WIRELESS-CONTROLLED BIDIRECTIONAL PUMPING SYSTEM FOR ARTIFICIAL ORGANS WITH HYDRAULIC ACTUATION

Simone Onorati (1), Michele Ibrahimi (1), Federica Semproni (1), Stefano Pane (1), Veronica Iacovacci (1), Arianna Menciassi (1)

1. The BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera (Pisa), Italy

Introduction

Hydraulic soft actuation is often adopted to activate implantable systems like artificial organs, thanks to its intrinsic safety, versatility and power efficiency [1], [2]. However, the associated flow control systems proposed up to now are still far from being implantable, lacking miniaturization, powering from an on-board battery and/or wireless communication with the user [3], [4]. In this work, we introduce a portable, standalone and low-power bidirectional pumping system dedicated to implantable soft robots. A preliminary validation with an artificial urinary bladder is also presented.

Methods

The device consists of three functional blocks (Fig. 1a): an electrohydraulic switch, the electronic circuit and a battery. The switch includes a small DC pump (M200M, TCS Micropumps, UK) and a small DC motor (1512U003SR 324:1, Faulhaber, Germany) connected to a custom camshaft. This can compress four soft tubes (Fig. 1b), allowing thus fluid flow between a reservoir and the soft actuator(s) in both directions, as well as passive flow blocking (retaining the actuators' pressure, *p*). As such, the switch can act at the same time as a set of valves and as a bidirectional pump, by including only two active components. The electronic circuit includes an Arduino Nano 33 BLE controller, which (*i*) activates the pump and the motor via a driver (DRV8833, Texas Instruments, US), (*ii*) stops the flow at a preset *p* threshold by measuring *p(t)* with a digital sensor, and (*iii*) interacts with a phone app via Bluetooth, receiving commands and providing feedback. A small lithium battery (3.1 Wh, 3.7 V) powers the device.

The performances of the electrohydraulic switch, in terms of flow blocking and tubes' *p* retention by the custom camshaft, were tested by externally pressurizing each one of the four occluded soft tubes with a minimal flow rate (1 mL/min), up to 30 kPa (i.e. twice the pump's maximum *p* of 15.5 kPa), and recording the *p(t)* trend with an external sensor. The device was then employed to actuate a detrusor muscle in an artificial bladder [4] (Fig. 1c). In four voiding tests, the Voiding Efficiency (VE: the % of output water) and the Actuation Time (AT: time to reach the set *p* threshold of 15.5 kPa in the actuators and switch to block mode) were measured.

Results

The occluded soft tubes showed a linear *p(t)* increase during their pressurization, indicating no appreciable losses, and a contained *p* loss (mean of -2.2% from 30 kPa) in the first minute after stopping the flow. The mean VE of the artificial bladder system was 83.6%; this is comparable to the previous work from the authors [4], where the control module was bulkier (140 x 90 x 70 mm vs. 106 x 47 x 36 mm). The mean AT was 38 s (although the total VE was obtained with further pump reactivations, until injecting ~ 40 mL per actuator).

Each switch of flow mode, realized by a 90° rotation of the shaft, consumes ~ 190 mJ = 53 µWh (~ 255 mW for 0.75 s); each actuator filling in the above example, ~ 26.7 mWh (~ 2.53 W for 38 s); in idle mode, the board consumes 12.3 mW (mostly due to the BLE module). The circuit in [4] required instead ~ 4 W while pumping, and ~ 150 mW when idle. In the artificial detrusor case, assuming seven two-way pumping acts (i.e. urinations) of 4 min overall per day, the battery would last 48 hours.

Discussion

Thanks to its reduced size, its low power usage, and its wireless-based design, the proposed device marks the first step towards the feasible implementation of fully implantable hydraulic soft robotic systems.

References

1. D. Zrinscak et al, Prog. Biomed. Eng., 5:012002, 2023.
2. R. Tiwari et al, J. Intell. Mater. Syst. Struct., 23(3):301-312, 2012.
3. M. A. Bell et al, Adv. Intell. Syst., 4:2100094, 2022.
4. G. Casagrande et al, Soft Robot., 10(2):269-279, 2023.

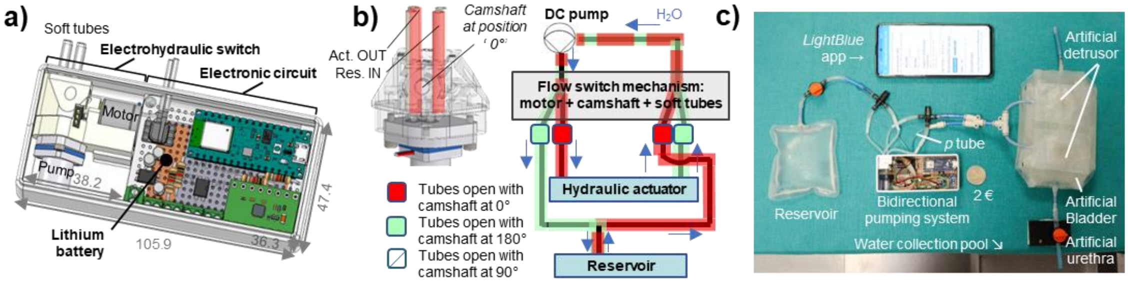

Figure 1: The bidirectional pumping system for implantable applications. a) Design overview. The whole device weights 120 g. b) Concept of the electro-hydraulic switch. c) Device application to support an active artificial urinary bladder.