Soft Robotics for Telepresence and Human Interaction

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ABSTRACT
Soft Robotics open up new possibilities for human interaction that have yet to be realized. They bring forth new materialities and expression dynamics that are different from what we would normally expect of robots. When used for telepresence, they are able to extend our organic-self truthfully and honestly. We present preliminary research for creating a soft, silicone based and pneumatically actuated, telepresence avatar that is remotely controlled through a web interface and is designed for meaningful and expressive human interaction. The design of the entity draws inspiration from the soft and curly shape of the Japanese symbol for the 'human soul'. We present original multi DOF actuators inspired by previous research, and a novel modular inflation system for facial expressions and shape shifting, inspired by animal behavior and actively operated by the controller using Emojis. We are open sourcing all of the work for further collaborative development.

Author Keywords
soft-robotics; robotics; telepresence; pneumatics; web; affective computing; conflict resolution;

ACM Classification Keywords
H.4.3 Communications Applications: Computer conferencing, teleconferencing, and videoconferencing;

I.2.9 Robotics : Kinematics and dynamics

INTRODUCTION

Robotic Telepresence
Robotic telepresence allows us to exist in a remote space using a controlled agent that physically occupies it and interacts with its surroundings. One may differentiate between two prevalent forms of robotic telepresence: a) A Video conferencing agent – A display of a streaming video of the controller that is supplemented with some motoric functionality. The most common manifestation of this form is a tablet device that is attached to a Segway-like moving base [1]. b) An Avatar – A fully formed entity that acts as a representation of the controller. Avatars may range from robots that resemble the controller itself, to more abstract humanoid forms and also to nonhuman entities. Notably, the robotic labs of Hiroshi Ishiguro have implemented both the human-resemblance type with the *Geminoid* [2] project and the abstract humanoid with the *Telenoid* [3] and *Elfoid* [4]. While avatar forms do not show a realistic and real-time representation of the controller, they have several advantages over video conferencing telepresence. First, the completeness of the agent's figure grants it more authentic and affective bodily expressions. Furthermore, an avatar enables the possibility of anonymous or role-playing communication, as in the game "Second Life" [5], thus opening telepresence to more use cases such as gaming or even conflict resolution. Research shows that assuming a different embodiment may decrease racial bias, both among the controller and the interlocutors [6]. Moreover, in her book *Cultural Politics of Emotion* [7], Sarah Ahmed writes: *The impossibility of reducing hate to a particular body allows hate to circulate in an economic sense, working to differentiate some others from other others, a differentiation that is never 'over', as it awaits others who have not yet arrived".* Meaning there is great importance to enabling interaction with a physical embodiment in order to tone down extreme emotions such as hate, to deflect tendencies for prejudice and to optimize the affectiveness of the encounter. Thus, when designing an embodiment that transports a living human, it is desirable to obtain a representation that is inspired by the realm of the living and can achieve a higher level of expressiveness and authenticity.

Soft Robotics
Soft Robotics introduce a new structural paradigm into the realm robotics, one that brings it closer to organic form, both in terms of the materiality and of movement. While a majority of the research on Soft Robotics is focused on usability for medical or engineering [8], the prospects of the new materialities for art and humanities are now being discovered [9]. In the field of telepresence, it is common to use soft materials such as silicone for the skin of the avatar, as in the case of *Telenoid*, but with an underlying metal structure. It is only natural to extend this usage to a truly soft robot for the purpose of telepresence. In this paper, we present a work in progress on a general purpose soft avatar. The present research is focused on the avatar's head: We

showcase research on pneumatic actuators that are able to support the avatar's neck with the ability to look around as well as pneumatic facial expression and morphing structure. We also present a prototype telepresence web interface enabling vision, speech, translation and control over expression.

CONCEPT DESIGN

We designed a telepresence entity that does not aim to be human-like, but does possess some familiar human characteristics. Designing a life-like yet nonhuman creature allows us to not only bypass the uncanny valley [10], but also to avoid any initial racial bias in the encounter. The challenge lies in finding the balance between nonhuman characteristics that grant neutrality and human characteristics that enable affection and empathy. Since an avatar-based remote telepresence is essentially the teleportation of your mind into a distant body, we decided to use the traditional Japanese shape of the Soul (魂) and the human spirit (人魂) as a reference model for the remote entity (Figure 1). The avatar would be a stationary in space, but would interact with humans in its surroundings using vision, voice, movement, touch and a visual display. For these capabilities, some non-soft elements have to be embedded within the soft body, namely a camera, microphone, speaker, a graphic display and pressure sensitive touch sensors. The entity would have 3 main types of actuation:

1. Free movement of the neck, in order to look around.
2. Morphing of the face and body its shape when expressing certain emotions, inspired by animal morphology and human facial expressions.
3. Curling of the body inward and outward in order to reveal the embedded display and touch interface.

