ANIBOTICS

PROTOTYPING CALL

REPORT

April 2023

Contents

Introduction

Anibotics is a company based in Bristol that specializes in developing friendly robots, particularly one that resembles an elephant kitten. One of the key features of these robots is their trunk, which is likely designed to mimic the functionality of a real elephant's or kitten's trunk. The project initially began as a feasibility study to design an animated trunk system for an educational robotic animal. This animated trunk system is likely aimed at replicating the movements and functions of a real animal trunk.

Statement from the company: “The support given by a voucher would help us to develop a prototype of a animal robot for testing, and therefore allow us to initiate our b2b business development strategy more quickly and with a more thorough testing of possible design ideas.

The prototype will enable us to carry out real world testing within the We The Curious (WTC) museum in Bristol from an early stage in 2023. So far, our partnership and research with children with WTC has helped us move our b2c product forward and generally help us understand product needs. This autumn is the perfect time to gather and act on research input for this b2b prototype from our ongoing work with schools.

We envisage an aluminium or wooden framework, onto which we will fit silicone mouldings and we are also looking at using soft robotics. We want to explore - with your help - the best design using sustainable materials and processes. This voucher is not expected to fully fund a prototype, but to help us create research props and design ideas alongside our own work. We anticipate some aspects will be teleoperated others puppeteer while we research and iterate the robot itself and the interactive experience around the robot using a child avatar we are creating.”

The real thing

An elephant's trunk is a "muscular hydrostat" – Large connection of muscles joined together that can be controlled independently with no bones, like a human tongue but orders of magnitude times as complicated.

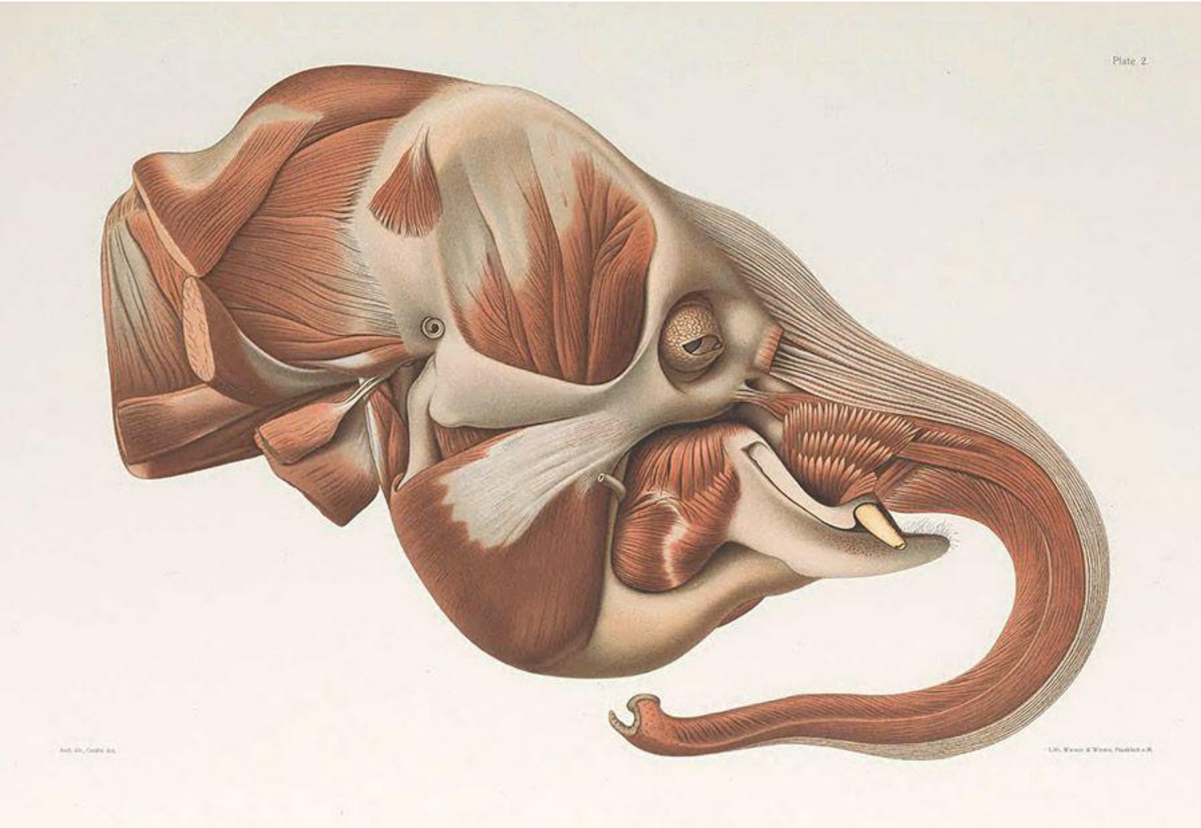


Figure 1 Anatomy of the trunk

List of possible routes

There are a few different possibilities we could explore in order to address the task:

Servos/joints

Lots of joints – usually between 6 and 12 – connected that can be controlled independently with stepper / servo motors. Joints can all face the same direction or be out of line to enable 3D movement. This method would enable the most precise control of all the methods presented. However, this would be the most complicated and involved to get right. The motors could also be noisy, and the mechanism could be fragile.

