**JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY**

ABSTRACT

School of Materials Science
Graduate School of Advanced Science and Technology

Doctor of Philosophy

# Scalable Eel-like Robot Using Series of Soft Actuators: Design Basis, Evaluation, and Applications

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**Research Content**

In this thesis, we developed an eel-inspired soft robot for both aquatic and terrestrial locomotion and showcased theoretically and experimentally how the structure and control parameters many benefit efficient swimming. In terms of theoretical approach, a hydrodynamic model that considers the effect of whole-body movement of the eel-like body's locomotion was constructed. The model was built based on the continuum approach, in which the reactive force at any point along the mid-line is determined. The model was then utilized to predict the propulsion of the eel robot at different working regimes. Also, the model brings in an approach for estimating the drag force coefficient of anguilliform movements, even when it is difficult to set up an experiment and conduct measurement due to the complex motion of the object. Regarding the practical aspect, a control regime was proposed for mimicking the anguilliform swimming of the eel soft robot built by a series of soft actuators. Here, pulse signals with the shifting phase are supplied into actuators. For the efficient generation of sine-waveform, four pairs of the actuators that were divided into three segments were chosen to construct the robot body, therein, the head segment was built from two pairs because it plays a role as a wave source, while the others work as propagation parts. Smooth propagation waves generation is considered the key to realizing swimming

efficiency. Besides, three novel swimming strategies (C shape mode, passive body level 1 - one-fourth passive body, and passive body level 2 - a half passive body) that cannot be done by natural animals and traditional rigid robots were introduced. Surprisingly, differing from the natural eel and rigid elongated body robot, the soft eel robot with a passive tail and performing C shape can even swim with higher efficiency than the fully active one. This result is important for the development of the robot for long journey tasks for energy-saving purposes, also, enlarges the working conditions of the robot.

By scaling down the soft eel robot, we present the preliminary design and evaluation of a self-propelled soft colonoscopy robot employing a series of soft actuators, equipped with a control strategy for creating forwarding movement. The design permits the robot to move efficiently, thanks to creating transient bending segments between crest and trough segments, resulting in smooth propagating waves along the robot's body. Control parameters, including frequency, shifting phase (that characterizes the creation of propagation waves from head to tail,) and pressure of supplied air strongly affect the locomotion gait. The obtained results in this paper would be applied to the creation of an autonomous soft colonoscopy robot in the future.

**Keywords**: eel inspired robot, pneumatic actuator, anguilliform, body partially damage, colonoscopy robot