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PERFORMANCE REPORT

**NEURAL NETWORKS FOR
REAL-TIME SENSORY DATA PROCESSING
AND SENSORIMOTOR CONTROL**

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Grant N00014-90-J-1545

Period of Performance: 3 Years

Starting Date: January 1, 1990

Wednesday, December 12, 1990

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1. Experimental Work

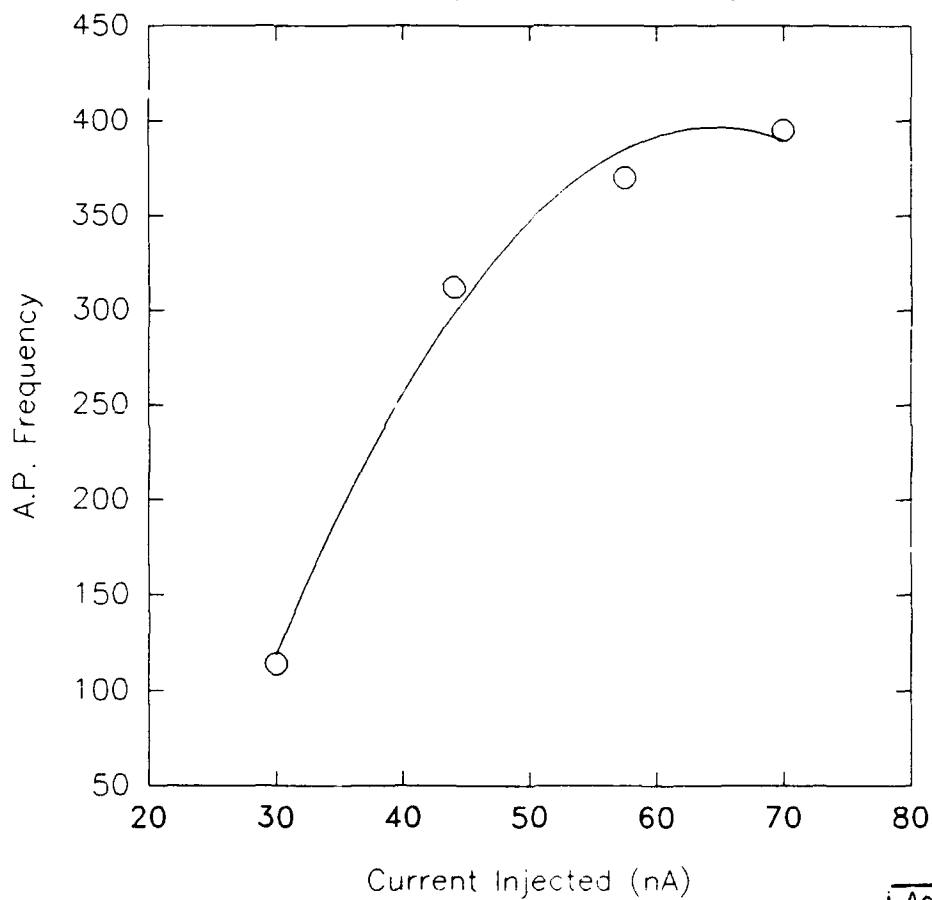
Our experimental work over the past six months has focused upon two areas. First, we have completed our analysis of the turning movements. We have also videotaped several free-ranging animals to compare to our more precise tethered preparations. From both of these sets of data it is now clear that there are actually three types of turns. In all three variations, the actual turning motion is generated by the middle legs and depends precisely on the joint between the femur and tibia of that pair of legs. In all cases the femur-tibia joint of the middle leg extends on the side ipsilateral to the wind and flexes on the side contralateral to the wind. Thus both legs move towards the wind and in a freely moving animal this would turn it away from the wind source.

The three types of turns are distinguished by anterior-posterior leg movements which are generated by the coxal-femur joint. In type I turns, both of the hind legs thrust back providing power for the turning movement. In type II turns, the contralateral legs move forward, pulling the animal back on the contralateral side while pushing forward on the ipsilateral side. The result is a much more rapid turn similar to that made by a rowboat in which the oarsman pushes on one oar while pulling on the other. These turns are associated with wind from 90° and from the front. In the type III turn, both hind legs move forward but the feet are in contact with the ground so that the animal actually backs away from the wind source while the middle legs generate a turning movement. There is then a second movement forward and again turning away from the wind source to complete the turn. This two-stage movement generates very large turns and is associated almost exclusively with wind from the front.

We have also found that initial leg angle effects the rate of movement of individual joints during the turn. Especially in the ipsilateral femur-tibia joint, e.g. if the joint is flexed at the time of stimulation the extension is greater than if it is already partially extended. This suggests that information from joint angle detectors is factored into the control of the movement. We are pursuing this with the help of a colleague, Dr. Sasha Zill from Marshall University.

