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IN REPLY REFER TO

VIA CERTIFIED MAIL
RETURN RECEIPT REQUESTED

September 15, 1994

Scientific Officer
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5660

Attention: Thomas McKenna

Reference: Contract N00014-94-C-0078

Subject: Progress Report CLIN 0001AB, SBIR Topic No. N93-139 Legged Vehicle for Underwater Mobile Operations

Encl. (1): Progress Report, Prof. Joseph Ayers, Northeastern Univ.

6pg

Gentlemen:

This letter report summarizes the status of the subject contract. Since the last progress report work has been proceeding both at Northeastern University and Massa Products Corporation. Professor Ayers at Northeastern's Marine Science Center has been continuing his improvements on the ambulation controller for the robot, analyzing rheotaxic behavior and performing analysis of gate patterns underlying walking in the lateral and backward direction. A summary of his work is contained in the memorandum of Encl. 1.

A great deal of work has been done both by Massa engineers and Jim Jalbert at Northeastern's Marine Systems Engineering Laboratory on analyzing Nitinol to determine how it can be best utilized as an actuator for the robot. The effort to characterize the Nitinol to determine how best to utilize it as an actuator has taken much more time and effort than originally anticipated. Jim Jalbert at Northeastern has been working on the problem associated with attaching lead wires to the Nitinol. Crimping can cause fatigue on the wire, and overheating from soldering can cause the Nitinol to loose some of its properties. He has found that using a wire-wrap gun may lead to a technique in which a piece of solid wire can be attached to the Nitinol. He is also investigating utilization of small strain gauges with a Nitinol actuator and the use of micro-thermal couples to determine the temperature of the wire.

Massa's engineering effort has focused on investigating Nitinol, and building a mechanism to demonstrate the control of three muscle pairs to perform walking motions under the control of the computer program developed by Professor Ayers that is based on the neural outputs produced by the lobster during ambulation. Several leg-like structures have been built, but there have been problems in connecting the Nitinol so that large numbers of cycles can be operated without fatigue and with proper controls of heating and cooling the actuators. In parallel, a large number of experiments have been conducted to determine how best to drive the Nitinol with electric currents to heat it and then how best to cool it to allow it to return to its original length. This work is still progressing.

Because of some potential problems that may exist with Nitinol as a final actuator in a practical robot because of concerns with controlling its heating and cooling and final power requirements, Massa engineers have been investigating the possibilities of utilizing other actuators such as motors. Conceptual systems are being developed that will allow these actuators to run from the same computer program Professor Ayers has developed which mimics the neural outputs of the lobster during ambulation.

Because final mechanical leg design concepts can not be efficiently developed until a final actuator is selected and the method of controlling that actuator is determined, Massa has not proceeded with any production engineering concepts associated with the final leg design. In addition, operating a single leg in air adds a significant complexity due to gravitational forces which does not exist in an ambulatory robot for use underwater. Therefore, Massa plans to prove the feasibility of the controller concepts during Phase I by building three muscle pairs using Nitinol as the actuator. These three muscle pair will represent the six muscles that control the movement of the three joints in the lobster leg during ambulation. Massa then plans to develop a control circuit that will take the signals from Professor Ayers computer program and drive the three muscle pair to show coordinated movement of the joints during ambulation. This will prove the viability of the system without the need to fabricate an actual mechanical leg. Some muscle pairs will also be fabricated utilizing other actuator technologies. Because the decision on a practical actuator must be made before a final leg is designed, and because this decision is going to require a larger scope of work than is called for during the Phase I effort, it is proposed by Massa that this decision would not be made until the initial period of the Phase II effort of this program.

Professor Crisman at Northeastern University's Robotics and Vision Systems Laboratory has been continuing her work on the simulation program. Because of the longer than expected time that has been spent on trying to characterize the Nitinol, she has not been able to input Nitinol actuators into her simulation.

Sincerely,

MASSA PRODUCTS CORPORATION

Donald P. Massa

Donald P. Massa
President

cc: Administrative Contracting Officer
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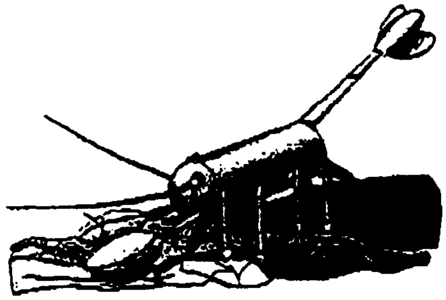

Memorandum

To: Don Massa
From: Joseph Ayers
Date: September 8, 1994
Re: Ambulatory Robot Interim Progress Report II

Development of Ambulation Controller

I have continued development of the biologically based ambulation controller to begin implementation of integrated behaviors with the goal of establishing current and surge adaptations, navigation, compensatory reflexes to gravity and searching. The following new modules have been implemented:

- AntiGravity Recruiter - Allows recruitment of depressor for pitch and roll compensation.
- Sensor Objects - I have integrated a new data structure which corresponds to the labeled-lines of crustacean sensors
- Sequencer - We have implemented queue structure for sequencing components of behaviors such as reflexes, modal actions patterns and goal oriented behaviors. It is essential for the implementation of complex behaviors such as searching, rheotaxis, etc.
- Modal Action Patterns - I have continued implementation of modal action pattern objects and conversion of all command elements to modal objects.
- Goal Achieving Behavior - I am implementing software objects to mediate goal achieving behavior necessary for searching.

In addition, We are examining small microcontroller platforms to which we will transfer our existing Mac based development system. Prime candidates are the Pic 8 bit Microcontroller and the Onset Model 8 microcontroller system.

Enclosure / to Massa Letter
Dated Sept. 15. 1994

Analysis of Rheotaxic Behavior

Lars Schlichting and I are continuing analysis of water current and surge compensation in lobsters and have performed extensive video analysis. Tasks performed to date include:

- Motion Analysis Extensions to ColorImage: I have added software objects to my motion analysis program ColorImage necessary for the complex reverse kinematic analysis of rheotaxic behavior. In particular, I implemented a set of algorithms for acquisition of complex display lists. The program now allows one to input up to 15 angles, positions or distances between two points for each of the frames of a video. The results are saved in a table file where the first column is the time of each frame and the subsequent columns are the measured parameters

- Video Analysis Performed: We have performed a rather complete video analysis of lobster responses to different laminar flow velocities and surge on our laminar flow and wave surge tanks. At present we have 7 2 hour videos which we are cataloging with our video data-base system and subjecting to kinematic analysis with ColorImage.

- Kinematic analysis in progress:
  - Two dimensional (pitch and yaw) carapace trajectories during turns
  - Forward load compensation strategies during laminar flow at different velocities.
  - Contralateral Coordination during turns

Gait Analysis In Progress

We are presently performing analysis of the gait patterns underlying walking in the lateral and backward directions which are at present poorly characterized.

- Lobster Treadmill Implemented: We have resurrected my original lobster treadmill which I developed at the University of California in the '70s and have developed a new walking balance which will permit us to shift from forward and backward walking to lateral walking.

- Multi-Leg Movement Transducer Developed: Al Badger has completed the 8 leg movement transducer. During forward and backward walking the system can monitor the protraction (swing phase of forward walking) and retraction (stance phase) movements of the limbs. During lateral walking the system monitors the extension and flexion movement. We are currently performing experiments to establish the relationship between the gait patterns and walking speed for the four walking directions. We record these movements with our SuperScope digital oscilloscope program are developing software instruments which will automaticaly quantify the intersegmental and contralateral phase lags/latencies for forward, backward, lateral leading and lateral trailing walking.