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**Miroslav Mihajlov**

# Modelling and Control Strategies for Inherently Compliant Fluidic Mechatronic Actuators with Rotary Elastic Chambers

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## Abstract

This thesis proposes modelling and control strategies for novel inherently compliant mechatronic fluidic actuators intended for machines working in direct physical contact with humans. The main specific feature of these actuators is use of an inherently compliant fluid vane motor called a REC – actuator (Rotary Elastic Chambers – actuator). The REC-actuator can be integrated in the revolute joint directly, without additional transmission elements, leading to a more efficient and simpler mechanical construction than when using the linear fluidic muscles. The REC-actuator can be operated by either liquid or gaseous working fluid. Both realizations are investigated in this work.

In the first part of the thesis, the development of the mechatronic actuators with rotary elastic chambers is briefly reported, the basic characteristics of the REC-actuator are investigated, and the modelling and control strategies are proposed. Two modelling approaches are used, first making use of first principles in a way common for "conventional" fluid power systems but taking into account specific properties of the considered actuator, and second, using simple phenomenological models describing viscoelastic behaviour of natural muscle. The general control concept of the REC-actuators is proposed as a cascade structure. For pressure control in the inner loop the feedback linearization (FL) as a nonlinear model-based control algorithm is considered. For position control design in the outer loop the control techniques requiring minimal modelling efforts are chosen. Quasi sliding mode control with time delay estimation (SMCTE) and alternatively, iterative feedback tuning (IFT) as a direct data-based control technique is considered.

In the second part of the thesis, the proposed modelling and control strategies are applied to the experimental set-ups with the REC-actuators. For the hydraulic REC-actuator controlled by a bi-directional miniature pump, the parameters estimation of its physically-based model is performed. The comprehensive nonlinear model is experimentally verified. The obtained model is further used for differential pressure control design by means of the FL algorithm. For the position control design, IFT is successfully applied for tuning a linear controller, eliminating the overshoot and long settling time commonly seen in control results of inherently compliant fluidic actuators. For the pneumatic REC-actuator controlled by pulse width modulated on-off valves, parameter estimation of the pneumatic subsystem is performed and the pressure control is designed applying the FL algorithm. Then, the parameters of the phenomenological model of the actuator's mechanical subsystems are estimated and the analytical phenomenological model is determined. For the position control in outer loop, the SMCTE algorithm is applied. An experimental evaluation of the controller performance shows good robustness with respect to considerable load changes.