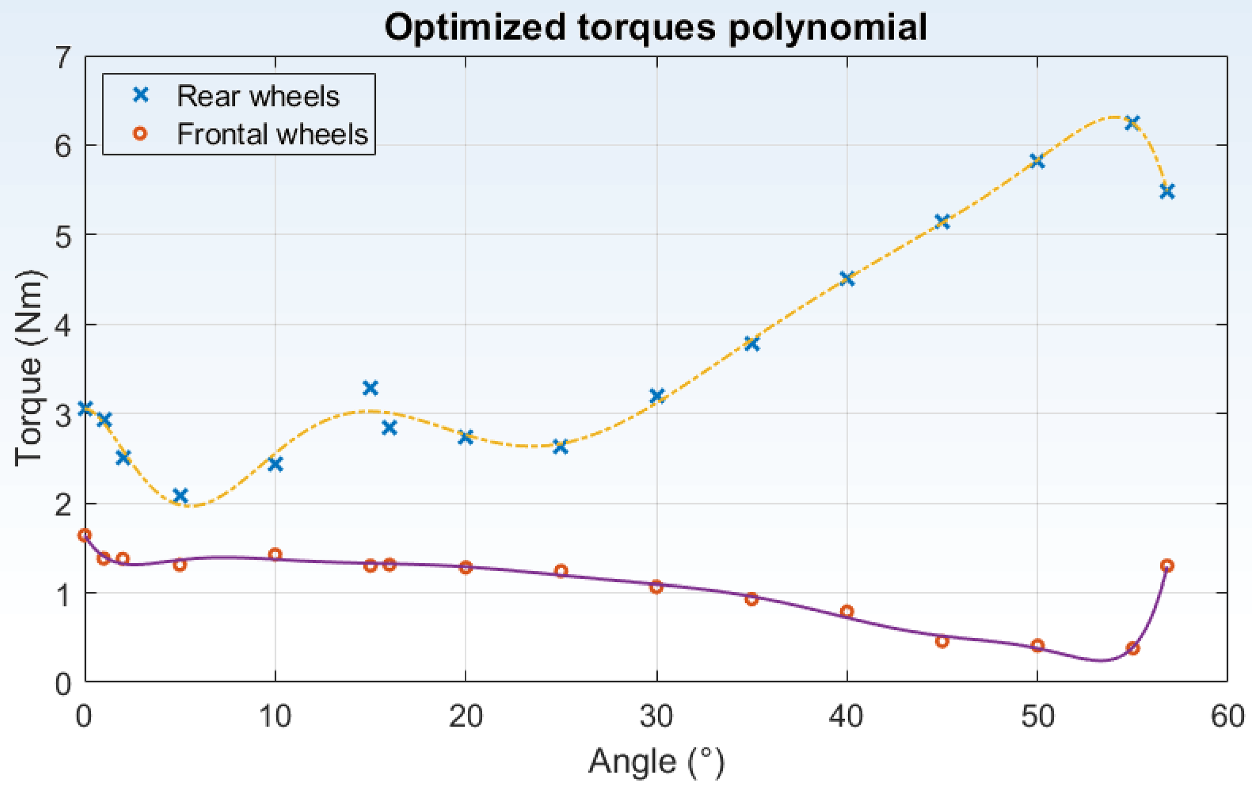
$$\begin{bmatrix} \cos(\alpha-\varepsilon_A) & -\sin(\alpha-\varepsilon_A) & \cos(\alpha-\varepsilon_B) & -\sin(\alpha-\varepsilon_B) \\ \sin(\alpha-\varepsilon_A) & \cos(\alpha-\varepsilon_A) & \sin(\alpha-\varepsilon_B) & \cos(\alpha-\varepsilon_B) \\ h-\frac{l}{2}\sin(\varepsilon_A-\alpha) & -\frac{l}{2}\cos(\varepsilon_A-\alpha) & h+\frac{l}{2}\sin(\varepsilon_B-\alpha) & \frac{l}{2}\cos(\varepsilon_B-\alpha) \end{bmatrix} \begin{bmatrix} F_A \\ N_A \\ F_B \\ N_B \end{bmatrix} = \begin{bmatrix} ma\cos(\alpha) \\ W-ma\sin(\alpha) \\ 0 \end{bmatrix}$$

A multi objective genetic algorithm is implemented to find sets of possible torque distributions according to different robot states, without considering system uncertainties. The torques at the frontal and rear wheels are optimized, while mechanical and electrical properties of the robot are considered as system restrictions. A dataset is built from simulations, while a 10th order polynomial fitting is used to predict the necessary torques for a certain task as a function of the chassis inclination.