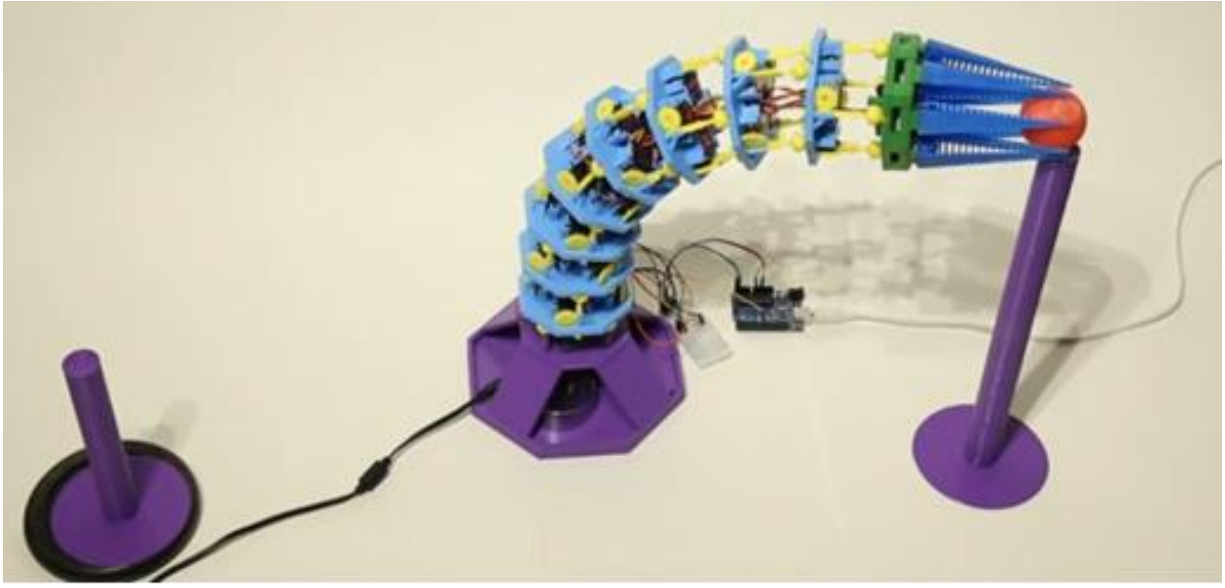


Figure 2 a 3d printed robot arm with joints. Source: "Scientists develop low-cost 'elephant trunk' robot using 3D printing technology - 3D Printing Industry"

Figure 3 'Le grand elephant', Nantes. source: https://3dprintingindustry.com/news/scientists-develop-low-cost-elephant-trunk-robot-using-3d-printing-technology-188935/

Continuum robotic arm (tendon)

Wires/strings/elastic are threaded through joints on one side so when they are pulled that side contracts. Wires can be threaded on the opposite side so it can move in two directions, or 3 sides so it can move in 3D. Stops or disks can be added to restrict movement to control the shape of the trunk when fully contracted.

Rigid joints – The core is solid and with joints such as hinges or ball-and-socket that enable movement.

