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Estimating terrain parameters for a rigid wheeled rover using neural networks

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Abstract

This paper presents a method for extracting data on regolith online with a planetary exploration micro-rover. The method uses a trained neural network to map engineering data from an instrumented chassis to estimates of regolith parameters. The target application for this method is a low-cost micro-rover scout on Mars that will autonomously traverse the surface and detect changes in the regolith cohesion and shearing resistance without the need for dedicated visual sinkage estimation on each wheel. This method has been applied to *Kapvik*, a low-cost 30 kg micro-rover analogue designed and built for the Canadian Space Agency. Data was collected using a motor controller interface designed for *Kapvik* using off-the-shelf components. The neural network was trained from parameters derived by classical terramechanics theory using Matlab's Neural Network Toolbox. The results demonstrate a proof of concept that neural networks can estimate the terrain parameters which may have applications for automated online traction control.

Keywords: Terrain parameter estimation; Neural network; Planetary rovers; Traction control

1. Introduction

The Mars Exploration Rover (MER) *Spirit* landed on the plains of Gusev Crater on 4 January 2004. Its original mission life was 90 Martian solar days, otherwise known as sols. *Spirit* continued to operate until sol 2210 when communication with Earth ended. Its right front wheel drive actuator failed during its extended mission. This failure caused the front right wheel to be pushed through the terrain instead of being driven. *Spirit* continued its extended exploration mission with five active wheels until it became embedded in loose terrain on sol 1871. Several attempts were made to extract *Spirit* from the loose soil. However, on sol 2104 the right rear wheel also failed which furthered impeded *Spirit*'s mobility. With only four functioning wheels, *Spirit* was unable to overcome the terrain resistance and continued to function merely as a stationary research base [1]. *Spirit* was not the only MER to be impeded by loose terrain. *Opportunity* encountered 30 cm of loose aeolian deposits at Meridiani Plains in which all six wheels became embedded. The rover required 23 Sols and 150 m of commanded wheel movements to move 26 cm and free itself from the "Purgatory Ripple" [2].

Spirit and *Opportunity* became immobilized due to the presence of a non-geometric obstacle: loose terrain. The loose terrain that trapped *Spirit* was believed to be a weakly cohesive mixture of sulfate and basaltic sands that caused the rover to experience greater wheel slip and wheel sinkage. The tractive force generated by the wheel-terrain interaction was not enough to overcome the terrain resistance. Classical terramechanics theory, with previously estimated terrain parameters, validated this conclusion [1].

The purpose of this work is to provide a proof of concept of estimating two Mars terrain parameters, cohesion and shearing resistance, online during a micro-rover's traverse phase using trained neural networks. Mars soil is herein referred to as regolith. Micro-rovers are intended to be low-cost scouts for a larger class of rover, such as *Curiosity*

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Nomenclature

CAN	Controller Area Network
MER	Mars Exploration Rover
MLP	Multilayer Perceptron
MSE	Mean Square Error
RSD	Relative Standard Deviation
SEEG	Space Exploration Engineering Group

and *ExoMars*. The research includes the development of motor controller interface software that provides the inputs to the neural network. The research presented is an extension of the motor controller interface software developed for the *Kapvik* micro-rover.

1.1. Kapvik micro-rover

Kapvik, as shown in Fig. 1, is a 30 kg micro-rover analogue designed as a tool for further developing Canada's planetary exploration capabilities. The Space Exploration Engineering Group (SEEG) at Carleton University was responsible for the development of the mobility system. *Kapvik* has an instrumented six-wheeled rocker-bogie system with differential drive similar to NASA's fleet of exploration rovers: *Sojourner* [3], *Spirit* [2] and *Opportunity* [1], and *Curiosity* [4]. The rocker-bogie allows all six wheels to maintain ground contact to enhance mobility while allowing the rover to climb over rocks [5,6]. *Kapvik* was designed with a view to flight qualification, and to help assess potential exploration missions to which Canada may contribute. It was designed for temperatures associated with summer in the high arctic. Its trial operations will be in an unknown environment-likely in the Canadian Arctic-analogous to the Mars equatorial surface.

Fig. 1. *Kapvik*'s mobility system, including the motor controller interface, was developed by the SEEG team at Carleton University.

1.2. Related works

Classical terramechanics theory developed by Bekker [7] and later Wong [8] has been applied to planetary vehicles since the Apollo program [9,10]. Much of the recent research on applying terramechanics to planetary rovers has been led by the Massachusetts Institute for Technology (MIT) Field and Space Robotics Laboratory and MIT Robotic Mobility Group. Therefore, the simplified wheel-terrain interaction model in this paper is based upon their research [11–13]. Many other research groups have been researching terramechanics for planetary rovers. The Space Robotics Laboratory at Tohoku University has been developing autonomous traction control for planetary rovers [14,15]. The terramechanics of wheel grousers for planetary rovers has been researched at Dalhousie University [16,17]. Current planetary rover research in Europe is studying flexible wheels [18,19].

Online terrain classification and estimation has also been studied. Kleiner [20] successfully classified terrain based on vision and wheel vibrations; however, the terrain greatly varied (grass versus asphalt versus gravel) and there was no indication this classification method could detect changes in the properties of a single terrain type. Brooks [21,22] also used wheel vibrations to classify between more similar terrain types but not to estimate terrain parameters. Tan [23] and Yousefi Moghaddam [24] each proposed a method for estimating terrain parameters online; however their application was for excavation and not based on wheel-terrain interaction. Iagnemma used a simplified wheel-terrain interaction model [11–13] for estimating the two terrain parameters online for an exploration rover. He solved for $[c, \phi]$ using linear least squares with a set of sensor data $[V, \omega, z, I]$, a quasi-static wheel load W, and assumed shear deformation parameter K. His laboratory experiments, using an instrumented testbed, showed that the least squares estimates for $[c, \phi]$ of the sand were within range of the bevameter measurements. An *a priori* value for the shear deformation parameter K was needed to solve the least squares estimate. He also estimated the terrain parameters for a six-wheeled rover in a Matlab