A Novel, Neuroscience-based Control Paradigm for Wearable Assistive Devices

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The author declares that this is his own work, except where due acknowledgement has been given. This thesis is submitted in fulfilment of the requirements of a PhD. in Engineering at Massey University, Albany, New Zealand.

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Abstract

The biological domain has evolved in such a way that it efficiently overcomes many problems we struggle to solve in the engineering domain; for example, bipedal locomotion, which requires a number of desirable attributes, e.g. compliance and adaptability. As such, the aim of this research has been to provide a bridge between the biological and engineering domains, capturing these attributes, and developing an enabling control technology. The application of this research has been around wearable assistive devices: devices that assist rehabilitation and recuperation of lost or impaired functions or enable an end user to perform difficult to complete tasks. As such, this thesis presents a novel, neuroscience-based control technology for wearable assistive devices. Major contributions of this work include reproducing both biological movement's compliant and adaptive properties in the engineering domain.

The presented approach consists of using an assistive device, whose joints are antagonistically actuated using compliant pneumatic muscles, and central pattern generators. The assistive device's actuators make the arm robust to collision and give it smooth, compliant motion. The pattern generators produce the rhythmic commands of the joints of the assistive device, and the feedback of the joints' motion is used to modify each pattern generator's behaviour. The pattern generator enables the resonant properties of the assistive device to be exploited to perform a number of simulated rhythmic tasks.

As well as providing a wealth of simulated and real data to support this approach, this thesis implements integrate-and-fire, Izhikevich, and Hodgkin-Huxley neuron models, comparing their output based on firing patterns observed in neurons of the nervous system. These observations can be used as a mechanism for deciding the "realism" needed to represent a neural system's characteristics. In addition, Hill's muscle model has been presented, and simulation of an implemented soleus muscle carried out. Parametric variation provides quantitative insight into passive and active series and parallel elements' roles in generating tension and tension's time-response characteristics. Furthermore, an antagonistically coupled pair of extensor and flexor muscles have been presented and shown to effect compliant joint actuation of a modelled limb under differential activation. Co-activation of the extensor and flexor has been shown to increase a joint's stiffness, leading to increased stability and rejection of limb perturbation.

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