This paper focuses on results for types (1) and (2), while (3) will be implemented in the near future.

MULTI DOF NECK ACTUATOR

Background

A telepresence entity would greatly benefit from the ability to look around. Traditional robots are able to do that using servo motors that actuate joints in 4 degrees of freedom (Pitch up/down, Yaw left/right). Soft actuators are normally joint-less, and can usually bend in one direction, providing just one degree of freedom. Several multi DOF soft actuators were previously developed [11] [12] [13] [14], but most of them rely on a rather cumbersome formation that joins together several bending actuators in different directions, mostly reinforced by fiber wrapping. One exception is the FMA – Flexible Micro Actuator, developed by Suzumori Koichi already in 1989 [15]. The actuator constitutes of 3 chambers, that combine into one fiber reinforced cylindrical form.

Implementation

After some guidance from Professor Suzumori, we were able to recreate the technique based on the fiber reinforcement process that is published on the open source Soft Robotics Toolkit by the Biodesign lab at Harvard [16]. We followed the same technique of creating 3 complementing chambers, but increased the size and used 3d printed molds with a few modifications, resulting in the published design. The manufacturing process consists of 5 steps:

1. Casting three chambers using 3d printed molds with SmoothOn's Dragon Skin 30 silicone.
2. Gluing the chambers together into one cylinder using SmoothOn's SilPoxy glue.
3. Wrapping the combined shape, forward and then backward, in Kevlar fiber.
4. Removing the inner rods and encapsulating the finished shape using SmoothOn's Ecoflex 30 and a dedicated 3d printed mold.
5. Capping the open end of the finished actuator and gluing 3 silicone tubes to the 3 chambers.

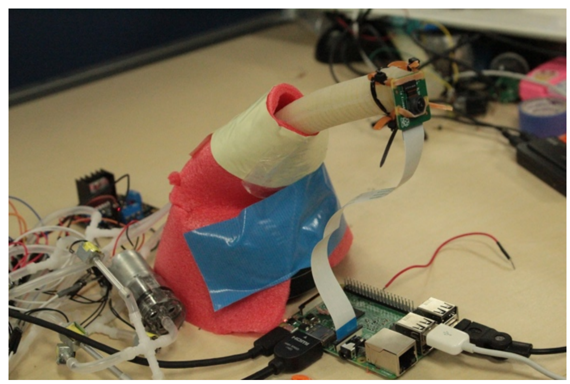

Figure 2. Multi DOF Actuator, first prototype. Video at https://youtu.be/Am_UXkqsaZ8

A more detailed process will be available on our Wiki page [17]. Once the actuator was ready, we tested it by attaching a Raspberry Pi camera and developed an Arduino control circuit for remote controlling the camera's orientation (Figure 2). The pneumatic network consists of one 9V pump, 6 solenoid valves and 3 pressure sensors for regulating the actuation in each chamber. We developed a web interface for connecting to the robot's Raspberry Pi, controlling the camera orientation, viewing the streaming audio and video and producing speech from text. The code for the entire platform is released with this paper [18].

HEAD SUPPORT

A cylindrical multi DOF actuator is useful for small headed structures, such as entities resembling reptiles, or for other body functions such as small moving tentacles or, a tail of some sort. However, for supporting a larger head, one

Figure 1 – From left to right: Expressive actuation, neck actuation, human spirit symbol (人魂), curled down interactive display, curled up display.

actuator is not enough and a more sophisticated support structure is needed. In order to maintain the consistency of the material, we designed a structure consisting of 3 separate extending actuators that are attached to a spaced concentric constraint comprised of 5 silicone rings. The rings were casted using Dragon Skin 30 on a laser-cut mold.

