

WormBot – A Mobile Robotic Worm

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Introduction

In the WormBot project we aim to demonstrate elegant robust robotic motion based on simple biologically plausible design principles in a high degree-of-freedom (DOF) system. We investigate in motion generated by multiple 1 DOF segments that are individually controlled by local Central Pattern Generators (CPG), but achieve overall motion stability by short- and long-range coupling. A robot platform to evaluate motion in such a system is not commercially available; therefore our research tasks in the course of this project are two-fold:

- Firstly the physical design (in hardware) of a robotic platform that consists of many individual segments. Every segment provides one actuated DOF and allows interaction with all other segments on the robot. The design needs to be simple and inexpensive (as we aim for building about 100 segments) and flexible (e.g. it shall allow easy reconfiguration and adjustable mounting angles between consecutive segments).
- Secondly the implementation (in software) of biologically plausible CPG algorithms which generate elegant motion by interacting with other segments. As in the biological systems, the CPGs shall be independent of each other but receive input from local sensors and adjustable short- and long-range connections to other segments' CPGs. Also, as in biology, a simple trigger signal from a master segment (the worm's head) shall be sufficient to set speed and direction of the robots motion.

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As a first task we evaluated hardware components for the mechanical design of the robot and build prototypes using two different actuators:

- Simple gearbox motors that Mark Tilden provided during the Telluride Workshop (refer to fig. 1 for a fully functional three-segment prototype). The main advantages of the motors are the price (around 2 US\$ per motor) and the small size. Unfortunately, these motors are relatively slow and very hard to control within the small range of rotation we require (a few degrees of rotation in both directions from neutral position). Additionally, the motors generate significant electric noise that interferes with the nearby micro-controllers. Therefore, we decided not to use these motors in a complex system.
- Commercially available model craft servos as an alternative to the simple motors (refer to fig. 2 for another fully functional three segment prototype). Their main advantages are the high speed and precision in turning and simple control. Additionally, the strong servo cases provide a solid frame for the robot. The disadvantages are their relatively big size and high price (about 12 US\$ per servo). Servos are currently our preferred choice for the system design.

The developed link between consecutive segments (shown in figure 1) allows fast adjusting of the connection angle, such that the robot can be reconfigured for planar motion (as e.g. in the lamprey) or for motion in 3D (as e.g. in worms). Additionally, new segments can easily exchange broken or damaged segments if desired.

Each segment contains a small PCB with a re-programmable micro controller, sensors, and a communication interface. The sensors on the prototype robots are three light-sensors in orthogonal directions, a temperature sensor and sensors for the segment's internal states (rotary position, applied torque, available voltage of power supply battery). A two-wire communication interface allows fast and flexible information exchange between all segments. In the current setup, segments communicate all sensor readings and internal states to all other segments, such that individual coupling can be adjusted in software (see below).

The microcontroller on each segment runs the CPG, controls the actuator, reads sensors and communicates with other segments. Currently, the microcontroller in each segment runs a n abstract mathematical CPG-based algorithm [1], but with a new design (and a slightly advanced microcontroller) much more complex software CPGs will be possible. Currently the coupling strength between segments is monotonically decreasing with the distance; this will change to an arbitrarily complex re-configurable coupling function provided with the new microcontroller. Sensor readings (light as equivalent to pressure, temperature, etc.) can have direct influence on the CPGs, such that simple behavior (e.g. obstacle avoidance or light following) will be possible.

In the current experimental setup user have two different ways of communication with the robot: one is a simple command line interface and the other a more comfortable graphical user interface (GUI) (ref. to fig 3). The simple interface is sufficient to explore properties of individual segments, but extremely inconvenient to adjust parameters of multiple segments. The GUI, however, offers a flexible way of changing parameters within the robot, such that different behaviors can be explored in real time.

With the current simple CPG algorithms we are able to achieve highly accurate coupled motion (rotation) in our prototypes. An excellent demonstration of which is that the robot can achieve traveling waves, with its head and tail fixed on the table. However, the experimental three-segment system is by far too short to travel distances.

Near Future Research

The development of the three-segment prototypes is finished and the system is behaving as desired. We are about to finish assembling two eight-segment prototypes with an advanced microcontroller, which will be used for further evaluation and first motion experiments. In late January, the hardware design (both mechanics and electronics) will be finished, such that we can then produce a huge number of segments. We need an estimated 1.5h to assemble a single segment (mechanic and electronic), a total of 150h for all segments. We have acquired 3 additional volunteers in Zurich to help with the assembly, so we need an estimated 30h per person. We will meet for one week in spring to build the segments and perform initial experiments. Additionally, we will then design a mobile head segment with a more powerful microcontroller ('the brain') that will initiate motion and serve as an interface to the experimenter via a wireless link. The new head will allow the robot to be completely autonomous, but still operate under user control. Eventually, we are planning to add a tiny wireless video camera on the head.