The second aspect of the project that we have focused upon is a determination of the current-frequency relationships of individual ventral giant interneurons (vGIs). In order to accurately model the transfer of information between cercal afferents and vGIs, we need to know how synaptic current is translated into action potential frequency in vGIs. A graduate student, Songhai Chai, who is funded from this grant, has determined this relationship for two of the vGIs (GIs 1 and 3; see Figure 1). The experiments involve impaling with a microelectrode individual vGIs in their neuropile segments of the terminal ganglion. We could then determine the frequency of action potentials generated by various levels of current injected through the microelectrode.

Current vs Frequency vGI 1 (1st Interval)



Statement "A" per telecon Dr. Thomas McKenna. Office of Naval Research/code 1142BI.

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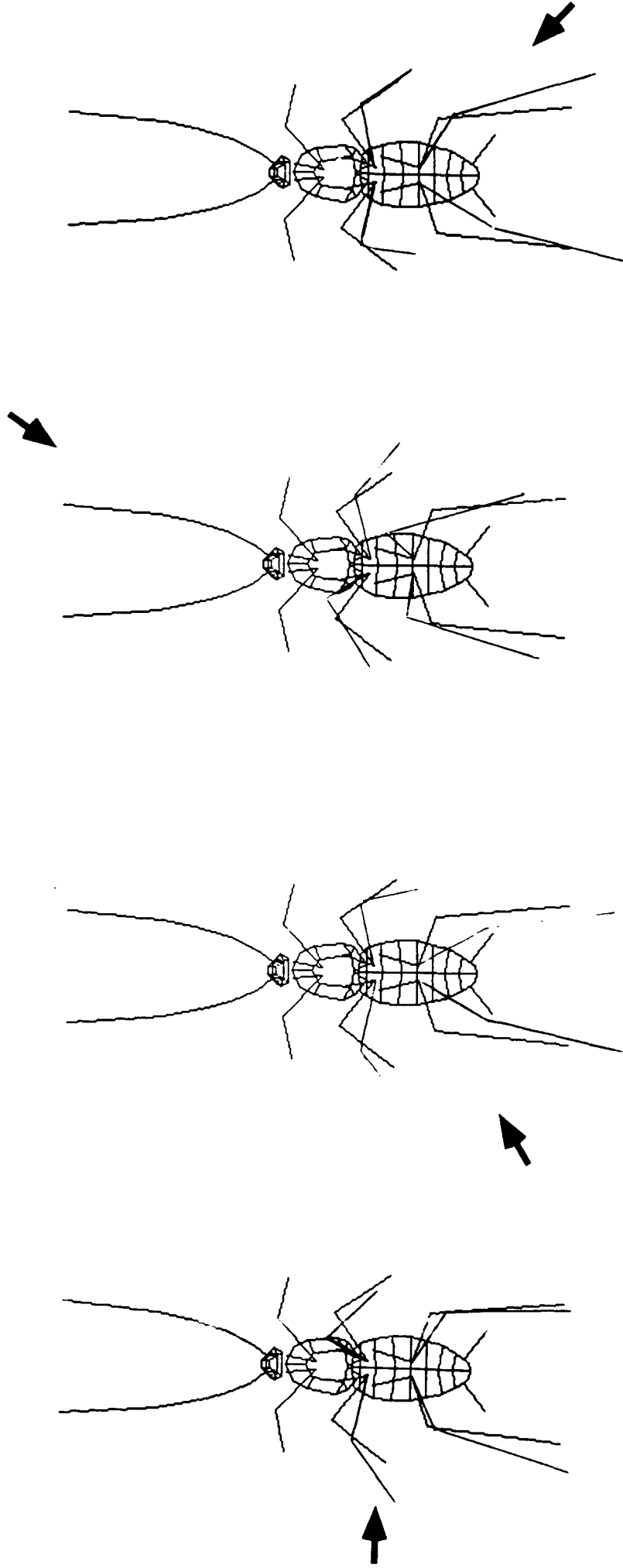
2. Modeling and Simulation

As described in our previous progress report, we succeeded in reconstructing the observed windfields of the ventral giant interneurons. However, two pieces of evidence suggested that the way in which these windfields were obtained was not the same in the model and the animal. First, the distribution of connection strengths was fairly uniform in the animal, while in the model there were only a few strong connections and the rest were very weak. Second, the response of the model to a cercal ablation was similar in some ways but not identical to the response of the animal. These discrepancies led us to examine the actual firing curves of selected ventral giant interneurons, as well as their physiological operating ranges. By taking this information into account when we map the observed windfields onto the sigmoidal firing curves of our model neurons, we have succeeded in reproducing the vGI windfields in such a way that the distribution of connection weights and response of the model to cercal ablation is much closer to that observed in the insect.

