The Virtual Evolution of 2D Soft Robots

by

Naudé Thomas Conradie

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Supervisor: Dr. M. P. Venter

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Abstract

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N. T. Conradie

Department of Mechanical and Mechatronic Engineering,
University of Stellenbosch,
Private Bag X1, Matieland 7602, South Africa.

Thesis: MEng (Mech)

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Abstract

Die Virtuele Evolusie van 2D Sagte Robotte

("The Virtual Evolution of 2D Soft Robots")

N. T. Conradie

Departement Meganiese en Megatroniese Ingenieurswese,
Universiteit van Stellenbosch,
Privaatsak X1, Matieland 7602, Suid Afrika.

Thesis: MIng (Meg)

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Dedications

I would like to dedicate this thesis to

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Nomenclature

Constants

g =	$9.81\,\mathrm{m/s^2}$	

Variables

Re_{D}	Reynolds number (diameter)	[ ]
x	Coordinate	[m]
$\ddot{x}$	Acceleration	[$\mathrm{m/s^2}$]
θ	Rotation angle	[rad]
τ	Moment	[N·m]

Vectors and Tensors

$\vec{\boldsymbol{v}}$	Physical vector, see equation ...

Subscripts

a	Adiabatic
a	Coordinate

Chapter 1

Introduction

1.1 Background

Chapter 2

Literature Review

2.1 Soft Robotics

The field of soft robotics is relatively new and developmental. Soft robots inherently differ from traditional robots. They are constructed from compliant and pliable materials. Soft robots generally have fixed joints and locomotive actuators between joints, as opposed to traditional robots which usually have locomotive actuated joints connected by rigid sections. Whitesides (2018)

Soft robots offer many advantages over traditional robots. They provide a safer working environment around humans and with fragile materials, as they are much lighter, more pliable and move slower and with less force than traditional robots. They require lower tolerances for manufacture due to their inherent less precise nature. The fact that they are very lightweight relative to traditional robots may also offer many advantages. Whitesides (2018)

2.1.1 Actuators

Actuators are components that cause controlled motion, generally used in robotics and machinery Sekhar and Uwizeye (2012). There are currently a few major types of soft robotic actuators in use Boyraz *et al.* (2018).

2.1.1.1 Actuator Types

Shape Memory Alloys (SMA) are metallic alloys capable of being formed into a specific shape while above an inherent transformation temperature, as well as being formed into another shape below the transformation temperature. When the material is then heated or cooled above or below the transformation temperature, it reforms into those respective shapes. This property exists due to the transition between the martensite phase of the material below the transformation temperature, and the austenite phase above the transformation temperature. SMA actuators are heated by applying a current directly to the material. SMA actuators are small, lightweight, silent, and have a high force-to-weight ratio. When shaped straight, they can exert high forces, but only achieve small displacements relative to their length. When coiled, they can extend more, but exert smaller forces. Villoslada *et al.* (2015)

insert illustrative figure

Shape Memory Polymers (SMP) are similar to SMAs, consisting of smart polymers with the same shape memory properties, instead of metallic alloys. The initial is shape is determined during the manufacturing process. The transformed shape is obtained by cooling the SMP and shaping it as desired. SMPs use electricity or light as a heat source for transformation **?**. They have a high deformation capacity and shape recovery. They are lighter, cheaper and easier to produce than SMAs. They are limited in size due to their low recovery stresses Rodriguez2016.

Dieelectric/Electrically-Actuated Polymers (DEAP) consist of layers of polymers interspersed with conductive material. When the conductive material receives an electrical input, a chemical reaction occurs that causes a change in volume across the layers. This causes the layers to bend in a predetermined direction. DEAPs are lightweight, silent and use little energy. They are biocompatible and functional in water. They are well-suited to mimicking real muscles. Their reactions under high voltages are not fully understood yet and accurately modelling them is highly complicated. Mutlu *et al.* (2014)

Electro-Magnetic Actuators (EMA) make use of magnetic microparticles within a polymer matrix. The particles are manipulated to cause motion by an external magnetic field from an electromagnet. This allows for a wide range of motion by varying the orientation and magnitude of the electromagnetic field. EMAs are small, require low voltages and are efficient. They have quick response times and high dynamic ranges. They are still an emerging technology in the early stages of development. Do *et al.* (2018)

Fluid Elastomeric Actuators (FEA) use soft polymeric structures with internal geometry designed for specific types of motion when driven by fluid pressure. Fluid pressure may be obtained from pressurized containers or chemical reactions. They are simple to design, manufacture and control, and are lightweight and usually inexpensive. They are scalable to different sizes and resistant to many types of damage. **?**Onal *et al.* (2017).

