Abstract for the ICRA08 Planetary Rovers Workshop

Slip Estimation and Compensation Control for Lunar/Planetary Rovers on Loose Soil

Kazuya Yoshida, Keiji Nagatani, Genya Ishigami
Dept. of Aerospace Engineering, Tohoku University, Japan
Giulio Reina
Dept. of Innovation Engineering, University of Salento, Italy

For a mobile robot, it is critical to detect and compensate for slippage, especially when driving in rough terrain environments. Due to its highly unpredictable nature, drift largely affects the accuracy of localization and control systems, even leading, in extreme cases, to total immobility of the vehicle. In this presentation, the authors discuss analytical and empirical models for the mechanics of wheel traction and slippage, practical methods for effective slip estimation, then the algorithms for on-line slip compensation control.

For the traction mechanics, terramechanics-based models originally developed by Bekker [1] and extended by Wong [2] are employed as a background theory, with which wheel traction forces both in longitudinal and lateral directions are modeled as a function of slippages measured by the *slip ratio* in the longitudinal direction and the *slip angle* in the lateral direction [3]. Also the Dugoff's tire model [4] is discussed to describe the relationship the longitudinal and lateral slippages.

For the slip estimation during the traverse of loose terrain, the authors recently developed a couple of methods, both of which use an optical camera. One is a method based on the *optical flow* analysis and the other analyses the traces of the wheels marked on the terrain [5]. Both methods are validated very useful in practical situations by the experiments using a rover test bed named *El Dorado* (see Fig.1).

For the slip compensation control, an illustrative example is presented for the case that a four wheel rover (*El Dorado*) traverses a sandy side slope. Without any compensation control, the rover makes sideslips due to the gravity pull in the downward direction of the slope. Then the counter steer action is necessary to follow the given trajectory. The amount of the counter steer angle of each wheel is derived from the slippage model discussed in the first part of the presentation. These values are used as a feed forward signal in the compensation control. Also by monitoring the real slip motion of the vehicle using the optical methods discussed in the second part of the presentation, a feed back control is constituted to compensate the residual tracking errors. The combination of feed forward and feed back control achieves a good performance in the slip compensation control (see Figs.2 and 3).

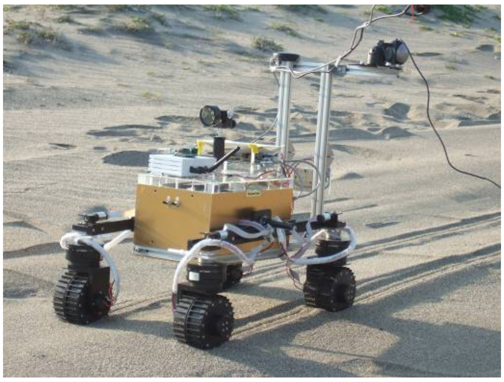


Fig.1: A rover test bed “El Dorado” in a beach sand environment

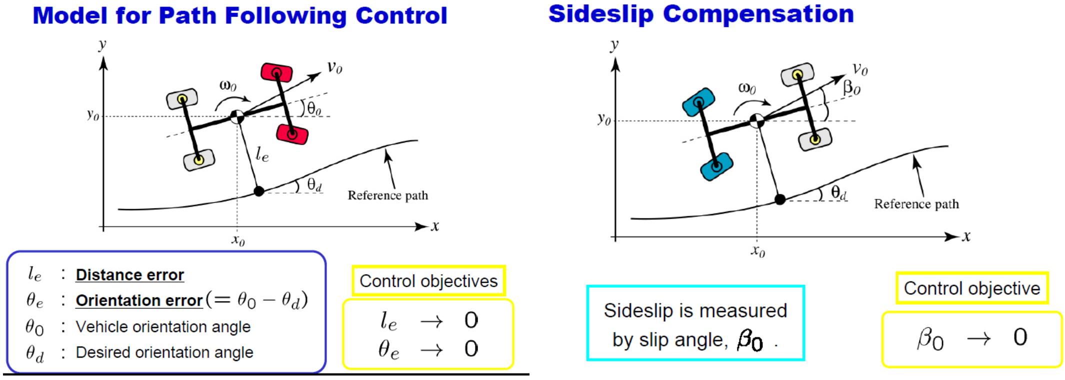
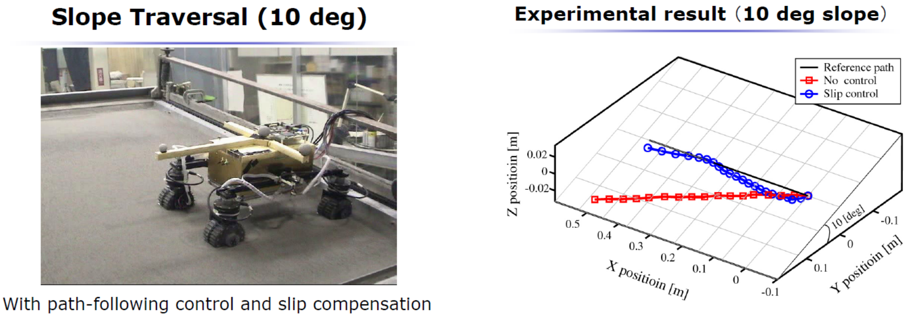


Fig.2: Principle models for path following control with slip compensation



With path-following control and slip compensation

Fig.3: Experiments for the path following control with slip compensation on a loose side slope

[1] Bekker, M. G., *Introduction to Terrain-Vehicle Systems*, Ann Arbor, The University of Michigan Press, 1969

[2] Wong, J. Y., *Theory of Ground Vehicles*, John Wiley & Sons, 1978

[3] G. Ishigami, A. Miwa, K. Nagatani and K. Yoshida, “Terramechanics-Based Model for Steering Maneuver of Planetary Exploration Rovers on Loose Soil”, *The Journal of Field Robotics*, Vol. 24, Issue 3, pp. 233-250, 2007.

[4] H. Dugoff, P. S. Fancher, and L. Segel. “An Analysis of Tire Traction Properties and Their Influence on Vehicle Dynamic Performance”, *SAE Trnsactions*,79, pp. 341-366, 1970.

[5] Giulio Reina, Genya Ishigami, Keiji Nagatani, and Kazuya Yoshida, “Vision-based Estimation of Slip Angle for Mobile Robots and Planetary Rovers”, to appear in *ICRA2008*.