Posture Control of a Cockroach-Like Robot

GABRIEL NELSON and ROGER QUINN

In this issue, "25 Years Ago" revisits the article "Posture Control of a Cockroach-Like Robot" by Gabriel Nelson and Roger Quinn, in *IEEE Control Systems Magazine*, vol. 19, no. 2, pp. 9–14. Below is an excerpt from the article.

As legged robots become more animal-like, it is likely that these robots will have many complex limbs with redundant degrees of freedom (DOF). This is especially true when we desire them to move like an animal. Animals are capable of spontaneous and non-stereotyped locomotion, such as turning, swaying, twisting, deliberately falling, jumping, climbing, and running. Therefore, it becomes difficult to provide joint space trajectories, in real-time, for these complex movements when many limbs are simultaneously involved, and when some or all of these limbs contain redundant DOF. When locomotion takes place rapidly, it has been suggested that there is a feedforward control component that involves a proactive, higher level computation in the nervous system [1]. In this paper, we suggest and demonstrate an intuitive and computationally simple algorithm for controlling the posture of a complex, multileg robot with many redundant DOF. The algorithm avoids inverse kinematics by issuing feedforward force commands to both maintain static posture and generate body motion. In so doing, it is also shown that the multileg mechanics of postural control can be reduced to a simple center-of-pressure representation, or equivalently, an instantaneous virtual leg model. A previous Bio-Robotics Laboratory robot, Robot II [2], was inspired by the stick insect and had three degrees of freedom in each of its six legs. It was built as part of the ongoing Bio-Robotics program [3] at Case Western Reserve University. Joints were driven by DC motors using proportional position control with variable gains. The robot could walk in a continuum of insect-like gaits and traverse irregular terrain using an insect-based

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distributed controller. Posture control was achieved by a mixture of processes local to joints and legs, and two global algorithms.

The first global algorithm compared an individual leg load to the average across all legs, and incremented the desired foot position to help equalize load among legs. The second monitored body orientation by averaging shoulder positions and adjusting desired foot setpoints to conform the body to overall terrain orientation.

Robot III [4], [5], is a hexapod robot modeled after the *Blaberus* cockroach (see Fig. 1). The robot has an overall body length of 30 inches, which is 17 times larger than the animal. The total weight of the robot is 30 pounds. Three, four, and five DOF in each rear, middle, and front leg, respectively, enable propulsion, lifting and turning, and sensory functions [6]. These 24 DOF are actuated using 36 off-the-shelf, double-acting pneumatic cylinders 171. Each joint uses a pair of three-way solenoid valves driven with 50 Hertz pulse-width-modulation. Single-turn potentiometers provide angle feedback at each joint. 100 psi air is supplied to the valve blocks at the rear of the abdomen. The force output of the cylinders can be approximated by a sigmoidal function of the duty cycle, with piston-face area and supply pressure parameters.

POSTURE CONTROLLER

Posture control is the active and continuous maintenance of body stability in all regimes of locomotion. These regimes include standing, walking, and running. In ongoing research in physiology, wherein researchers are seeking to understand how control responsibility for posture and locomotion is distributed throughout the nervous system, one aspect that is clear is the importance of higher centers of the nervous system for normal posture.

This suggests that posture control is more than local reflex interaction. It is the orchestration and tuning of these reflexes according to some central desired behavior.

Horak and Macpherson write in the Handbook of Physiology [8]:

> *Posture is no longer considered simply as the summation of static reflexes but, rather, the complex interaction of sensorimotor processes and internal representations of those processes. Postural orientation involves active control of joint stiffnesses and such global variables as trunk and head alignment, based on the interpretation of convergent sensory information. Postural equilibrium involves coordination of efficient sensorimotor strategies to control the many degrees of freedom for stabilization of the body's center of mass during either unexpected or voluntary disturbances of stability.*

Although investigated in different contexts and by various researchers, the approach to posture control for Robot III was inspired by the Virtual Model control scheme as presented by Pratt, et al. [9]. […] This paper proposes an internal model tailored to the locomotion needs of a system such as Robot III. The concepts represented by this model are by no means new [12], [13], but one goal of this work is to demonstrate the successful implementation of these ideas into a complex, animal-like robot.