Extending actuators

The extending actuators operate simultaneously in order to drive the movement of the encompassing silicone head structure. We tested two different kinds of extending actuators:

1. A fiber reinforced cylinder, largely based on the design in the Soft Robotics Toolkit.
2. Our own stackable chamber design.

For the stackable method, we designed molds for modular chambers that can be stacked one on top of another until the desired length is reached. Each chamber contains a bottom rigid part and a top inflatable part while all of the chambers are connected via a single air channel. The inflatable gaps were made by inserting wax cylinders into the chambers during casting. The wax cylinders themselves were casted from silicone molds. Once the chambers are cured, the wax is melted and the air gaps are revealed (Figure 3).

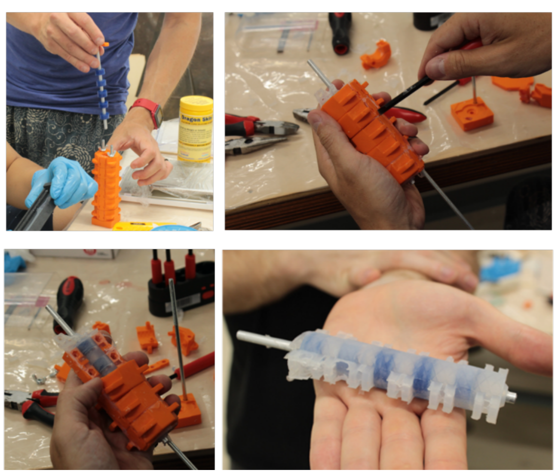

Figure 3. Stackable extending actuator with embedded wax chambers

Initial testing for the stackable design is promising, but the casting process requires further optimization as is currently quite susceptible to bubble damage and production failures, therefore we chose to stick with the fiber based design for supporting the head.

Implementation

We have optimized the casting process of the fiber design by introducing a cylinderical mold that can be disassembled after curing. The actuator is made of a single chamber tube that is first casted with Dragon Skin 30, then wrapped forward and backward with Kevlar fiber and finally encapsulated with Ecoflex 30, much like the 3-chamber actuator. Detailed process instructions are available on our Wiki page along with the 3D model files for the molds. Initial testing of the head support proved useful. The actuators were able to carry substantial weight and achieve a 45-degree rotation angle to each direction (Figure 4). For actuation, the same code base, pneumatic and electronic and circuits of the three-chamber fiber reinforced actuator are used.

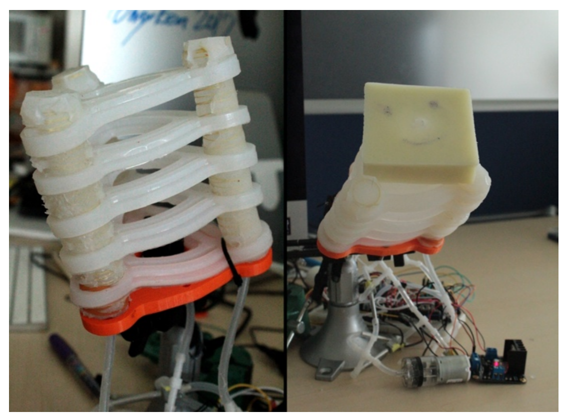

Figure 4. Multi DOF neck with Ring Support

[Video at https://youtu.be/I5ELFCWXtdE](https://youtu.be/I5ELFCWXtdE)

SOFT EXPRESSIVENESS

Background

Robot researchers are paying increasing attention to the emotional expressiveness of robots and are developing specialized models such as the DESIRE model [19]. Expressing emotions can increase the empathy and relatedness between the human and the machine, an important aspect especially when the robots are designed to provide service and care to humans. For telepresence robots, emotional expression can greatly increase the bandwidth of the information that is transmitted from the controller to its interlocutors. Prior research has put emphasis on the static appearance of robots to convey emotions, for example facial expressions or body poses [20]. Contemporary research however, is also focusing on the expressiveness of movement itself [21].