Our primary interest in this work is the neuronal basis of distributed sensorimotor control of behavior. While much work remains to be done in reconstructing other aspects of the neuronal circuitry, we have begun to address issues in modeling the control of the escape behavior itself. In particular, we have begun to reconstruct the essential leg movements which underlie escape turns. We have utilized the model vGIs discussed above, coupled with a simplified neural network model of the remaining escape circuitry. Portions of this model circuitry were constrained by known information, but much more experimental work remains to be done in further characterizing this circuitry. Using data derived from high speed video films of actual escape turns, this model escape circuit was trained with constrained back-propagation to reproduce the observed leg movements. As illustrated in Figure 2, when the resulting model circuit was coupled with our three dimensional kinematic model of the insect's body, it was successful in reproducing many of the basic features of the observed escape movements described in our previous progress report.

To serve as a useful tool for understanding the system, it is not enough for the model to simply reproduce what is already known. In order to test and refine the model, we must examine its responses to various lesions and compare them to the response of the insect to analogous lesions. As described briefly above, this process has already led to a refinement of our ventral giant interneuron models. We have begun to examine the model's response to several lesions, including cercal ablation and vGI lesions. The behavioral deficits resulting from these lesions are quite similar in those observed in the animal in the sense that wind from the unlesioned side produces largely normal escape turns, while wind from the lesioned side produces incorrect escape turns.

Reconstructed Escape Turns



The model escape circuit was trained to reproduce escape turns using back-propagation constrained by known characteristics of the escape circuitry (Daley and Camhi, *J. Neurophysiol.* 60(4); Ritzmann and Pollack, *J. Neurobiol.* 19(7)). The response of the model to wind puffs from various directions is shown above. Wind direction is indicated by an arrow. Training data was derived from Nye and Ritzmann, *Soc. Neuro. Abstracts* 20.

In summary, work is continuing on three fronts: (1) the construction of neural models which reproduce experimentally-observed characteristics of the neuronal circuitry underlying cockroach escape turns, (2) the coupling of these neural models to a body model in order to study their behavioral ramifications, (3) testing and refining of both neural and body models through constant comparison with data from the actual insect. We plan to extend the approach to vGI windfield reconstruction to the thoracic interneurons as further experimental data concerning their properties becomes available.

3. Robotics

As shown in the attached photograph, the mechanical construction of the hexapod robot is nearing completion. The main frame and six complete leg assemblies have been built. We decided to use aircraft plywood rather than plexiglass to construct the frame and leg assemblies because we found the former to be stiffer, lighter, and easier to work with. Two motors and two potentiometers were installed in each leg.

In addition, we have constructed a seventh complete leg assembly which is mounted on an arm and pivot. This leg has been used to test and refine the simulated single-leg neural controller we designed previously. Using this neural controller, we have succeeded in making this leg walk at a variety of speeds. This neural network is simulated on a PC and communicates with the motors and potentiometers via D/A and A/D boards. Our immediate plans include completing the wiring of the leg assemblies and extending the neural network controller to address the coordination of multiple legs.

Publications

Beer, R.D., Kacmarcik, G.J., Ritzmann, R.E., and Chiel, H.J. (1991). A Model for Distributed Sensorimotor Control of the Cockroach Escape Turn, in D.S. Touretzky (ed.) *Advances in Neural Information Processing Systems 3* (in press). Morgan Kaufmann Publishers.

Beer, R.D., Kacmarcik, G.J., Ritzmann, R.E., and Chiel, H.J. (1990). A computer model for escape in the cockroach. *Society for Neurosciences Abstracts* 16:759.

Nye, S.W. and Ritzmann, R.E. (1990). Videotape motion analysis of leg joint angles during escape turns of the cockroach. *Society for Neurosciences Abstracts* 16:759.

Nye, S.W. (1990). A Videotape Motion Analysis of Leg Joint Angles During Escape Turns of the Cockroach, *Periplaneta americana*, M.S. Thesis, Biology Dept., Case Western Reserve University

In Preparation

"Reconstruction of Cockroach Ventral Giant Interneuron Response Properties Using Constrained Backpropagation," by Randall D. Beer, Gary J. Kacmarcik, Songhai Chai, Roy

E. Ritzmann, and Hillel J. Chiel.

"Thoracic Interneurons in the Escape System of the Cockroach, *Periplaneta americana*, are Multi-modal Interneurons," by Roy E. Ritzmann, Alan J. Pollack, Susan Hudson and Audrey Hyvonen.

"Motion Analysis of Leg Joint Angles during Wind-evoked Escape Turns of the Cockroach. *Periplaneta americana*," by Scott W. Nye and Roy E. Ritzmann.