# Proprio- and Exteroceptive Reflexes for a Pneumatically Actuated Finger based on the artificial Robot Nervous System

Alexander Tödtheide*, Johannes Kühn*, and Sami Haddadin

## I. Introduction

Nowadays prosthetic research is transmitting the achievements from other research fields such as Soft-Robotics to a new generation of devices. Previous prostheses have been using few sensors and simplified mechanics to be robust in daily life use. In contrast, embodied intelligence could lead to prostheses with more abilities like mimicing human subconscious behavior of a limb such as pain driven reflexes or situation depending stiffness adaption.

This paper shows possible reflex behaviors for blunt/sharp contacts as well as based on proprio- and exteroceptive information for a simplified prosthesis, realized by a pneumatically actuated and impedance controlled finger joint [1]. The reflexes are generated using the artificial Robot Nervous System (aRNS) introduced in [2]. The Biotac sensor serves as input for the exteroceptive reflexes whereas a joint momentum observer is used for proprioceptive reflexes.

## II. Approach

Figure 1 shows the experimental setup of the antagonistic and pneumatically actuated finger joint. At the finger tip a Biotac sensor is mounted which is used for pressure sensing. The system uses a cascaded joint level impedance controller with underlying piston level force control, see [1].

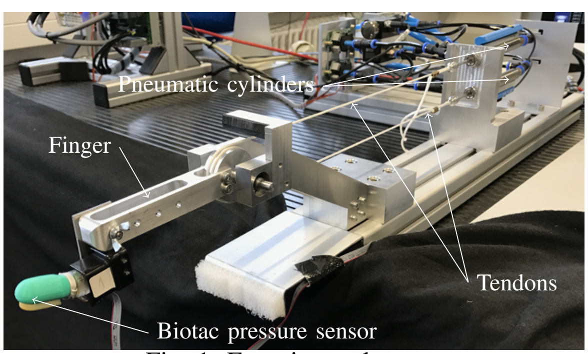



Fig. 1: Experimental setup.

The aRNS based joint-level impedance controller [2] applied to the finger joint is defined as

$$\tau_d = K_d(\boldsymbol{s})(q_d(\boldsymbol{s}) - q) + D_d(q, \boldsymbol{s})\dot{q} + \tau_{ff}(\boldsymbol{s}) + \tau_G(q), \quad (1)$$

with $\tau_d$ being the desired torque and $\tau_G$ the gravity compensation term. $q$, $q_d$ and $\dot{q}$ denote the actual, desired joint position and velocity. Furthermore, the stiffness $K_d$, damping $D_d$, feedforward torque $\tau_{ff}$ and $q_d$ can be adapted depending on the *generalized pain spiking state* vector $\boldsymbol{s} = [\sigma,\ \xi]$ with $\xi$ being the repetitivness rate. The contact pressure is determined by

$$\sigma = \max[\sigma_{BT}, c_0\hat{\tau}_{\text{ext}}], \quad (2)$$

where $\sigma_{BT}$ is the internal pressure value of the Biotac sensor and $c_0$ being a scaling factor. The external torque $\tau_{\text{ext}}$ is estimated by a *generalized momentum observer* [3]

$$\hat{\tau}_{\text{ext}} = K_{\text{O}} \left( \int_0^T \left(\tau_{\text{m}} - M_{\text{j}} l_{\text{CM}} \cos(q) - \hat{\tau}_{\text{ext}}\right) dt - J_{\text{c}}\dot{q} \right) \quad (3)$$

where $K_{\text{O}}$ is the observer gain. The joint torque $\tau_{\text{m}}$ is measured by the pressure sensors of the cylinders. Mass, inertia and center of gravity of the joint link are $M_{\text{j}}$, $J_{\text{c}}$ and $l_{\text{CM}}$. In this paper, only $q_d$ is adapted by