Biomorphism

Preliminary research on expressiveness of soft robots found that the biomorphic nature of their movements can greatly increase expressiveness [22]. Clearly, the movement of soft actuators is more fluid compared to traditional robots, and can generate an impression of a living organism. We would like to further develop the notion of soft robotic expressiveness and introduce morphing of the robot's body, inspired by animal and human behavior. Inflation of body parts is used in the animal world as a means of courtship, display of power or 'fight or flight' response (Figure 5). For example, the hooded seal male inflates a bladder above its nose to attract nearby females [23]**,** the puffer fish inflates itself in order to warn predators [24], anole lizards puff their throat both when in danger or during courtship [25]. In other cases, a sort of extension morph occurs, such as the bristling of the hair when expressing fear in felines, the flicking of external gills in various amphibians or the opening of the frill of the frilled lizard during social encounters or in response to potential predators [26].

Figure 5. The Anole Lizard and Hooded Seal.

Implementation

For our robot's head, we combined the animal inspired biomorphic approach and the human facial expressions that we all know and relate to. We designed a modular structure that can be placed along different angles beneath the face and support multiple inflating actuators. The support restricts the inflation of the actuator such that it is only inflated in the direction toward the face. We have placed four actuators along the face, two above the eyes and two around the cheeks. Additionally, we have designed a NinjaFlex [27] tube that attaches to the mouth and is able to deform it. The tube is bent by another inflating actuator that rests above it (Figure 6).

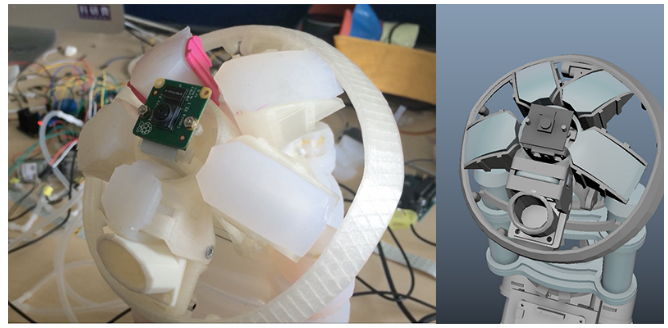

Figure 6. Modular face actuators for expression. Video at https://www.youtube.com/watch?v=GioboBunxvI

In initial testing of the actuators we were able to attain expressions that are on one hand anthropomorphic and resemble a human figure, and on the other hand not clearly human, which is the desired effect. However, in some cases the impressions were too subtle and left little impression on the viewer. This can be mediated by tuning the inflation parameters, but it could imply that when the face is not entirely human, the transformation needs to be blunter to have an emotional effect. In the future, we plan to add a bristling-like morphing, that would extend and bend parts on the exterior of the head. It would be interesting to test different morphologies and their affect, creating a vocabulary of expressions. As mentioned earlier, beyond the morphology itself, there is a great role to the nature of the movement when switching between one state to another. Laban's movement analysis, originally used for the study of dance, can also be used to develop emotional expression in Robots [28]. With pneumatic actuation, it is quite simple to modify pump and valve variables to obtain different velocities of air inflation, release and oscillations that result in varying movement styles. Additionally, the nonlinearity of the underlying silicone [29] adds a second dimension of expressiveness. Due to the fact that the neuromuscular system itself exhibits nonlinear behaviour [30], we can assume that nonlinearity generates, even subconsciously, an impression of an organic substance.

WEB INTERFACE PROOF-OF-CONCEPT

Technologies

We have placed the robot's prototype on the exhibition floor and tested the various features by remote controlling a custom designed web interface (Figures 8,9). The interface groups all of the robot's features into one unified control. While it may be tempting to use advanced input/output mechanisms such as Depth Sensing, Face recognition, VR, haptic feedback and so on, we are aiming for the most common denominator, the PC's mouse and keyboard and the smartphone's touch interface, to ensure that anyone can just "jump in" and transmit their mind and soul from their private home to wherever the robot is situated. The interface is purely web based and is accessed both by the robot's Raspberry Pi browser and by the controlling user at home.

Affective computing

In the field of affective computing, there is a leading trend that uses deep learning methods to analyse the current sentiment of the user. For example, IBM Watson's "Natural Language Understanding" [31] can detect the sentiment in text, whether it is positive or negative and what emotions are present. Google's CloudVision API [32] can detect whether faces in an image are happy or sad. We would like to take a different approach and instead of passively analysing the participant's emotions, to try and encourage them to express them voluntarily in a variety of creative ways. This is not only to avoid possible errors of detection, but also because we believe that a conversation in which the participants are actively expressing their emotions is more likely to produce meaningful results. The most basic interface for emotional expression that requires no external hardware is the typing of *Emojis*. Emojis are an accepted Unicode standard for transmitting emotion [33] and have been shown to be associated with human feelings [34]. The current web interface supports common types of Emojis and translates them into a facial expression. We also added a console for manually selecting the expression, and inventing your own expressions. In the final version of the robot that will also contain a display, it can more creative and interactive ways of emotion expression can be used. The current interface lets the controller choose a YouTube song, and play it for the audience, a feature that demonstrated positive potential for initiating and enhancing the encounter in initial tests. The goal for future development is to further encourage expression and make it more intuitive.