Two mobile robots have been tested in this work, applied in different scenarios: PUMA+, a high-torque modular robot developed at the PUC-Rio Robotics Laboratory, and the BotKits 4WD Research Robot (BotKits.com).



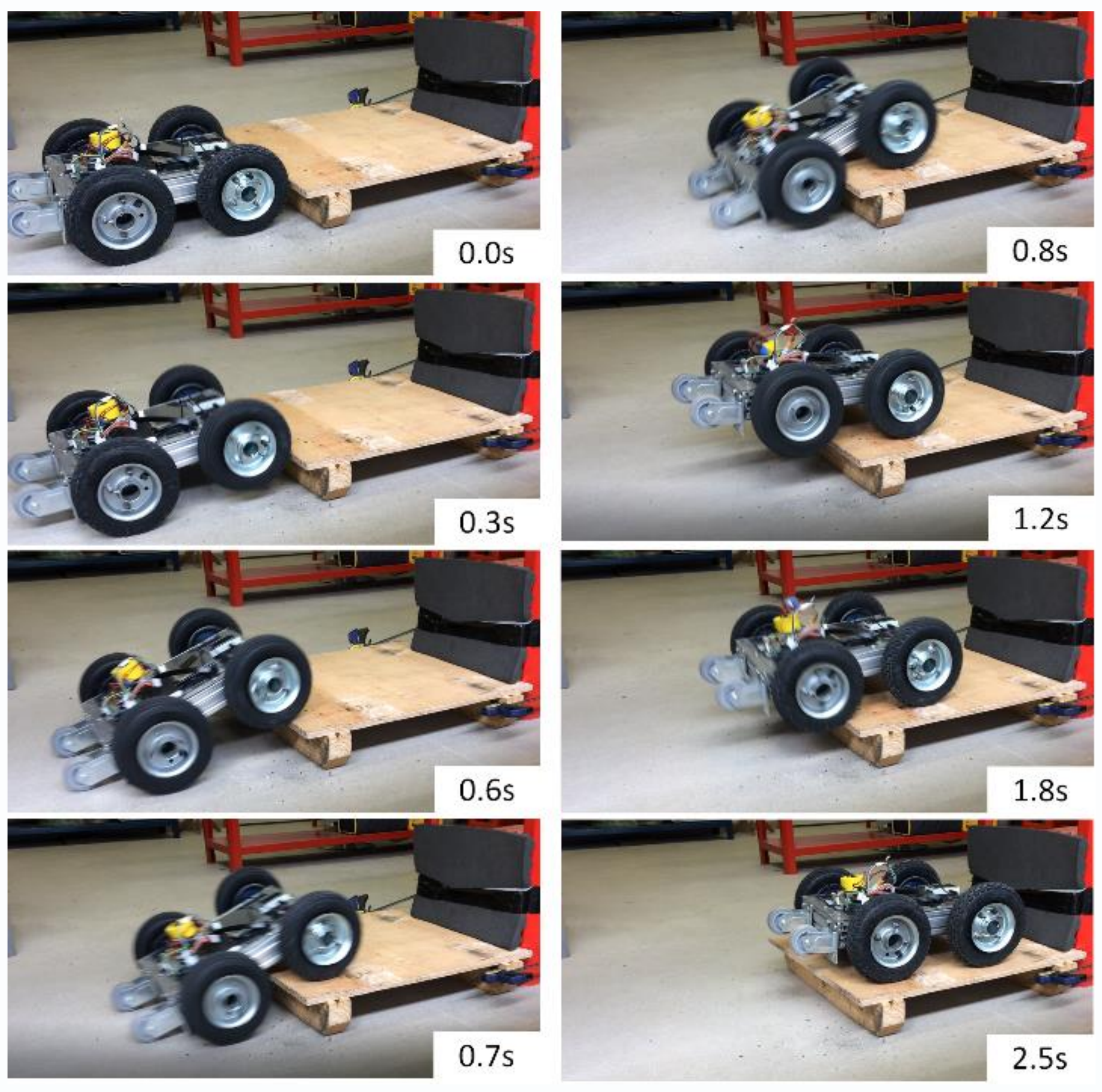
PUMA+ description	Value	Unit
Wheel radius	0.102	m
Distance between wheel axes	0.27	m
Robot total length	0.46	m
Robot total width	0.48	m
Robot mass	19.6	kg
Maximum power/motor	1.05	kW
Nominal voltage	21.0	V
Nominal current/motor	4.0	A
Stall current/motor	155	A
Maximum torque/wheel	7.2	N·m
Maximum linear velocity	11.0	m/s