$$q_d := q_d(t_c) + \int_{t_c} \dot{q}_p(s_1)\mathrm{d}t, \quad (4)$$

$$\dot{q}_p := \begin{cases} -c_1 l s_1 & s_1 > 0 \\ -\text{sign}\{q_d - q_d(t_c)\} \int c_2 \mathrm{d}t, & s_1 = 0 \land q_d \neq q_d(t_c) \\ 0 & s_1 = 0 \land q_d = q_d(t_c), \end{cases} \quad (5)$$

and $K_d$ by

$$K_d := K_d^* + \min[\Delta K_{d,max}, \int_{t_c} \dot{K}_p(s_2)\mathrm{d}t] \quad (6)$$

$$\dot{K}_p := \begin{cases} c_3 s_2, & s_2 > 0 \\ -\int c_4 \mathrm{d}t, & s_1 = 0 \land K_d > K_d^* \\ 0, & s_1 = 0 \land K_d = K_d^* \end{cases} \quad (7)$$

where $c_{1-4}$ define constants, $l$ is the center of collision, $t_c$ the time instant of collision, $K_d^*$ the nominal and $K_{d,max}$ the maximum stiffness.

## III. Experimental Results

Two experiments were performed. The first experiment investigates the reflex behavior for blunt and sharp contacts, see Fig. 2 and Fig. 3. The blunt contacts represent nominal interaction behaviour, i.e., no reflex is triggered. In case of sharp contacts the finger follows the desired trajectory of the aRNS reflex generator. Stiffness increases with the level of signal strength or repetitivness (see also Fig. 4) that occur usually for highly accelerative motions.

Alexander Tödtheide, Johannes Kühn, and Sami Haddadin are with Faculty of Electrical Engineering and Computer Science, Institute of Automatic Control, Leibniz Universität Hannover, Appelstr. 11 D-30167 Hannover, Germany lastname@irt.uni-hannover.de

* Equal contribution.

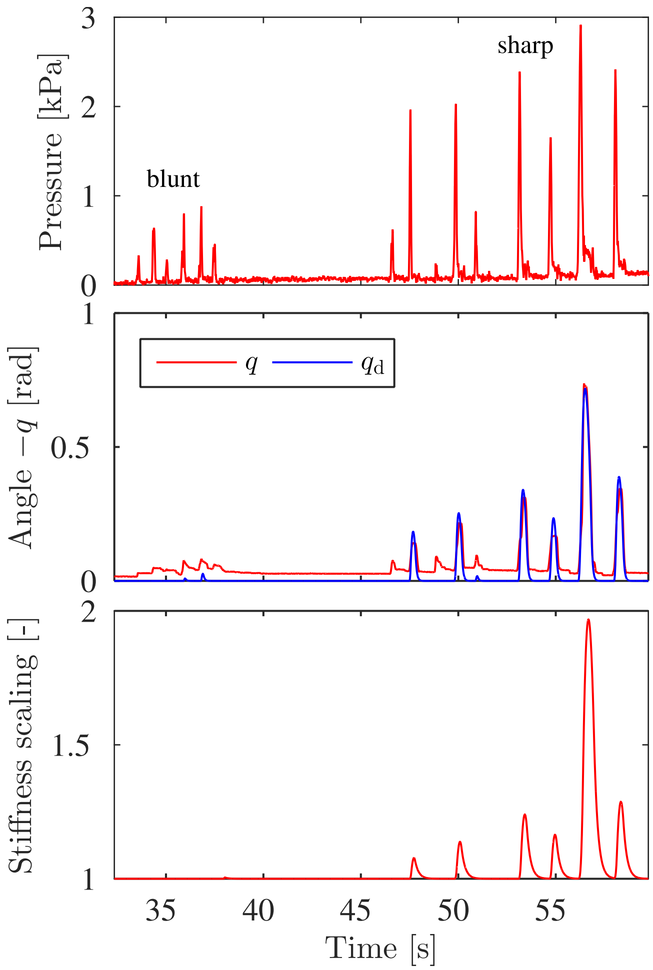



Fig. 3: aRNS reflex response for blunt and sharp contacts.

