DEVELOPMENT OF A SOFT LINEAR ACTUATOR TO USE IN WEARABLE ASSISTIVE EXOSUITS

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DECLARATION

I declare that this is my own work and this Thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The supervisors should certify the Thesis with the following declaration.

The above candidate has carried out research for the Doctor of Philosophy Thesis under our supervision. We confirm that the declaration made above by the student is true and correct.

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Signature of the Supervisor: *UOM Verified Signature* Date: 24/02/2023

DEDICATION

To

Vidhun,

Mihiru,

and

Minuki.

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ABSTRACT

Wearable exosuits require flexible, linearly contractile, and lightweight actuators to provide sufficient force to move the respective limb. This thesis presents the concept, design, fabrication, experimental performance characterization, and numerical modeling of two types of respectively thin and low-profile vacuum-driven, soft, linearly contractile actuators. The proposed soft actuators are made of an inextensible yet flexible thin-skinned pouch supported by a collapsible skeleton that orients the collapse of the actuator in the longitudinal axis upon the evacuation of the air within the pouch. The proposed novel soft, lightweight, contractile actuators are thin (ThinVAc) and low-profile (LPVAc). Both these actuators are lightweight (ThinVAc: 0.75 g; LPVAc: 14 g), provide high maximum blocked forces (ThinVAc: 5.2 N; LPVAc: 39 N), provide maximum stresses similar to that expected from biological muscles (ThinVAc: 184 kPa; LPVAc: 117 kPa) and have high force-to-weight ratios (ThinVAc: 477; LPVAc: 285). The ThinVAc can combine to create multifilament actuators for force scaling. Combining 15 units of 500 mm ThinVAcs generates a maximum blocked force of 54 N (Max. stress: 62 kPa), 290 times the self-weight. The LPVAc integrates a position sensor based on an inductive sensor allowing closed-loop control with minimal error at 0.25 Hz. Numerical models for the contraction and blocked force of mono- and multi-filament actuators allow for predicting their behavior independent of external sensors. The proposed actuators are tested in wearable applications to check their suitability. The ThinVAc is integrated into a knee rehabilitation assist device, and the LPVAc is incorporated into a novel mono-articular sit-to-stand transition (StSt) assist exosuit, helping to reduce muscle activity by 45%. These actuators have the potential to be integrated into a wide range of assistive devices and orthoses, such as knee or ankle braces, exoskeletons, and prosthetics, to provide the necessary support for people with mobility impairments.

Keywords: Linear soft actuators, contractile vacuum actuators, Exosuits, Soft robotics, Soft sensors

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