Abstract of Dissertation for Formal Hearing

A Study of Adaptive Morphology That Facilitates Sensing and Grasping in Soft Robotics

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1 Introduction

Morphological computation was proposed initially to summarize the underlying mechanism of morphology and control trade off phenomenon found in biological agents and in smartly designed engineering structures. It has been adopted recently by engineers to design intelligent robots with augmented functionality and simplified control [1, 2]. There are previous explorations about morphological computation in locomotion, grasping, sensing and control [3, 4, 5]. On the one hand they demonstrated that morphology has a key role to play in shaping and augmenting the robotic function, on the other hand they imposed challenges as well. One is that once the morphology is fixed for one functionality, the robot then loses the adaptability to other functions required to remain robust in changing environment [2].

Adaptive morphology offers a promising solution in that it is variable and controllable so that the robots having it can adapt the morphology actively to different environments. Although there are early research looking at how adaptive morphology benefits dynamic locomotion [6] and palpation [7], a long list of aspects remain unexploited in this regard. This study investigates how adaptive morphology facilitates such functionality as sensing and grasping in soft robotics, aiming to contribute to the soft robotics exploration towards fully autonomous robotic agents. It was based on two prototypes, namely WrinTac (Figure 1 A) and RetracTip (Figure 1 B). Note that these are two separate samples that have been brought together in this thesis because of the dissertation theme, “adaptive morphology”. Here we investigated the functional role of adaptive morphology benefiting sensing (WrinTac) and grasping (RetracTip), respectively.

WrinTac is a soft tactile sensor that has been formed in wrinkle morphology. When actuated by stretching or bending, the wrinkle morphology can change its wavelength and magnitude continuously thus varying the sensing property of the sensing element embedded in the wrinkle bump. The fabrication process was simulated using finite element method (FEM) to show the effectiveness, and the morphological changes were characterized by analytic and FEM modeling. It was found that the more it is stretched or bent, the longer the wavelength is and the stiffer the overall structure becomes, which all affecting the sensing ability of the sensor. In order to find out how the morphological changes influence the sensing functionality, we examined the sensitivity to normal and tangential force. Furthermore, we implemented two applications, that is shape discrimination and texture detection. In shape classification, we adopted machine
learning (decision tree, k nearest neighbor and supporting vector machine) and deep learning
techniques (convolutional neural network) as the “brain” to interpret the difference. In texture
detection, we used Fast Fourier Transform (FFT) to analyze the performance and found the
optimal morphology for this task. Finally, we found out that there is always an optimal
morphology for each task and the adaptive morphology offers promising opportunity to adapt
the sensor morphology to different environment based on the specific performance.

RetracTip is an universal and energy-efficient gripper coupled with sensing functionality. It is
capable of gripping a wide range of objects with arbitrary size and shapes. The design was
initially inspired by the sea anemones that can detect and catch preys nearby. The gripping
behaviour was enabled by a bistable dome structure, as shown in Fig. 1 B, that can settle
at either of its two stable configurations, “nature” and “retracted”. The sensing function was
realized by tracking the movement of the markers printed on the inner surface of the dome using
the embedded camera. We conducted a series of testings to verify the capability of sensing
and gripping, including self-state sensing, direction and terrain detecting, and gripping force
testing and object gripping testing. Compared with its artificial predecessor [8], RetracTip was
equipped with the gripping function by the adaptive bistable structure and prolonged pins.
Because of the same structure, the power efficiency for gripping was greatly improved by elim-
inating the need for continuous energy input during holding an object. Here, we demonstrate
that adaptive morphology can add new functions to existing designs and can also improve the
energy efficiency of soft grippers in the literature.

![Figure 1: A. WrinTac. B. RetracTip.](image)

2 Contribution

This study aims to investigate how adaptive morphology can facilitate the sensing and grasping
functionality of soft robotics, and to identify novel mechanisms for active tactile exploration
which has been realized mainly by changing sensori-motor control strategy in current literature.
The specific contributions are as below:

1. The development of two novel prototypes with adaptable morphology, both of which can
serve as individual platform for further exploration on the morphology-function relation-
ship.
2. The proposal to achieve active sensing by morphology optimization that is believed to
be computationally cheaper, supplementing the prevailing approach dominated by active
sensori-motor control.
The early investigation that systematically looks at how adaptive morphology contributes to improvement of a variety of functionality vital to soft robotics. The analytic and FEM modeling of a wide range of samples that can well predict the morphing behaviour of each sample.

The findings in this study will significantly contribute to the design of future autonomous soft robots that can actively interact with dynamic and changing environment and can adaptively fulfill different tasks with enhanced performance and reduced control complexity.

3 Publications, Funding and Awards

Journal Published


Journal under Review


Journal in Preparation


Conference for Oral Presentation


Conference under Review


Funding

1 Grants-in-Aid for JSPS Fellows (1,700,000 JPY), 2020.04 - 2022.03, PI: Qiukai Qi
   Title: “Development of active tactile sensors with wrinkle morphology and the application to soft robots”
2 JAIST Houga Research Grant (900,000 JPY), 2020.04 - 2021.03, PI: Qiukai Qi
   Title: “Morphological investigation of a soft robotic fingertip for enhanced tactile perception”

Awards

1 Best paper finalist (RoboSoft 2020)
2 JSPS Doctoral Research Fellowship (DC2), 2020.04 - 2022.03
3 JAIST off-campus research grant for research in University of Bristol, UK, 2019.09 - 2020.03
4 Student travel award by JAIST research grant, twice at 2018.10 and 2019.05, respectively
5 JAIST Doctoral Research Fellow scholarship, 2018.04 - 2020.09
6 Monbukagakusho honors scholarship, 2018.04 - 2019.03

References