A New Approach to Snake Robots: Body with Active Bending at Any Point and Deflection-Based Contact Force Sensing

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1 Introduction

In the natural habitat, snakes utilize active body bending against obstacles to generate propulsion, allowing them to move efficiently on rough surfaces [1]. However, implementing this propulsion strategy in snake robots poses hardware and sensor challenges.

The hardware challenge arises from the presence of non-bendable areas in the robot's body. Snake robots typically consist of motors or actuators connected in series, and the areas between the motors are not actively bendable. These non-bendable areas limit the robot's interaction with the environment, leading to difficulties in navigating tight spaces. While snakes in nature have numerous degrees of freedom (DOFs) to overcome this problem, snake robots have a mechanical limit on the number of motors per length. An ideal hardware solution would allow the robot to actively bend any part of its trunk with a limited number of motors.

The sensing challenge is the need for more reliable sensors to detect contact with the environment. Traditional snake robots use pressure and torque sensors to measure contact forces. However, pressure sensors only provide localised force information, and torque sensors are susceptible to impact damage. An alternative approach is to use deflection in soft snake robots to estimate continuous force distributions along their length [2]. Several methods have been proposed for shape sensing in soft robots, including imaging [3], electromagnetic tracking [4], fibre optic sensing [5], and other soft sensors. However, these methods often require fixed external equipment or are subject to noise and unreliability.

To address these problems, we propose a new snake robot (Fig. 1) with two distinctive features: a body that actively bends at any point, and shape sensing using potentiometers embedded in the body. The design consists of a flexible body and a drive unit with motors that move inside the body or bend it by rotating the motors. The drive unit can reach any point along the body, so any point along the body can be bent. We use potentiometers with high linearity and simple construction for robust shape sensing. The flexible body with potentiometers measures its own shape as it is deformed by external forces. A finite element model uses

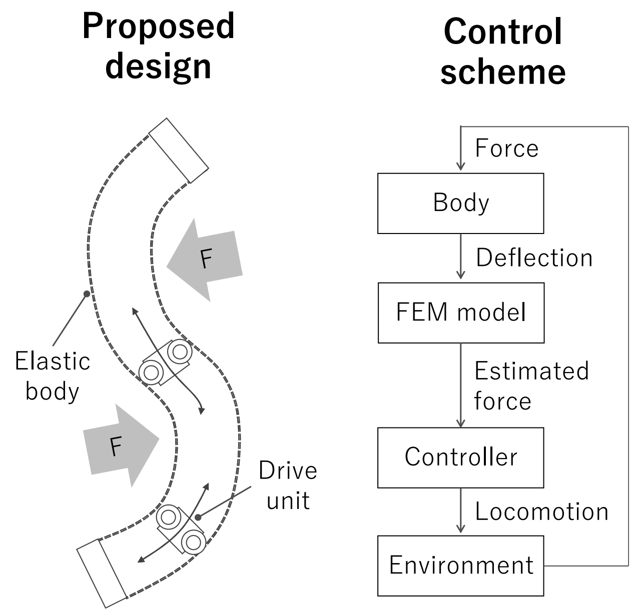

Figure 1: The proposed robot has an elastic body and a drive unit that moves inside it. The drive unit can bend any points on the robot body. External forces cause deformation of the elastic body, which can be analyzed through a finite element model (FEM) to obtain information on the distribution of these forces.

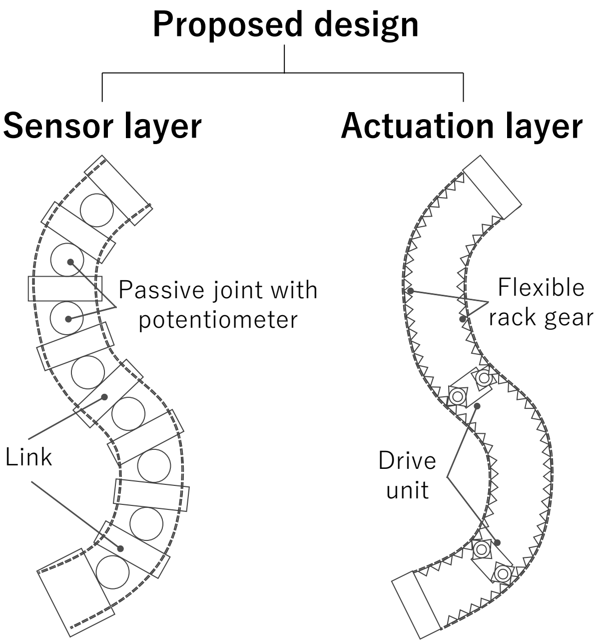

Figure 2: The proposed design is divided into sensor layer and actuation layer.

the measured data to estimate the external forces acting on the robot.

2 Proposed design

Here we explain our proposed method, as shown in Fig. 2. The proposed robot consists of two layers: the sensing layer and the actuation layer. The sensing layer consists of links connected in series by passive joints equipped with potentiometers to measure the robot's shape. This design is similar to traditional snake robots but with passive joints offers two advantages: one is to enable a sufficient number of joints with fewer motors, and the other is to increase impact resistance. The actuator layer includes a flexible rack that forms an elastic body of the robot and a drive unit that bends the robot body. The drive unit has motors with a gear that meshes with the gears on the flexible rack. As the gears rotate, the rack gears move relative to the drive unit, causing the drive unit to move or the robot to bend. This actuation allows the robot to bend at any point on its body [6].

3 Estimating force from shape

We briefly explain how to calculate forces from shape data (Fig. 3). First, we consider the robot as an elastic beam. When the elastic beam bends under an external force, the potentiometers measure the deformed shape of the beam. Second, we represent the measured shape as discrete point data. Finally, we use FEM to estimate the external force applied to each discrete point. These operations give us the loads distributed along the length of the robot.

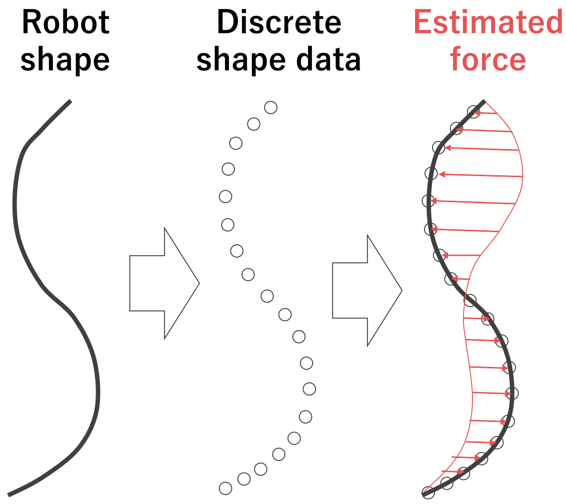

Figure 3: Estimating distributed forces by minimizing errors between discrete shape data and continuous rod models.

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