PERFORMANCE REPORT

A Biologically-Inspired Autonomous Robot

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Randall D. Beer
Principal Investigator
Department of Computer Engineering and Science
Department of Biology
Case Western Reserve University
Telephone: (216) 368-2816

Research Progress

- The distributed nature of the stick insect leg coordination mechanisms permitted a straightforward implementation of reflexes for the negotiation of rough terrain in our second robot. Using a searching behavior based the work of Pearson and Franklin with the locust, the robot can also walk over slatted surfaces. Horizontal compliance was added to allow legs to comply with external disturbances by actively reducing the stiffness. In response to a sufficiently large horizontal disturbance, the legs exhibit a stepping behavior reminiscent of the stepping strategy reported by Zill in locust. In addition, when one leg of a walking robot is placed on a substrate that is stationary relative to the moving robot (so that it does not step), the remaining legs continue to step due to the distributed nature of the controller. This experiment is analogous to one performed on the stick insect by Cruse and colleagues.

- A 36 degree of freedom dynamic simulation of a free-walking cockroach has been developed. This simulation allows the insect's ground reaction forces and joint torques to be predicted given kinematic data from high-speed video. Preliminary results show good correlation with actual measurements.

- We have now completed a preliminary model of the relationship between EMG activity and active muscle force development in the flexor and extensor muscles of the femur-tibia joint in the metathoracic leg. In addition, we have refined our models of the insertion geometry and damping characteristics of these muscles. We are in the process of incorporating all of these various components into a complete musculoskeletal model of this joint.

- The basic description of muscle activity and kinematics of a freely running cockroach is approaching completion. In the metathoracic legs ,the coxa-femur (CF) and femur-tibia (FT) joints move in synchrony and the extent of movement at these joints is essentially the same. In the mesothoracic legs, these two joints move synchronously but the extent of movement of the FT joint is approximately half that of the CF joint. A comparison of the motor activity in those joints shows little difference in the initiation and completion of depressor (CF) and extensor (FT) activity or in their relationship to antagonistic muscle activation. However, a closer look at the relationship between muscle potential frequency and velocity of joint movement reveals an interesting difference between mesothoracic and metathoracic joints. First of all, we found a linear relationship between muscle potential frequency and velocity of joint movement for the speed of walking that we studied. The points for the CF joints were evenly distributed in both the mesothoracic and metathoracic legs. However, the frequency of mesothoracic FT extensors was consistently lower than the frequency for metathoracic FT extensors. These points, therefore, are found in two separate locations along a continuous function. The conclusion is that the smaller FT movements in the mesothoracic legs relative to the metathoracic legs is due to a lower frequency of motor activity over the same burst period.

- In high speed running, joint speed can increase up to a point by increasing frequency of slow motor activity. Beyond this point, fast motor neurons must then be activated to make the leg joints move at higher velocities. Although there is some overlap in joint velocity due to high frequency slow motor activity and single fast motor potentials, very fast running clearly requires recruitment of fast motor neurons. Fast depressors (CF joint) and fast extensors (FT joint) are recruited at the same time and tend to be initiated at the joint transition between the end of flexion and the beginning of depression.

- We have also observed some turning movements that occur during running. Unlike escape movements, during a run the animal must factor in which of the two sets of legs (tripods) are on the ground at the time of the turn. Regardless, the turn is accomplished by altering the relative activity of the right and left mesothoracic and metathoracic legs. For example, a turn to the right can be accomplished by activating the right mesothoracic leg joints at a higher frequency while activating the left metathoracic leg joints at a lower frequency or by activating the right metathoracic leg joints at a higher frequency while activating the left mesothoracic leg joints at a lower frequency depending on which of these two sets of legs are in contact with the substrate at the time of execution.

Publications

Beer, R.D. (submitted). On the dynamics of small continuous-time recurrent neural networks. Submitted to *Adaptive Behavior.*

Beer, R.D., Marx, W.J., Nelson, G.M., Espenschied, K.S., Quinn, R.D., Watson, J.T., Ritzmann, R.E. and Chiel, H.J. (1994). Contributions of peripheral properties to insect and robot locomotion. *Soc. Neurosci. Abstr.* **20**: 1594.

Dellaert, F. (1994). Toward a biologically-defensible model of development, M.S. Thesis, Case Western Reserve University.

Dellaert, F. and Beer, R.D. (1994). Toward an evolvable model of development for autonomous agent synthesis. In Brooks, R. and Maes, P. (Eds.), *Artificial Life IV* (pp. 246-257). MIT Press.

Espenschied, K.S., Quinn, R.D., Chiel, H.J. and Beer, R.D. (1994). Biologically-inspired hexapod robot control. Proceedings of the 5th International Symposium on Robotics and Manufacturing (ISRAM 94), Maui, August 14-18, 1994.

Espenschied, K.S., (1994). Biologically-inspired control of an insect-like hexapod robot on rough terrain, Ph.D. Dissertation, Case Western Reserve University.

Watson, J.T. , R.E. Ritzmann (1994). Kinematic and EMG analysis of fast and slow running in the cockroach. To appear in *Soc. Neurosci. Abstr.* **20**: 1594.

Watson, J.T. and Ritzmann, R.E. (submitted). Combined intracellular stimulation and high speed video motion analysis of motor control neurons in the cockroach, submitted to *J. Neurosci. Meth.*

Yamauchi, B. and Beer, R.D. (1994). Integrating reactive, sequential and learning behavior using dynamical neural networks. In D. Cliff, P. Husbands, J. Meyer and S. Wilson (Eds.), *From Animals to Animats 3: Proceedings of the Third International Conference on Simulation of Adaptive Behavior* (pp. 382-391). MIT Press.

Presentations

R. Quinn gave a talk at an ONR workshop, Arlington, Virginia, Dec. 12, 1994.

R. Beer gave an invited talk at the workshop on "The Role of Dynamics and Representation in Adaptive Behavior and Cognition", San Sebastian, Spain, Dec. 9-10, 1994.

H. Chiel gave an invited talk at Oberlin College, Oberlin, Ohio, Dec. 8, 1994.

R. Quinn gave an invited talk at Pennsylvania State University, October 19, 1994.

K. Espenschied Gave a talk at the GSRP Annual Symposium, NASA Goddard Space Flight Center, Greenbelt, Maryland, Sept. 21-23, 1994.

R. Beer gave an invited talk at Washington University, St. Louis, Missouri, Sept. 15, 1994.

R. Quinn gave an invited talk in the NASA/ASEE Summer Faculty Fellowship Program Lecture Series, Lewis Research Center, July 22, 1994.