Design and fabrication of soft robotics assistive device for voiding bladder

Supervisor:
Dr. A. Sadeghi
Dr. Ir. D.P. Saakes

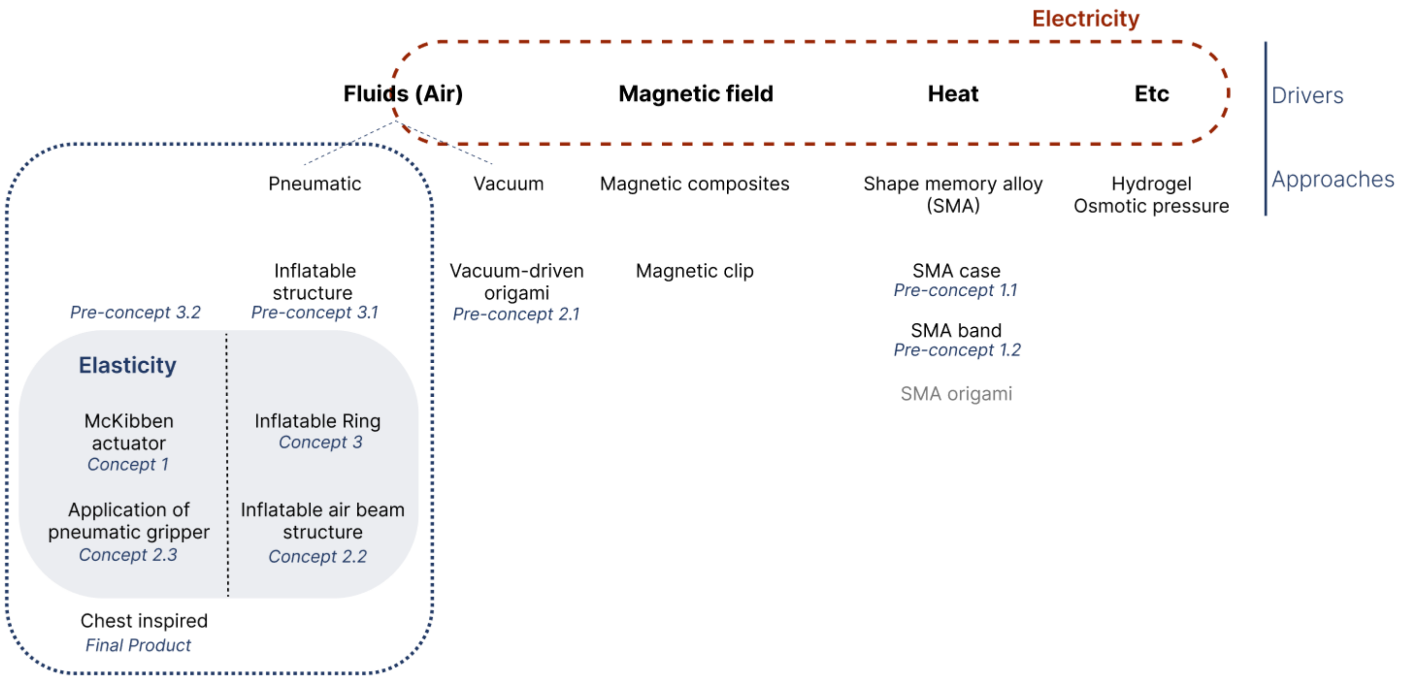
University of Twente
Industrial Design BSc
Haemin Lim, 2425629

Underactive bladder (UAB) is defined by weakened contraction intensity of the bladder muscles, resulting in an inability to achieve sufficient voiding, negatively impacting quality of life [1]. Despite this, UAB has received limited attention, lacking research and permanent treatment. Present solutions include short-term electrical stimulation, medication with side effects, or catheterization, which poses infection risks and complications such as urinary tract injuries [2].

Conventional "rigid" robots are unsuitable for addressing UAB due to their lack of flexibility and intricate movement capability, hindered by weight and rigidity. Exploring materials and techniques for enabling such motions is crucial. While soft devices are expected to offer a solution, they have limitations in terms of energy efficiency, response time, and force delivery compared to rigid devices.

To overcome these challenges, it is essential to address these concerns and create a bladder assistive device that not only aligns with functional needs but also reflects user preferences and operational efficiency. Thus, this project aims to tackle these constraints and answer the question:

"How can we design a UAB assistive device that efficiently provides the required pressure without damaging other body parts?"



The design process was guided by established goals at each stage, which were expanded through ideation and then refined via comparison, following an iterative 'divergence and convergence' approach. During each stage, the most promising options were selected and progressed to subsequent design phases.

