Determining Resistance to Motion for Small Wheeled Robots Using Soil Strength Failure Envelopes

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Keywords: Small mobile robots, Wheels, Terramechanics, Motion resistance, Failure envelopes

Abstract:

To accurately determine sinkage and resistance to motion, we use modern soil mechanics theory which utilises soil strength failure envelopes. This method allows the modelling of the terrain interaction with both driven or towed wheels. Our model is a significant improvement for small mobile robots, those weighing less than 50 kilograms and with a wheel diameter under half a metre, for which state of the art fails to properly determine dynamic sinkage or the resistance to motion. Small mobile robots are an area of great interest with applications in difficult terrain including; search and rescue, mapping, security, exploration, and agriculture. Our model describes the motion resistance faced during locomotion in these difficult terrains dependent solely on the structural parameters of the robot, the soil's type and its shear strength.

The proposed model addresses many of the issues apparent with the classical terramechanics approach to calculating resistance to motion. Primarily, these models were created for large agricultural or military vehicles. Additionally, they decouple the effects of multi-directional loading on the terrain. These both contribute to inaccurate predictions of the terrain interaction for small mobile robots. We address these problems by using the failure envelope method. This approach more accurately models the interlinked forces and moments that exist at the soil-wheel interface. The solution amalgamates various physical phenomenon previously calculated independently, such as compaction and rolling resistance, greatly simplifying the analysis. The number of empirical soil parameters is also significantly reduced to a single term in undrained soils and two in drained soils. These parameters are well established in the literature.

A failure envelope defines the bearing capacity of a soil at a particular footing. To find parameters centred around the axle, the failure envelope must be transformed from an approximated footing to one that is described by the weight, towing force and torque applied at the wheel's axle. Our model uses the property of the failure envelope surface which defines the type of failure the soil experiences under the applied forces and moments. Solving numerically for a given weight, wheel radius, wheel width and soil strength, gives a single solution for steady state locomotion where there is no vertical deformation in the soil. Our approach can be applied for both a driven or towed wheel, returning a required torque or towing force respectively. The model is augmented with a term that evaluates the work required to overcome unavoidable small, repeated obstacles found in difficult terrain such as uneven ground or flora. A natural scaling law is used to predict the distribution of various sized obstacles and the equivalent average resistance to motion that these obstacles present. As a whole, the model predicts the minimum required work needed to traverse a particular terrain populated with repetitive obstacles as might be found in terrains of interest such as forests, fields, rubble, desserts, or tundra.

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