UNIVERSITY OF ILLINOIS AT URBANA - CHAMPAIGN

Earthworm Robot

Project Proposal

Project #56

Kunakorn Puntawong
Zehua Li

TA:
Luke Wendt

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Contents

I. Introduction

A. Objective

The purpose of this project is to construct a robot designed to emulate the earthworms' shape and muscle with artificial material, and their movement patterns with electrically powered actuations and computer controlled locomotion.

B. Background

Mechanisms enabling limbless movement has the special attribute of being versatile with relatively simple and repetitive structures. Biomimicry is the engineering emulation of time-tested and nature-inspired solution to problems in the nature environment, and examples of limbless mechanisms includes bacterias, snakes, worms, etc. While the emulation of snake's moving patterns have seen implementations, we are inspired by earthworm's ability to crawl through surfaces of different drift, density, and composition (i.e. dirt, sand, and obstacles fields), due credit to its elastic body structure, circular and longitudinal muscles, and the movement patterns controlled by them [7].

The robot can be extended to equip with modules for specific tasks [4]. For example, in the area of agriculture and environmental studies, the robot can be equipped with an array of sensors and sample collector to conduct geological surveys with minimal disturbance. Another potential application is search and rescue, where the robot can crawl through obstacles, locate target, and potentially relay materials and serve as a communication link .

C. High-Level Requirement list

1. Robot must be capable of longitudinal and circular actuation:
2. Robot must be capable of mimicking the 3D locomotion exhibited by earthworms.

II. Design and Requirement

A. Block Diagram

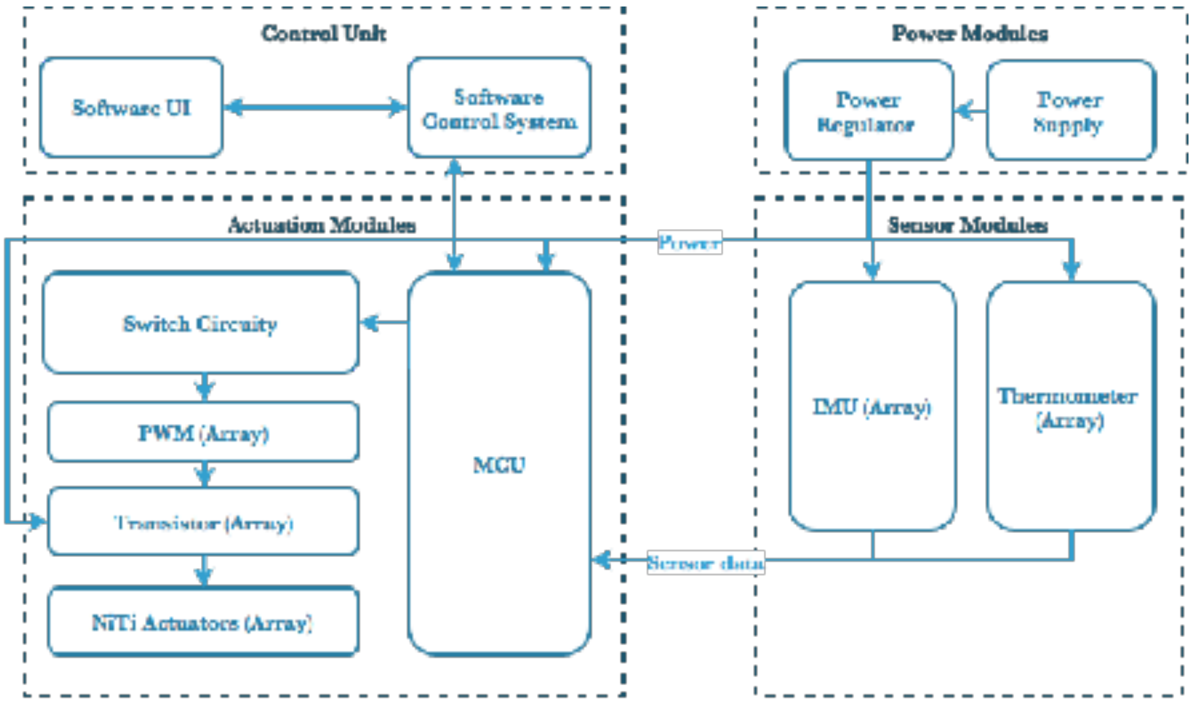

Fig.1 Block diagram of the robot and its control

B. Physical Design

We propose to build a cylinder grid with NiTi wires (specifications: thickness ≤ 1 mm). The arrangement of the wires will be sufficient to emulate the two muscle types of an earthworm. To enable 2-dimensional locomotion, we use a series of controlled longitudinal and circular actuation. To prevent toppling in 3-dimensional locomotion, we use a controlled circular activation to flatten the robot's body for it to stabilize and grab on the surface better. We will use electrical heating to activate the NiTi to a pre-programmed austenite state to enable contraction.[2] The austenite state shape will be programmed by annealing using a 400 celsius heat source (i.e. an industrial oven / a torch). The wires' activation will be controlled with a control circuit outside of the structure.

C. Design Overview

Control Unit

The control unit facilitates the communication between the user and the robot.

- **UI** provides a way for the user to input commands to the control system, which subsequently gets translated into tasks to be handled by the MCU. It also relays the any messages originated from the control system and the MCU to the user.
- **Control system** translates and breaks down commands into executable tasks for the on board system.

Actuation Modules

The onboard control Unit processes the commands sent from the computer, signals from the sensors, and and feedbacks from the actuation modules. It controls the behavior of the robot and sends feedbacks back to the computer regarding the status of the robot and the execution of commands.