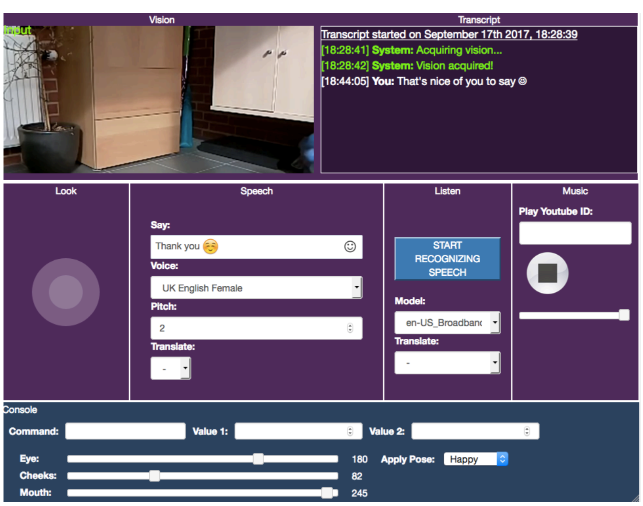

Figure 8. Soft Telepresence Web Interface

Since telepresence allows encounters with no physical barriers, we are only left with the barrier of language. Therefore, it is essential to provide a translation solution in a telepresence robot. For our interface, we developed a Two-Way translation service. When the controller types text, it can undergo translation before being spoken by the robot. Respectively, when a human speaks back into the robot, it is picked up and transcribed using IBM Watson's Speech-to-Text engine [30] and then translated back on the controller's web console.

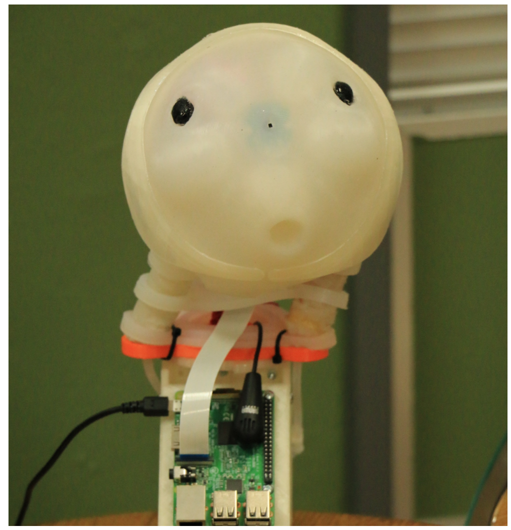

Figure 9. Soft Telepresence prototype
Video at http://youtu.be/V7pTx4Hcb6Q

CONCLUSION AND FURTHER RESEARCH

Further testing and evaluation are required, but it is shown that Soft Robotics are a highly suitable medium for telepresence and human interaction. The actuators presented in this article provide a simple and low-cost method for generating fluid, nonlinear multi DOF movement and dynamic biomorphic expression. From our own personal working experience, we can testify that there is a considerable difference between working with silicone and with traditional electronics. The materials take time to settle and require plenty of attention and care. The viscosity and nonlinearity of the actuators make us feel like we are operating on living substances. Apart from additional work on optimizing the head structure and expressiveness, subsequent research will focus on the body and tactile interaction. Tactile pressure sensors have been previously used for detecting human contact with the silicone [35]. We will test this form of interaction in telepresence, providing a 'holding-hands' type of experience for the user and transmitting the contact feedback back to the controller. We are also looking into methods of embedding the graphic display seamlessly into the silicone. One possible direction is using flexible fiber optic cables embedded in the silicone. The first official use case for our robot will indeed take place in a conflict environment, where will test soft telepresence's ability to transcend both cultural and emotional barriers. We are hopeful and looking forward to present the upcoming results.

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