2.1.1.2 Actuator Shapes

linear extension and resulting motion and application

torsional extension and resulting motion and application

Appendices

Appendix A

Discrete Element Method Theory

A.1 Ball elements

A.1.1 Ball mass and inertia parameters

Consider a volume element $\mathrm{d}V$ with respect to a static base S of an arbitrary solid body with density ρ. The mass of the body is obtained by integrating over the volume of the body,

$$m = \int\limits_{\text{body}} \rho \, \mathrm{d}V \tag{A.1}$$

In figure A.1, a ball with radius R_i and uniform density ρ_i is depicted. The mass of the ball is after integration of equation (A.1)

$$m_i = \tfrac{4}{3}\pi\rho_i \, R_i^3. \tag{A.2}$$

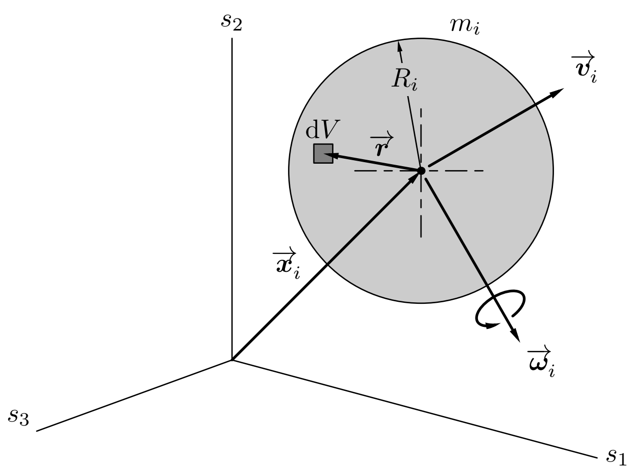

Figure A.1: Ball Element Parameters

List of References

Boyraz, P., Runge, G. and Raatz, A. (2018). An Overview of Novel Actuators for Soft Robotics. *Actuators*, vol. 7, no. 3, p. 48. ISSN 2076-0825.

Do, T.N., Phan, H., Nguyen, T.-Q.Q. and Visell, Y. (2018). Miniature Soft Electromagnetic Actuators for Robotic Applications. *Advanced Functional Materials*, vol. 28, no. 18, p. 1870116. ISSN 16163028.

Mutlu, R., Alici, G., Xiang, X. and Li, W. (2014). Electro-mechanical modelling and identification of electroactive polymer actuators as smart robotic manipulators. *Mechatronics*, vol. 24, no. 3, pp. 241–251. ISSN 09574158.

Onal, C.D., Chen, X., Whitesides, G.M. and Rus, D. (2017). Soft mobile robots with on-board chemical pressure generation. *Springer Tracts in Advanced Robotics*, vol. 100, pp. 525–540. ISSN 1610742X.

Sekhar, P. and Uwizeye, V. (2012 jan). Review of sensor and actuator mechanisms for bioMEMS. *MEMS for Biomedical Applications*, pp. 46–77. Available at: `https://www.sciencedirect.com/science/article/pii/B978085709129150002X`

Villoslada, A., Flores, A., Copaci, D., Blanco, D. and Moreno, L. (2015). High-displacement flexible Shape Memory Alloy actuator for soft wearable robots. *Robotics and Autonomous Systems*, vol. 73, no. October 2017, pp. 91–101. ISSN 09218890.

Whitesides, G.M. (2018). Soft Robotics. *Angewandte Chemie - International Edition*, vol. 57, no. 16, pp. 4258–4273. ISSN 15213773.