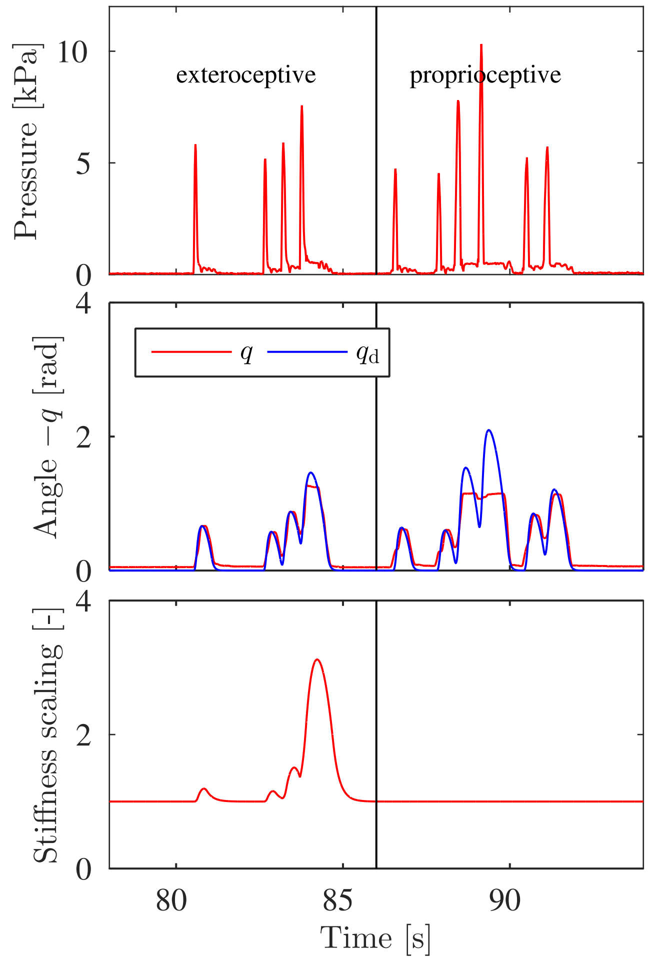
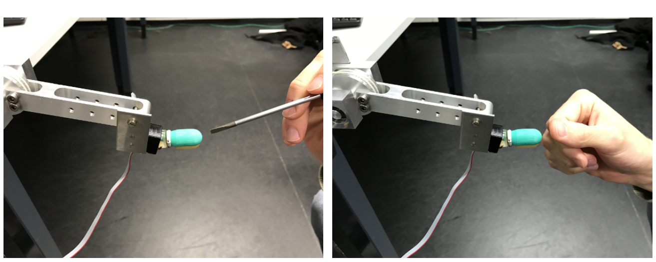



Fig. 4: aRNS reflex response based on extero- (Biotac) and proprioceptive (momentum observer) information.

The second experiment compares the aRNS based on exteroceptive (Biotac) and proprioceptive (momentum observer) information, where either the Biotac sensor or the finger structure is touched. The fusion of the two signals is given by (2). Fig. 4 shows corresponding experimental results. The aRNS was configured to adapt to stiffness for the exteroception case only. This was chosen freely and be easily transfered to proprioception as well.



(a) Sharp contact (b) Blunt contact

Fig. 2: Contact types of the experiment shown in Fig. 3.

## References


[1] A. Toedtheide, T. Lilge, and S. Haddadin, “Antagonistic impedance control for pneumatically actuated robot joints,” *Robotics and Automation Letters, IEEE*, vol. 1, pp. 161–168, Jan 2016.

[2] J. Kuehn and S. Haddadin, “An artificial robot nervous system to teach robots how to feel pain and reflexively react to potentially damaging contacts,” *IEEE Robotics and Automation Letters*, vol. 2, pp. 72–79, Jan 2017.

[3] A. De Luca, R. Farina, and P. Lucibello, “On the control of robots with visco-elastic joints,” 2005.