The required movements can be achieved by the utilization of drivers and actuators that enable the conversion of energy into operational motion. Various drivers such as heat, electricity, magnetic fields, and fluids were explored as potential mediums for actuation. Different matching mechanisms, including shape memory-based, origami, pneumatic, and magnetic approaches were compared, leading to the selection of a core mechanism. Within the chosen mechanism, different concepts were developed, accompanied by an advanced query:

"How can the air-driven device attain greater efficiency by employing minimal air to deliver adequate pressure to the bladder?"

Functional verification of designed products was attempted using rough mock-ups. Based on the unique characteristics of each concept, different tests were devised, including load-extension tests and pressure change detection. Sequentially, comparative analysis among different models sharing the same concept was achieved through testing, ultimately contributing to the enhancement of device performance.

The proposed approach involves utilizing a long elastic air chamber (balloon) as the actuator, covered with an outer layer that limit expansion. This chamber contracts only in the axial direction while expanding radially when air is injected. These two characteristics of single actuator can be utilized to provide contraction force to the bladder:

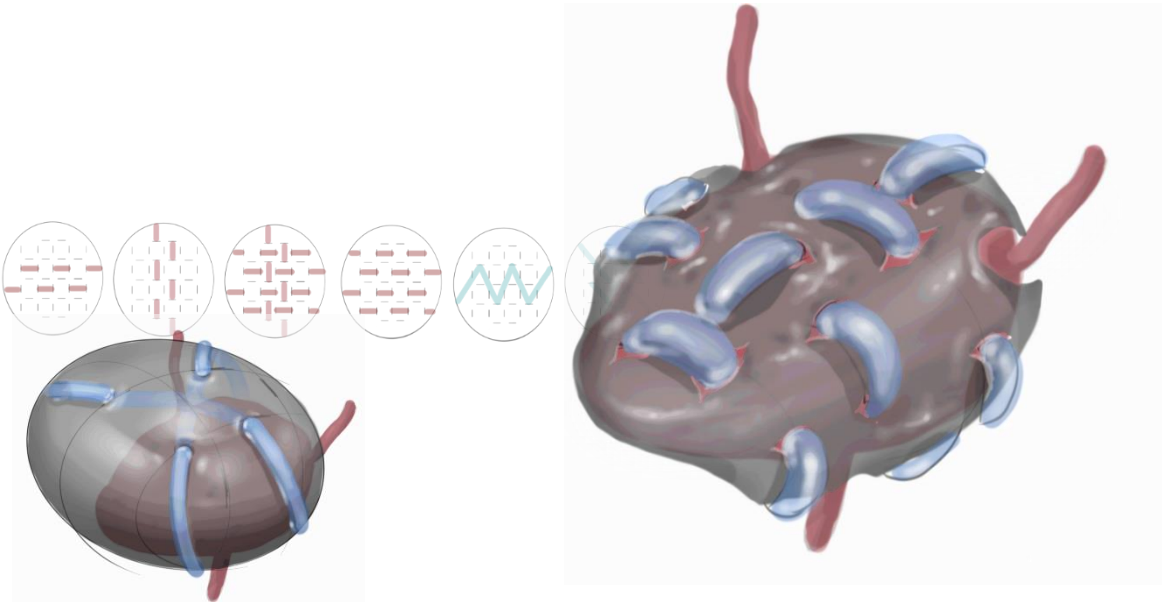
1) Reduction in the overall length of the actuator.
2) Increase in the actuator's cross-sectional area.

