Leveraging morphological computation for expressive movement generation in a soft robotic artwork

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ABSTRACT

The paper describes the design of a cephalopod-inspired soft robot that is part of the art installation *Tales of C* (2017). Two soft modules for movement are presented, one actuated by a servo motor the other with pneumatics. It is shown that dynamic biomorphic movements can be realized with these modules using simple control signals (linear and constant changes).

CCS CONCEPTS

• **Applied computing → Arts and humanities**; Media arts • **Computer systems organization → Embedded systems**; Robotics • **Human-centered computing → Human computer interaction (HCI)**

KEYWORDS
Soft robotics, robotic art, aesthetics, morphological computation, robotic movement.

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1 INTRODUCTION

Within the research fields of Social Robotics, Human-Robot Interaction (HRI), Cultural Robotics, and Entertainment Robots the issue of how to generate and utilize expressive robot movement has surfaced as an important area of inquiry [1]. Research on soft robotics has on the contrary directed its main attention at the two other fundamental types of robotic movement: locomotion and manipulative movement [2]. This paper seeks to connect soft robotics research with research on expressive movement design for robots. It aims at shifting the focus on practical applications in soft robotics research towards the aesthetic potential of soft robotics as an expressive medium.

The paper shows by example that soft materials can offer a shortcut to generating expressive biomorphic robotic movement. It contributes a modular design of a cephalopod-inspired soft robot based on the concept of *morphological computation* commonly used to describe how pliable morphologies may obviate the need for extensive computation in the control loop of a robot [3][4]. This principle is leveraged for designing the soft robot "with expressive movement in mind" [1]: The expressive movement generation is delegated to the mechanical properties of the soft silicone morphology and its interaction with its surrounding medium (water). It is shown that with the design simple linear changes in control signal over time result in highly biomorphic movement dynamics.

The presented system is based solely on open source hardware and software and easily lends itself to modifications. It has a low cost of materials (around EUR 20 to construct the entire morphology excluding the control board and the embedded LED ring). STL files for the molds used to cast the morphology as well as the microcontroller code used to generate the movement are included as supplementary materials, making it possible to replicate or expand on the design for applications in other robotic artworks, creative robotics, entertainment robots or animatronics.

2 BACKGROUND

The practice-based artistic research project *Tales of C* (2017) by the author explores the ethology and aesthetics of cephalopods as metaphors of twenty-first century computational media dynamics. In its current form the installation consists of an aquarium containing a cephalopod-like robot, installed in an enclosure alongside the pneumatic and electronic systems that support the robot, a PC laptop, and an active loudspeaker.

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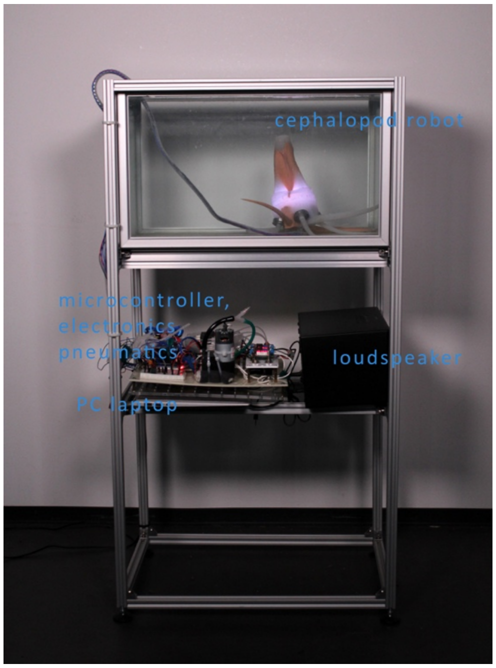

Figure 1: *Tales of C*, mixed media, 2017, approx. 135 x 65 x 40 cm. The installation setup photographed in daylight. (© Jonas Jørgensen. Photo: Jonas Jørgensen.)

An important aspect of constructing the installation was to design the cephalopod-like robot so that it would be perceived as embodying both “technological” and “biological” qualities. To accomplish this it was decided to fabricate it in soft silicone but to keep its shape as a combination of simple geometric forms (cones, tubes, and boxes).

Figure 2: *Tales of C* (2017). The artwork photographed installed in a darkened room running in exhibition mode. A video of the installation can be seen here: https://youtu.be/B4S0E5D4zck (© Jonas Jørgensen. Photo: Jonas Jørgensen.)

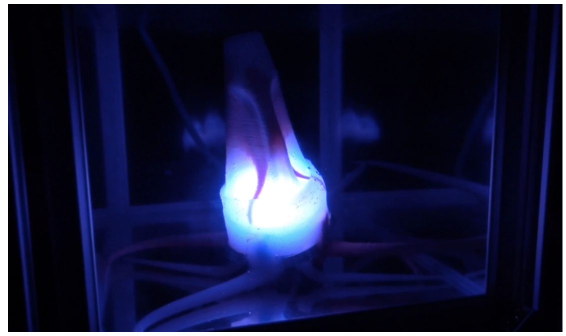

Figure 3: *Tales of C* (2017). Close-up of the soft robot. (© Jonas Jørgensen. Photo: Jonas Jørgensen.)