- **MCU** (**Micro-controller Unit**) receives the commands from the computer through the communication link. From command, the sensors information and its current state, it will use feedback control algorithm to send out control signal to manipulate the actuator accordingly. Some of the robot's movement will need micro-controller to execute signal in series. There are two main purpose to the control system. The first is to regulate the temperature of the NiTi actuator to an optimal temperature which would allow the reaction time of the actuator to improve. The second is to detect the orientation of the worm, correct it if possible and change the control orientation of the user.
- **Switch Circuity** is the TTL circuitry that enables the MCU to control each actuator separately.
- **PWM** receives the control signal from switch circuit and output PWM signal to heat up and contract the appropriate NiTi actuator.
- **Transistor** (**Driver**) receives the input signal in the form of square waves from and amplifies it with the power from the power regulator. The factor of amplification will

be constant. The power of the actuator will varies according to the duty cycle of the input signal, which determines the effective voltage (i.e. pulse width modulation).

- **NiTi Actuator**: There are two different types of actuation: longitudinal and circumferential. Both actuators are made from nickel titanium alloy (Nitinol) with the diameter of 200 microns that are wound around a cable to form a spring like shape. The resulted actuator will be place along the circumference of and length of the robot to form the muscle of the worm.
  - **Longitudinal Actuator** - The actuator expands and contracts the robot length.
  - **Circumferential Actuator** - The actor expands and contract the circumference of the section of the worm.
  - The two actuator move in sequence to create locomotion which moves the worm forward and change direction.

Sensor Modules

The Sensor Modules provide information on the status of the robot. On one hand, it creates a feedback control loop that enables adjustments of actuations and smooth locomotions. On the other hand, it can supply info to the computer for the users.

- **Inertial Measurement Unit** has a gyroscope, accelerator meter and magnetometer which can measures up to six degree of freedom to track the orientation of the robot.
- **Thermometer** measures the temperature of each actuator. The range of the temperature in which the recover process happen is just a few degrees, so the closer we can get to the margin, the faster the actuator can react to the input.

Power Modules

The power module provide power to the electronics components of the actuator module and the control module.

- **Power Supply** - The current scheme of the power supply is for it to be an external source which provide constant dc power due to the weight and volume constraint that our robot has.

- **Power Regulator -** Power regulator is necessary to provide clean power and offer some surge protection against external source.

D. Requirements

Requirement	Quantification	Verification
Maximum movement speed	≥ 10 m/h	Drive the robot with the signal to achieve the highest velocity over a certain distance, and use the elapsed time to calculate the speed.
Minimum turning radius of the body	≤ 0.5 meter	Command the robot to drive a concentric turn, then measure the turning circle and its radius optically.
Average cross-sectional weight	≤ 0.6 kg/m	Weight the robot and divide by length
Maximum inclination movement	≥ 10 degree	Drive the worm over an adjustable incline to see the maximum angle that it can climb.
Maximum longitudinal extension (from contracted form)	≥ 20%	Measures the worm length before and after the longitudinal actuation.
Maximum circumferential contraction (from extended from)	≥ 10%	Measures the worm circumference before and after the circumferential actuation.
Error in achieving the desired length for each spring structure segment in the NiTi actuator. (No external force)	With in Gaussian distribution with mean = 0 and std ≤ 5 (% spring length)	Measure the difference between the desired difference and the achieved distance, then construct distribution.
Error in achieving the desired turning radius of the body. (No external force)	With in Gaussian distribution with mean = 0 and std ≤ 0.2 (m)	Measure the difference between the desired difference and the achieved radius, then construct distribution.

E. Risk Analysis

The length of the NiTi wire expansion poses the greatest risk because the length of the martensite of the wires that can be achieved in the robot is influenced by the radius of the spring structure we from using the wire, and the tension/cooling rate of the entire worm, as described by the following formulas [2][6]:

$$\delta = \pi\gamma D^2 n/(d\kappa)$$

δ = Free Length difference between martensite and austenite for a NiTi coil

γ = shear strain of the spring

n = number of active coil in the spring

D = spring diameter`

d = diameter of the NiTi wire

κ = stress correction factor from Wahl's formula [5]

Thus the exact number, length, and radius of the NiTi spring structure need to be determined via further calculation and empirical testing of the material. Song [2] listed a few matrices to pay attention to and the methods to determine them with regard to the specific components.

The straightness and compression of the wire in martensite are also susceptible to environmental conditions and are hard to detect automatically during operations. To mediate the risk we have incorporated temperature sensors to monitor change in temperature. We will also need to construct a simulation model and study the performance of the structure to determine necessary reset procedures (transforming back into austenite and then relax into martensite again) in case the worm is deformed subjecting to external forces.

III. Ethics and Safety

Abiding to the IEEE Code of Ethics [3], there are a few duties we need to fulfill. We will provide sufficient safety mechanisms (insulation to shock and heat, regulations) and safety warnings regarding any utilization of power source and batteries.

Complying with Code of Ethics #? We will also provide specifics regarding the requirements of proper power/battery setup, and a estimation of performance on different terrain in case the device will be used in an out door environment or in different regions of the world.

The device has a rather large scope and we welcome all criticism and suggestions to its improvements and regarding its flaws. If circumstances where specific modification or improvement are required, we are responsible to provide assistance. Similarly, we welcome any inquiries regarding the research process and any specific aspects.

Our software design and implementation will abide to the ACM Code of Ethics and Professional Conduct [1]. The control system and algorithms draw inspirations from various previous works and we will "honor property right including copyrights and patent, and give proper credit for intellectual property." Similarly, we will keep an open altitude towards future projects., document the engineering process and provide references to replicate any experimentations and to facilitate further improvement of designs and implementations

IV. References

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