Tik-Tok: a high-performance legged locomotion platform

Jason Cortell[1]

[1]Cornell University

[1]jbc2@cornell.edu

Summary

We demonstrate initial performance of the electric biped/legged locomotion platform Tik-Tok, which aims to approach human-level locomotion performance in energy effectiveness, agility, and robust balance. Energy use is minimized through use of high-efficiency brushless motors and chain drives; high peak power capability at the joints allows rapid repositioning of the feet for robust maintenance of balance. This new robot is intended to traverse normal human built environments safely and reliably−sidewalks, floors, and eventually stairs−with minimal power use. With an energy cost of transport (COT, power/(weight*speed)) approximately that of a human, it should be able to walk over two hours and 10 km on the charge in a 2 kg battery.

Design specifications

Leg length	0.8 m
Height, including torso and head	1.5 m
Mass	30 kg
Battery mass	2 kg
Battery capacity	250 W-hr
Cost of transport (COT), overall, walking	0.25
Joint torque (knee, thigh), continuous	75 Nm
Joint torque (knee, thigh), peak	200 Nm
Joint speed, peak	10 rad/sec
Joint power, peak	2 kW
Walking speed	1.5 m/s
Jogging speed	3 m/s

The main design focus has been on the lower body, where it has 4 degrees of freedom (DOF) per side. From bottom to top, these include ankle flexion, knee, leg swing, and leg adduction/abduction. There is space at the top in the hip design for a future leg rotation DOF also.

Since Tik-Tok is intended to be primarily a locomotion platform and not a full humanoid, the upper body DOF presently include only shoulder flexion/extension and abduction/adduction, allowing the arms to swing during walking and balance. In total, Tik-Tok has 12 controlled DOF.

Features

1) RoboDrive brushless torque motor kits give high torque efficiency for their weight. Along with optimized gear ratios for walking and high-efficiency chain transmissions, this allows a human-like COT of about 0.25.
2) High-stiffness titanium springs in series with the leg actuators act as low-pass filters, thus reducing the bandwidth of external collision loads and giving the motor controllers more time to respond.
3) Overload slip clutches built into the transmission sprockets provide backup protection for components during impacts and falls.
4) Electronics. Each controlled degree of freedom includes one motor controller and one sensor board using the 300MHz Atmel SAME70 microcontroller, and networked via CAN-FD bus. These are in turn connected to a BeagleBone Black board running control and joint coordination code. The motor controllers were designed specifically for low power consumption at low (e.g., walking) loads, while being capable of up to 5 kW of power output for emergency motions.
5) Sensing. Each motor shaft has a magnetic angle sensor, as does each joint. Each joint circuit board also includes a low-cost 6-axis IMU and circuits for measuring strain (and thus estimating joint torque) in the titanium series springs. The feet feature an array of MEMS pressure sensors for detailed ground contact force estimation [1]. A high-performance commercial INS (Inertial Navigation System) unit is used to determine overall body orientation and location.

Robust balance

Unlike many other biped robots with wide, flat feet, Tik-Tok has narrow, light feet. It relies on rapid repositioning of the feet (step times under 0.2 seconds, comparable to humans) to maintain balance after a disturbance; it uses ankle torques and limb configuration changes only minimally, to adjust for minor disturbances. Recent work by Zaytsev, Wolfslag and Ruina [2] shows the dominant role of stepping and fast foot placement in preventing falls after a large balance disturbance (the Kick). By contrast, ankle torques and upper body motion can make only small contributions to balance recovery.

References

[1] Yaroslav Tenzer, Leif P Jentoft, and Robert D Howe. Inexpensive and easily customized tactile array sensors using mems barometers chips. *IEEE Robot. Autom. Mag*, 21(3):89-95, 2014.

[2] P Zaytsev, W Wolfslag, and A Ruina. Viability and controllability of simple models help understanding of walking stability. *IEEE Transactions on Robotics*, 2016 (in preparation).