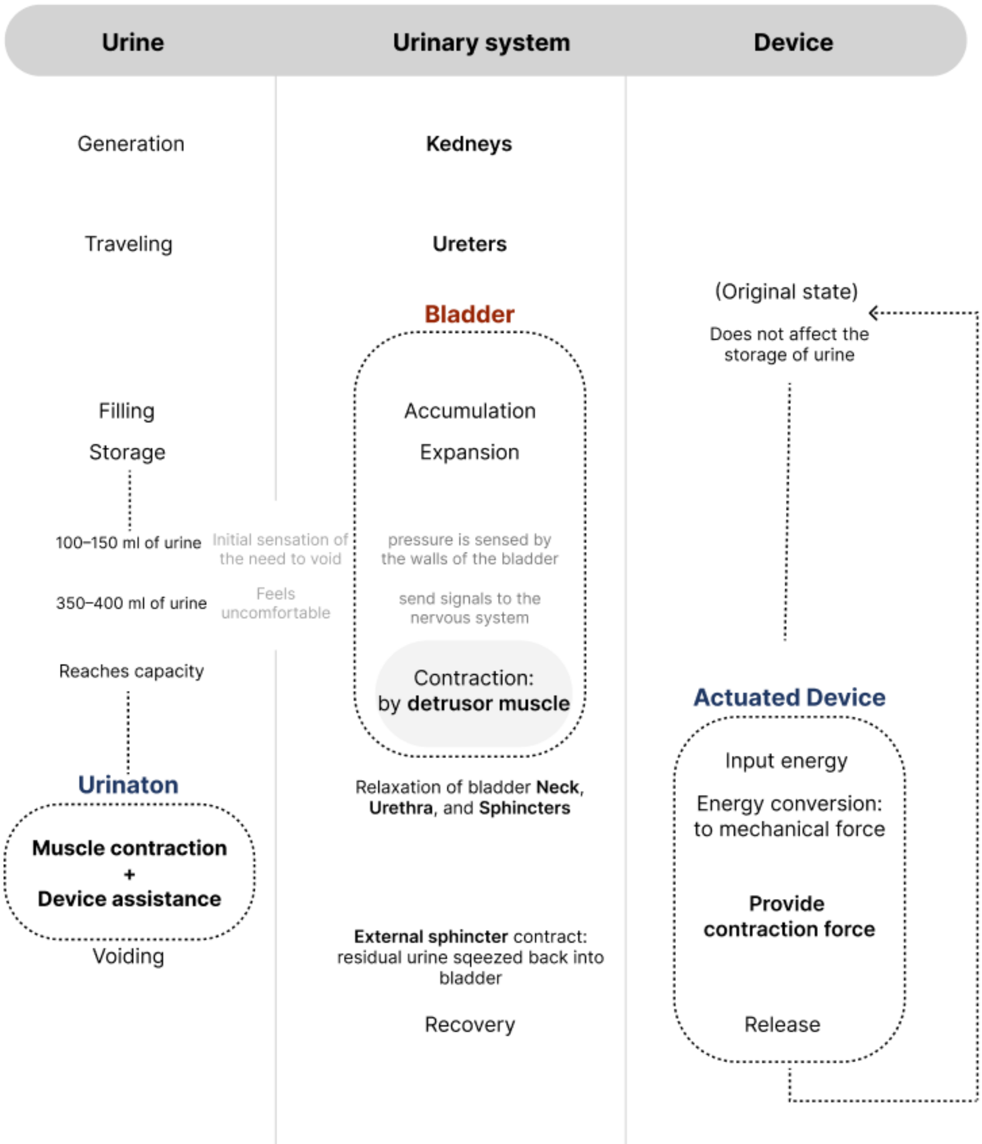
When they are positioned around the bladder, the aforementioned attributes of the actuator lead to the following outcomes, respectively:

1) Reduction in the device's surface circumference length, thus reducing the surface area.
2) Increase in the actuator's volume, exerting pressure on the bladder.

Furthermore, due to the elastic recovery, once the force is removed from the air storage pump, the injected air promptly escapes, causing the actuators to rapidly return to their initial state without additional effort.

A simple and stable design approach is suggested: using a fabric-layer pouch with balloon-sized holes strategically arranged in a grid pattern, allowing the balloons to be threaded through. This eliminates the need for additional fixation mechanisms and allows easy assembly and modification. In the end, 65% of voiding efficiency is expected to be achieved. Further studies can enhance the current voiding efficiency by improving the contraction ratio of a single balloon actuator or considering the use of other fluids, such as water which is incompressible relative to air. This approach also allows for easy customization, adapting to individual bladder dimensions without the need for extensive redesign. Moreover, the product holds the potential applications beyond bladder assistance, extending to other organs.




Urine
Urinary system
Device
Generation
Kedneys
Traveling
Ureters
Bladder
(Original state)
Does not affect the storage of urine
Filling
Storage
Accumulation
Expansion
100–150 ml of urine
Initial sensation of the need to void
pressure is sensed by the walls of the bladder
350–400 ml of urine
Feels uncomfortable
send signals to the nervous system
Reaches capacity
Contraction: by detrusor muscle
Actuated Device
Input energy
Energy conversion: to mechanical force
Urinaton
Relaxation of bladder Neck, Urethra, and Sphincters
Muscle contraction + Device assistance
Provide contraction force
Voiding
External sphincter contract: residual urine sqeezed back into bladder
Recovery
Release

Soft Robotics Lab

[1] A. D. Uren et al., "Qualitative Exploration of the Patient Experience of Underactive Bladder," European Urology, vol. 72, no. 3, pp. 402–407, Sep. 2017, doi: https://doi.org/10.1016/j.eururo.2017.03.045.

[2] Y.-H. Chang, J. J.-Y. Siu, P.-J. Hsiao, C.-H. Chang, and E. C.-L. Chou, "Review of underactive bladder," Journal of the Formosan Medical Association, vol. 117, no. 3, pp. 178–184, 2018. doi:10.1016/j.jfma.2017.09.006