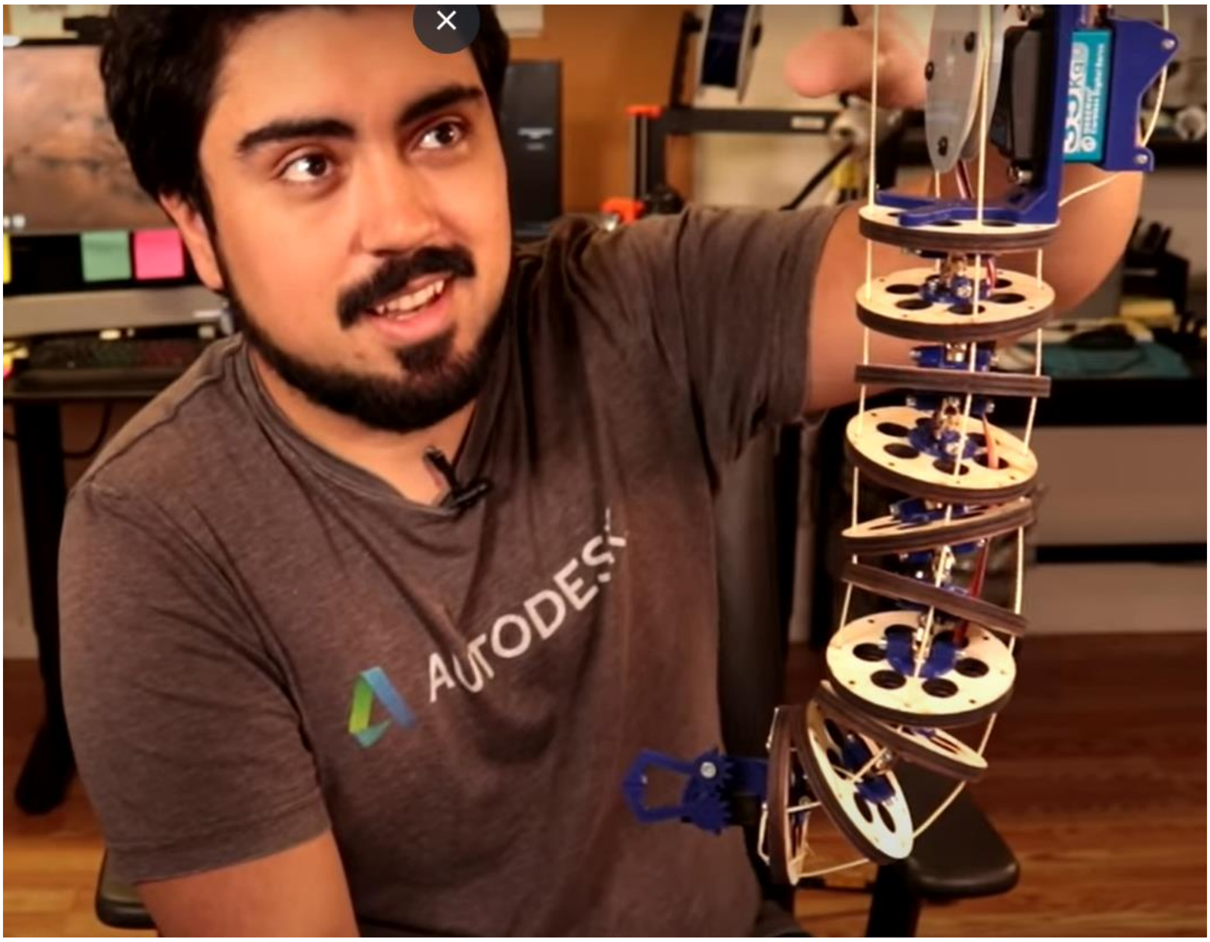


Figure 4 tendon structure – tentacle prototype: source [**youtube.com/watch?v=XRw1mcIFzkE&t=276s**](youtube.com/watch?v=XRw1mcIFzkE&t=276s)

Compliant joints

The core is made of compliant materials that can bend such as springs or plastic.