RESULTS

This algorithm has been successfully implemented, and is able to control the posture of Robot III in the presence of disturbances, as well as in response to commanded body positions and orientations. Although not discussed here, the algorithm can be modified to maintain posture while legs lift and plant. In all cases, independent of the number of legs in stance, the same methods can be used.

One particularly remarkable result is given the robot's mechanical characteristics, and using this controller, the robot is able to easily lift a payload equal to its own body weight. Fig. 6 shows Robot III lifting a 30 pound payload suspended below the robot with cables. The robot is able to do "push-ups" while lifting this payload.

Another very attractive result involving this algorithm is computational simplicity. As implemented above, the largest procedural calculation is the solving of three different 3x3 systems once per cycle. This occurs once when C_{1N} is estimated and could be eliminated with a suitable attitude sensor on the body. However, no such sensor exists in the cockroach.

CONCLUSIONS

This paper presents two main contributions. The first is that the force distribution problem for a multi-legged system such as Robot III has already embedded within it a single leg model which intuitively describes the mechanics. This model is derived mathematically, yet is intuitive and connects well with previous observations by both biologists and roboticists [21]. It is central in solving the redundancy problem and produces a computationally simple algorithm for controlling posture during locomotion. The second point is that this algorithm has been successfully implemented on a complex 24 DOF cockroach-like robot.

The resulting controller is able to control all six three-dimensional DOF of the body, and should provide an excellent basis for general locomotion.

REFERENCES

[1] A. Prochazka, "Proprioceptive feedback and movement regulation," in *Handbook of Physiology*, sec. 12, L. Rowell and J. T. Shepherd, Eds. New York, NY, USA: American Philosophical Soc., pp. 89–127, 1996.

[2] K. S. Espenschied, R. D. Quinn, H. J. Chiel, and H. J. Beer, "Biologically based distributed control and local reflexes improve rough terrain locomotion in a hexapod robot," *Robot. Auton. Syst.*, vol. 18, pp. 59–64, Jul. 1996, doi: 10.1016/0921-8890(96)00003-6.

[3] R. D. Beer, R. D. Quinn, H. J. Chiel, and R. E. Ritzmann, "Biologically inspired approaches to robotics," *Commun. ACM*, vol. 40, no. 3, pp. 31–38, Mar. 1997.

[4] G. M. Nelson, R. D. Quinn, R. J. Bachmann, W. C. Flannigan, R. E. Ritzmann, and J. T. Watson, "Design and simulation of a cockroach-like hexapod robot," in *Proc. IEEE Int. Conf. Robot. Automat.*, Albuquerque, NM, USA, 1997, vol. 2, pp. 1106–1111, doi: 10.1109/ROBOT.1997.614284.

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if the Chapter could inspire young researchers with a reasonable amount of work, and I decided to increase my commitment to start new attempts."

—Toshiyuki Ohtsuka, chair of the Kansai Chapter, Japan.

"I like to contribute to developments and programs of scientific organizations. Seeing that there was no CSS Chapter in Hungary, there was no question to establish it."

—Levente Kovács, chair of the Hungary Chapter and 2021 recipient of the CSS Outstanding Chapter Award.

LOOKING AHEAD

During the inaugural CSS Day in 2022, Chapter activities emerged as an integral component of the program. Locally arranged activities were broadcast to the global CSS community through the online conference platform; see also [4]. This possibility to reach an even wider audience than the regional CSS members was widely appreciated. Moving forward, identifying platforms and strategies to showcase the diverse range of Chapter activities to all CSS members is a priority. CSS Day will also be a recurring event, and we look forward to strong Chapter participation in 2024. Finally, the IEEE CSS Member Activities Board annually bestows one Chapter with the Outstanding Chapter Award. It recognizes Chapters that demonstrate notable activity or innovation and exert a positive influence on the Society and its members, also considering diversity and inclusiveness. The Chapter volunteers who are recipients of this award not only serve as an inspiration to other Chapters but also to myself and the Society as a whole.