The important following step is implementing more advanced CPG algorithms on the individual segments (e.g. as suggested by Cohen and Verschure during the Telluride Workshop 1998). Experiments on elegant directed motion in 2 and 3D and on aspects of reliability under extreme conditions such as failure and/or damage will follow. Ultimately, simple behaviors (e.g. obstacle avoidance, photo-taxis) will be implemented on the robot. Also, we are planning to provide the 100 segments for the Neuromorphic Engineering Workshop 2003 in Telluride, so that participants can experiment and probably run competitions with multiple CPG-controlled high-DOF robots.

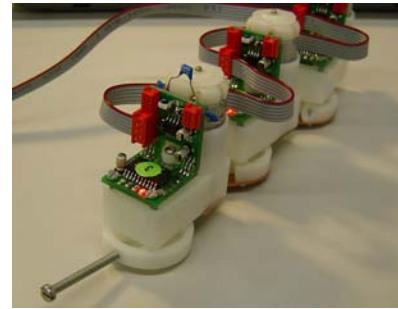
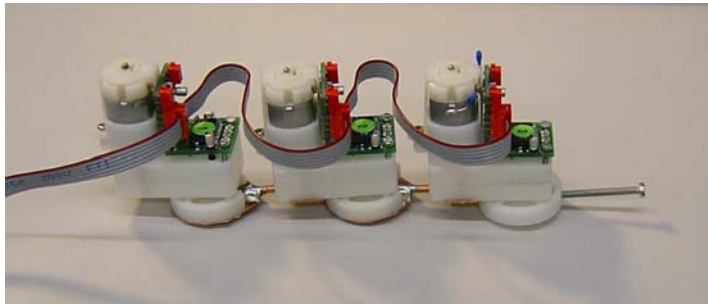


Figure 1. (left) A three-segment prototype worm robot made of simple gearbox motors.
 (right) A detailed view of the robot from the front.
 A 6-wire connection is used for communication and to power all segments externally.

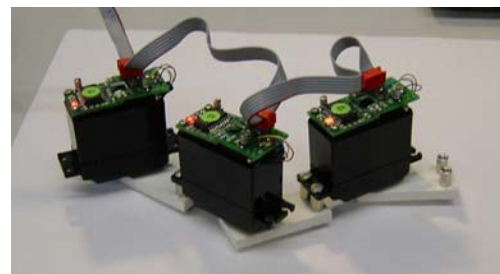
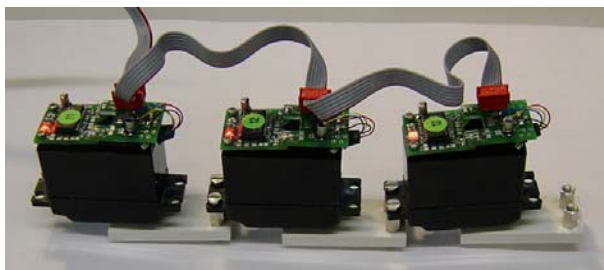


Figure 2. (left) A three-segment prototype worm robot made of servomotors in its default position. (right) the same worm robot in motion. Here, the original PCBs from the gearbox-motors have been used. We have designed a new PCB for the final version that fits the shape of the servos better. For this prototype, a simple planar connection between the segments was chosen.

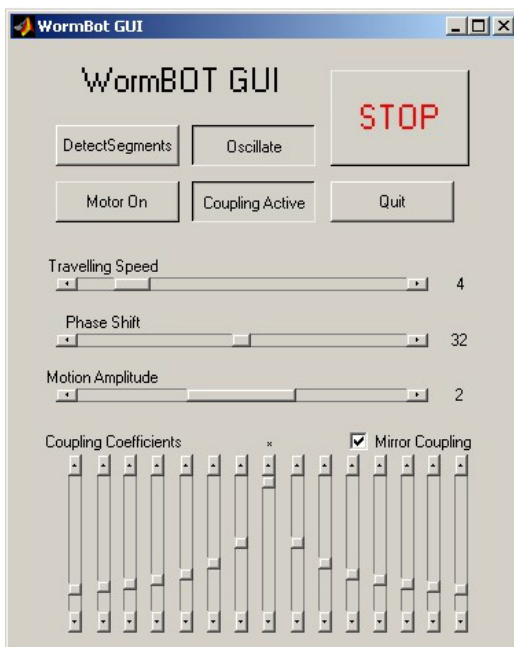


Figure 3. The WormBot GUI (MatLab interface)

References:

[1] Cohen, A. H., Holmes, P. J., and Rand, R. H. (1982) The Nature of the Couplings Between Segmental Oscillators of the Lamprey Spinal Generator for Locomotion: A Mathematical Model, *Journal of Mathematical Biology*, Vol.13, pp.345-369.

Accompanying video can be viewed at <http://www.ini.unizh.ch/~conradt/projects/WormBot/>