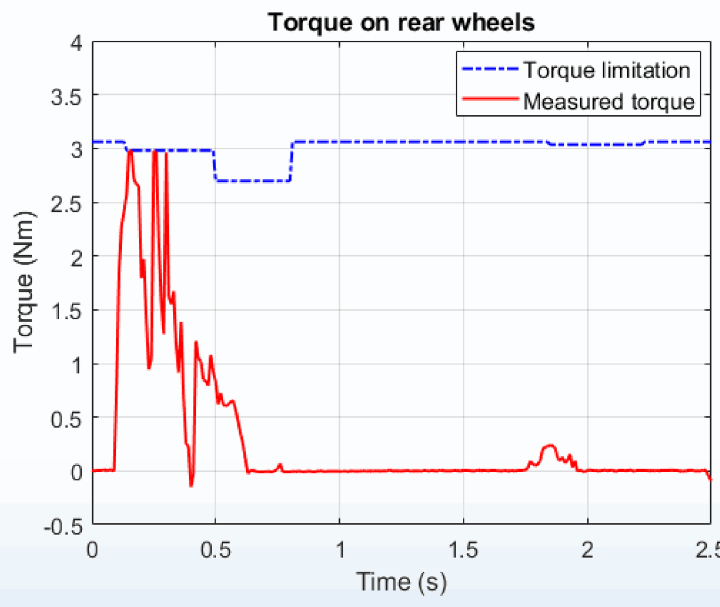


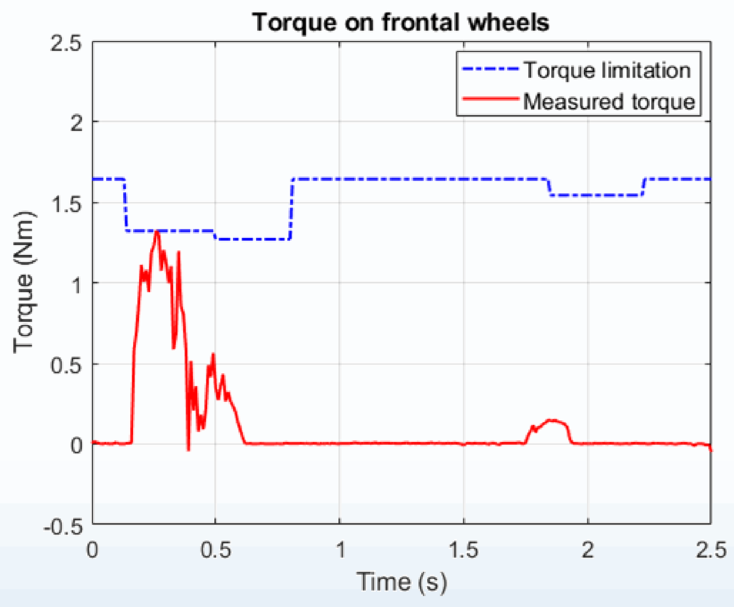
PUMA+ frontal and rear wheels optimized torques for tasks involving climbing ramps and general flat terrains, along with 10th order polynomial fittings, as a function of the chassis inclination. Real-time control is then implemented based on the fitted polynomial equations and measured chassis inclinations. A generalization is performed to show the algorithm can be used as well to climb steps or other small obstacles.

Experimental Analysis

The proposed torque optimization technique is validated using the BotKits robot for flat terrains, being able to climb up to 46-degree slopes with the algorithm. For step climbing tasks, the optimization is applied to the high-torque PUMA+, being able to fully climb steps with a height equal to its wheel radius in less than 3 seconds. In both cases, the robots accomplished tasks that were not achievable without the developed torque control strategy.







Conclusions

- The presented technique is suitable for general-purpose robots with four-wheel drive systems and individual torque control.
- It can be used in diverse terrains, as long as all wheels maintain contact with the ground.
- A 3D generalization of the algorithm will be developed to improve the method's applicability.