Emma Tegling
Chapter Activities Committee chair

REFERENCES

[1] "IEEE Member and Geographic Activities, Operations Manual 2023," IEEE MGA Board, Piscataway, NJ, USA, Jun. 2023. [Online]. Available: https://mga.ieee.org/images/files/Current MGA_Operations_Manual_2023_June_29_2023_CG_v1.1.pdf

[2] D. E. Rivera, "IEEE Control Systems Society Outreach Fund [Member Activities]," *IEEE Control Syst. Mag.*, vol. 39, no. 4, pp. 15–83, Aug. 2019, doi: 10.1109/MCS.2019.2913488.

[3] "CSS Chapter Activities website." IEEE Control Systems Society. Accessed: Jan. 4, 2024. [Online]. Available: https://www.ieeecss.org/activities/chapter-activities

[4] E. Tegling, "IEEE Control Systems Society chapters celebrate CSS Day [Member Activities]," *IEEE Control Syst. Mag.*, vol. 43, no. 2, pp. 12–13, Apr. 2023, doi: 10.1109/MCS.2023.3234379.

PRESIDENT'S MESSAGE (continued from p. 10)

Karl Astrom profoundly describing control as a "soul with no body" at the 1993 IFAC World Congress.

Most of us usually associate control with an application area when trying to describe what control does—robotics is our usual default. Nevertheless, despite the relative invisibility of control, it is universally useful, and a simple Google Scholar search rewarded us with [1], which addresses the issues of climate change and energy use from an essential "control" perspective, examining the potential effect of various interventions and mitigation (control actions). For JR, the application of control in renewable energy is particularly rewarding, while ME has gravitated toward environmental monitoring applications. They both point to the same thing, though—controls relevance to the broader climate conversation. However, while relatively well-defined problems, such as energy maximization, are somewhat straightforward, the higher-level (but more important) issues of cost reduction of renewables or supply/demand matching are more challenging. Nevertheless, we must chip away at any pieces of these global problems, and, hopefully, the great global researchers of our time will show the route to sustainable solutions.

John Ringwood and Magnus Egerstedt

REFERENCE

[1] M. Stephenson, *Energy and Climate Change: An Introduction to Geological Controls, Interventions and Mitigations*. New York, NY, USA: Elsevier, 2018.

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[5] R. J. Bachmann, G. M. Nelson, W. C. Flannigan, R. D. Quinn, J. T. Watson, and R. E. Ritzmann, "Construction of a cockroach-like hexapod robot," in *Proc. 11th VPI & SU Symp. Structural Dyn. Control*, 1997, pp. 647–654.

[6] J. T. Watson, A. K. Tryba, and R. E. Ritzmann, "Analysis of prothoracic leg movement during walking and climbing in the cockroach," *Soc. Neurosci. Abstr.*, vol. 22, no. 1077, pp. 86–90, 1996.

[7] G. M. Nelson, R. J. Bachmann, R. D. Quinn, J. T. Watson, and R. E. Ritzmann, "Posture control of a cockroach-like robot (video)," in *Video Proc. IEEE Int. Conf. Robot. Automat.*, Leuven, Belgium, 1998. [Online]. Available: http://biorobots.cwru.edu/Projects/robot3/robot3.htm

[8] F. B. Horak and J. M. Macpherson, "Postural orientation and equilibrium," in *Handbook of Physiology*, sec. 12, L. Rowell and J. T. Shepherd, Eds. New York, NY, USA: Oxford Univ. Press, pp. 255–292, 1996.

[9] J. Pratt, P. Dilworth, and G. Pratt, "Virtual model control of a bipedal walking robot," in *Proc. IEEE Int. Conf. Robot. Automat.*, Albuquerque, NM, USA, 1997, pp. 193–198, doi: 10.1109/ROBOT.1997.620037.

[12] M. H. Raibert, M. Chepponis, and H. B. Brown Jr., "Running on four legs as though they were one," *IEEE J. Robot. Automat.*, vol. RA-2, no. 2, pp. 70–82, Jun. 1986, doi: 10.1109/JRA.1986.1087044.

[13] R. Blickhan and R. J. Full, "Similarity in multilegged locomotion: Bouncing like a monopode," *J. Comparative Physiol. A*, vo1. 117, pp. 509–517, Nov. 1993, doi: 10.1007/BF00197760.