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Towards an Enhanced Controller for Stable Slope Climbing

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Abstract

Quadruped robot locomotion is a difficult task due to the increased system complexity and its rough environment. In addition, critical stability issues emerge when considering multibody systems such as quadruped robots. Legged robots have complex dynamics and many degrees of freedom that must be well orchestrated for achieving a robust and dynamically stable locomotion pattern. Handling positive or negative slopes enhances the locomotion qualities of legged robots, but demands more from its actuation system. However, higher torque requirements have an adverse impact on a robot's total mass.

Legged robots have an advantage in dealing with various terrain types, or in handling terrain discontinuities with the use of accurate foot placement. Such systems have hybrid dynamics that are described by different sets of differential equations, according to the phase at which the robot is in (flight phase, double stance phase, etc.). Up to now, enhanced controllers, e.g. by means of computer vision [1], have been implemented for trotting on rough terrain. However, legged robots are difficult to control and as a result, they are subject to dangerous tipover instabilities. Tipover prevention criteria have been introduced aiming at prevention of dangerous situations for mobile manipulator systems [2]. Such criteria take into account tipover or rollover when operating over uneven terrain, and/or when exerting large forces or moments [6].

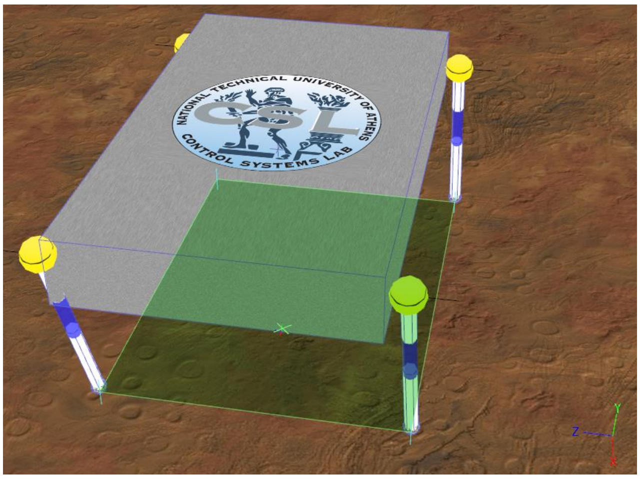

Figure 1: The 3D model of the NTUA quadruped in Webots 8 Simulation Environment during dynamic running. The projection of the body's CoM is within the robot's support polygon. Pronking on a 20° slope has been achieved.

In our current work, we investigate stability issues of quadruped robots on positive and negative slopes subject to various disturbances. For this purpose, a 3D quadruped robot model has been implemented in Webots 8, [4]. The model is equipped with the necessary sensors (gyros, accelerometers, force sensors, laser range finder etc.) for state estimation and accurate phase triggering. The control algorithm uses sensor measurements to calculate the necessary torque and touchdown leg angles for stable pronking. Initially, the robot is controlled to perform pronking on level ground. Gradually, the inclination is increased. The quadruped's performance is validated to be similar to [5]. We analyze how stable dynamic running can be performed as terrain morphology changes, how the quadruped's gaits can be rearranged in order to carry out these tasks, and what

makes a gait more persistent to disturbances compared to alternative ones. The answer to these key questions will help us achieve stable motions similar to mobile manipulators on various terrain types and enhance already presented tipover criteria [2].

In this work, we seek to enhance the controller in various ways by answering the previously stated questions. To this end, we examine the different support situations for quadrupeds. Firstly, during the double stance phase, the legs are in contact with the ground and form a support polygon. As a result, the force angle stability measure and time to tipover can be calculated [6]. Secondly, we study quasi-static situations, during which the projection of the robot center of mass (CoM) lies at the edge of the support polygon formed by the three legs that are in contact with the ground. Then, if the robot tends to fall toward the only leg that is not in contact with the ground, the stability can be ensured again. Finally, experiments with the NTUA quadruped show that, during dynamic running, tipover may occur when the robot rotates around the (front) left toe – right toe axis (or back left and right toes respectively). In this case, we seek solutions in which the total force acting on the CoM is pointing towards the side of the robot with a leg about to contact the ground. Overall, no single approach for every terrain or inclination exists, but instead stable running also depends on the friction between the tow and the ground as well as the compliance of the ground.

Simulations will be performed for level ground and for a maximum slope of 20°. Initial experiments have been conducted with the quadruped model in Webots 8, performing pronking or bounding using a controller previously developed [3]. With this controller, forward velocity on lift-off and apex height, are maintained within desired limits. During these simulations, and using the force-angle stability measure, the time to tipover will be calculated. At ECOMASS 2015, we will present our latest results and conclusions towards an enhanced controller for stable slope climbing. In addition, we will show that dynamic running cannot be performed if ground inclination or robot's CoM increases beyond a specific level, depending on friction, weight and torque capabilities.

References

[1] S. Bazeille, V. Barasuol, M. Focchi, I. Havoutis, M. Frigerio, J. Buchli, C. Semini, and D. G. Caldwell, "Vision enhanced reactive locomotion control for trotting on rough terrain," in Technologies for Practical Robot Applications (TePRA), 2013 IEEE International Conference on, 2013, pp. 1–6.

[2] E. G. Papadopoulos and D. A. Rey, "A new measure of tipover stability margin for mobile manipulators," in Proceedings IEEE International Conference on Robotics and Automation, 1996, vol. 4, pp. 3111–3116 vol.4.

[3] N. Cherouvim and E. Papadopoulos, "Use of a novel multipart controller for the parametric study of a trotting quadruped robot," in Proceedings IEEE International Conference on Robotics and Automation, 2008, pp. 805–810.

[4] O. Michel, "Webots: Professional Mobile Robot Simulation," Int. J. Advanced Robotic Systems, vol. 1, no. 1, pp. 39–42, 2004.

[5] Kontolatis I. and E. Papadopoulos, "Dynamic Running Quadruped for Crater Exploration," in 11th International Symposium on Artificial Intelligence, Robotics and Automation in Space, (i-SAIRAS), Turin, 2012.

[6] D. A. Rey and E. G. Papadoupoulos, "Online automatic tipover prevention for mobile manipulators," in Proceedings of the 1997 IEEE/RSJ International Conference on Intelligent Robots and Systems, (IROS '97), 1997, vol. 3, pp. 1273–1278.