A number of soft robots exist that are inspired by cephalopods. These are, however, either based only on parts of the animal's anatomy (often a single arm) or relatively complex systems aimed at fulfilling the specific task of locomotion either by way of crawling or pulsed-jet swimming. The design presented here was inspired by arm and leg designs from the OCTOPUS and PoseiDRONE projects [5], but uses only one hobby servo motor for actuation of each arm rather than pull-string or crank mechanisms. For the purpose of the installation this more simple system that would still fulfill the aim of displaying biomorphic dynamic movement was preferable.

3 DESIGN

The robotic morphology is based on two previously fabricated prototypes: The first a conical “arm” constructed from highly elastic and soft Ecoflex 0030 silicone cast onto the horn of a 9g hobby servo motor (TowerPro SG90). With this prototype, it was observed that the servo arm was able to move unhindered from side to side at angle variations of up to approx. 45 degrees even if cast into the silicone (see Fig.4). Moreover, the design was waterproof and servo sweeps (linear increments in servo angle over time followed by linear decrements) resulted in biomorphic fluid movements of the arm when submerged in water (video at: https://www.youtube.com/watch?v=ifLChDLxdjE).

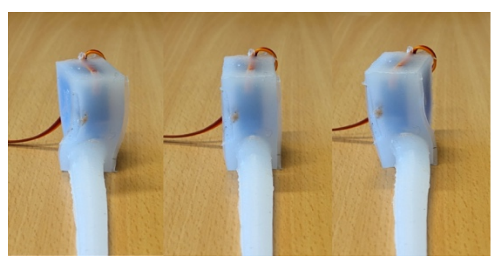

Figure 4: A servo motor with a silicone arm attached embedded in silicone. The servo angle is set to 45, 90, and 135 degrees (left to right) respectively. The softness of the enclosure makes it possible for the servo arm to deform the material and move unhindered to both sides. (© Jonas Jørgensen. Photo: Jonas Jørgensen.)

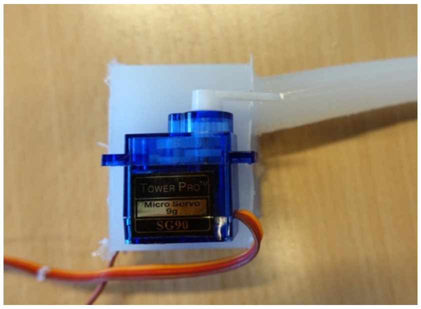

Figure 5: A servo motor placed on top of a servo enclosure to illustrate where the motor and the servo arm are located inside the enclosure. (© Jonas Jørgensen. Photo: Jonas Jørgensen.)

The second prototype was a pneumatically actuated three-chambered silicone tentacle. Experimenting with it revealed that the volume of this structure could increase significantly upon inflation. This led to the idea that it might be used as a controllable floating device.

The cephalopod-inspired morphology was conceived as a modular design that integrates four arms derived from the "arm" prototype. These active arms are combined with an inflatable top part based on the tentacle design. A further four passive arms without any actuation were added to the design.

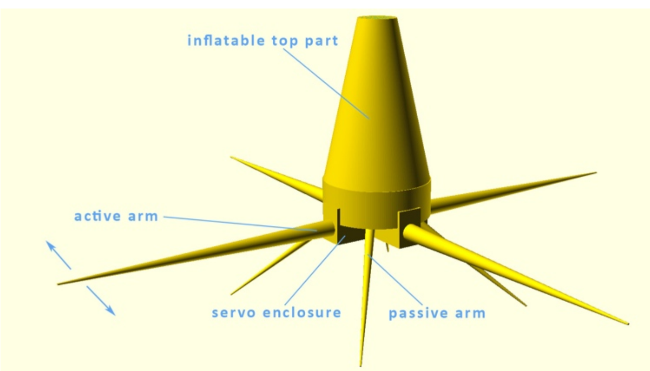

Figure 6: A CAD rendering of the complete robot morphology. The height of the robot's body (measured from the top of the inflatable part to the bottom of the servo enclosures) is 192 mm. The active arms are approx. 235 mm long (measured from tip to servo enclosure) and 15 mm in diameter at the widest part (© Jonas Jørgensen. Illustration: Jonas Jørgensen.)

4 FABRICATION

The fabrication process of the morphology involved casting the silicone parts separately in 3D printed molds with the needed electronics (servo motors, an LDR sensor, an LED ring) embedded. Casting the servo motor inside the silicone was successful in 8 out 10 cases (two motors were not working after the procedure). The molds were designed in OpenSCAD and exported as STL files. They were printed in PLA on a consumer-grade FDM 3D printer (Ultimaker 2 Extended) and sliced using the free Cura software. The cast parts were assembled by using uncured Ecoflex 0030 and SilPoxy adhesive to bond them together.

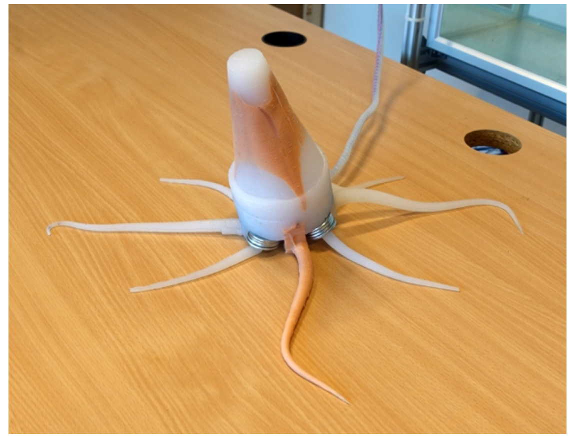

Figure 7: Photo of the assembled soft robot. Four iron washers were attached at the base of each of the passive arms with zip ties in order to increase the weight of the robot to prevent it from floating. (© Jonas Jørgensen. Photo: Jonas Jørgensen.)

5 CONTROL AND MOVEMENT IMPLEMENTATION

5.1 Control hardware

The morphology is controlled with the *Fluidic Control Board* that is part of the open source Soft Robotics Toolkit [6]. It is programmed in the Arduino IDE. The three chambers of the inflatable top part are connected to push fit pneumatic connectors on the board with 3mm (outer diameter) PVC tubing. The servo motors and the LED ring embedded in the morphology are powered from an external power supply with 5V and their control signals generated using PWM pins on the Arduino MEGA microcontroller.

5.2 Movement concept

Through experimenting with the prototype three expressive motion primitives for arm movement were discovered empirically:

a) Slow sweeps with the same backwards and forwards speed (a probing relaxed gesture)
b) Fast sweeps with the same backwards and forwards speed (movements suggestive of locomotion)
c) Sweeps with high speed in one direction and low speed in the other (an aggressive kind of twitching)

The movement concept underlying the programming of the robot is based on the idea that the robot should perform only subdued motion that is just enough to maintain notions of liveness when the synthetic voice (coming from the laptop and the loudspeaker) is narrating the installation. When the narration stops, the robot should react with more energetic behaviors and after this go back to the subdued movement pattern. Inspired by the interpretations of the movement primitives (listed in parenthesis above) and the findings of Inderbitzin et al [7] that the speed of body movements are correlated with perceived arousal level, type a) movements were chosen for the first situation and type b) and c) for the latter. The energetice movement pattern also includes inflation of the top part, which makes the robot ascend, and dynamic light changes on the LED ring.

5.3 Movement programming

The control of the arms occurs with a function called "servoSweeps()". It is called with four control variables: The number of sweeps to perform, the delays in ms before incrementing or decrementing the servo angle 1 degree, and the maximum displacement angle of the servo arm from the equilibrium position of 90 degrees.

The Arduino microcontroller is set up as a slave that communicates with a C++ program running on the PC laptop over serial connection via ÙSB. When the microcontroller does not receive any signal the servoSweeps() function is called with a low angle and high delays (for one or all four motors) yielding movements of type a). Every time the speak is concluded on the PC laptop a signal is sent over the serial connection. This triggers either inflation, changes in lighting, or more energetic flapping of the arms for a period, i.e. servoSweeps() calls with shorter delays and a higher servo angle displacement corresponding to movements of type b) or c). The variable values used for the function calls are all overlaid with some randomization noise, i.e. the values are not fixed but confined to specific intervals corresponding to a call of type a), b), and c) respectively. This was done to achieve variation in the robot's movement that was deemed essential to creating an illusion of animatedness

6 RESULTS AND DISCUSSION

Albeit a simple system it was possible to create biomorphic movement with some variety. Emergent changes in functionalities that contribute variation in behavior were also identified when the system was running. These include a shift from the servo motors flapping the arms in the water to them moving the body from side to side when the robot drops to the bottom of the tank. But also a bending backwards of the arms when the robot is ascending (due to their softness).

Informal preliminary user interviews (N=4) conducted in the lab with the robot running movement patterns without speak revealed that subjects frequently used the terms "natural", "fluid", and "lifelike" to describe it. The movement patterns were, however, perceived as repetitive and predictive after a couple of minutes, suggesting that more contrast and variation might be beneficial to sustaining an illusion of animatedness.

7 CONCLUSION

This paper has described the design of expressive movement in a simple cephalopod-inspired soft robot. Using linear servo sweeps in combination with constant rate inflation it was possible to achieve biomorphic movement with the morphology. The design was successful in this task by leveraging the inherent movement dynamics of a thin arm constructed from Ecoflex 0030 submerged in water and changes in the morphology's density accomplished by inflation.

SUPPLEMENTAL MATERIALS

- Movement code for Arduino MEGA 2560 and STL files for 3D printing the molds: https://github.com/RobotisMollis/TalesOfC-github

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