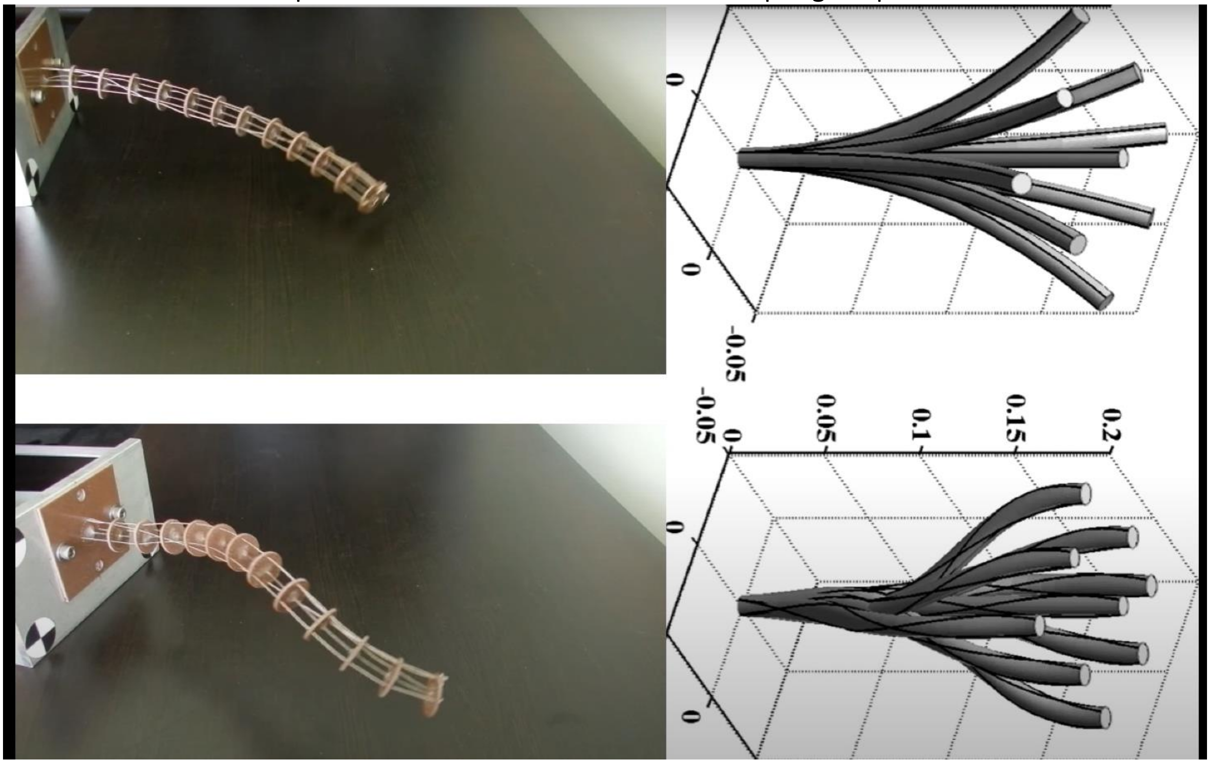


Figure 5 Bio inspired tendon, source: https://www.youtube.com/watch?v=Vi1hwdWUHvU

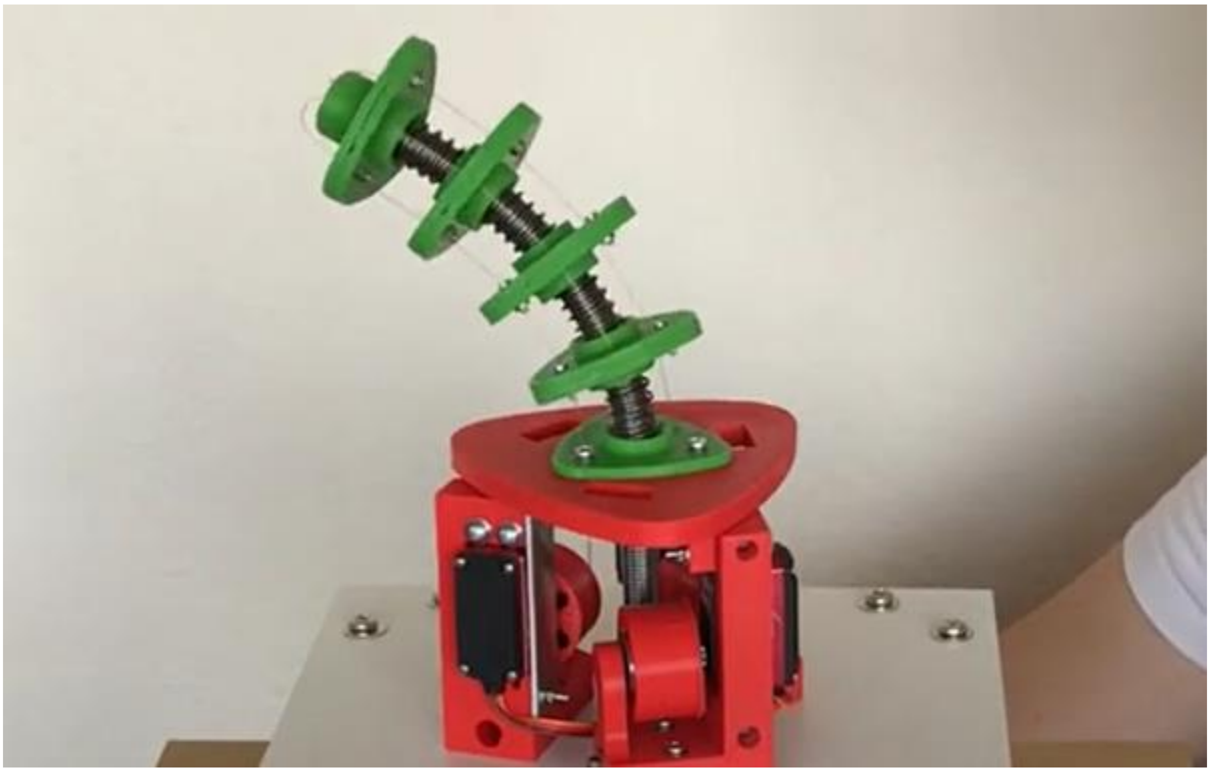


Figure 6 snake robot, source: https://www.youtube.com/watch?v=VldqRCAPQzc&t=290s

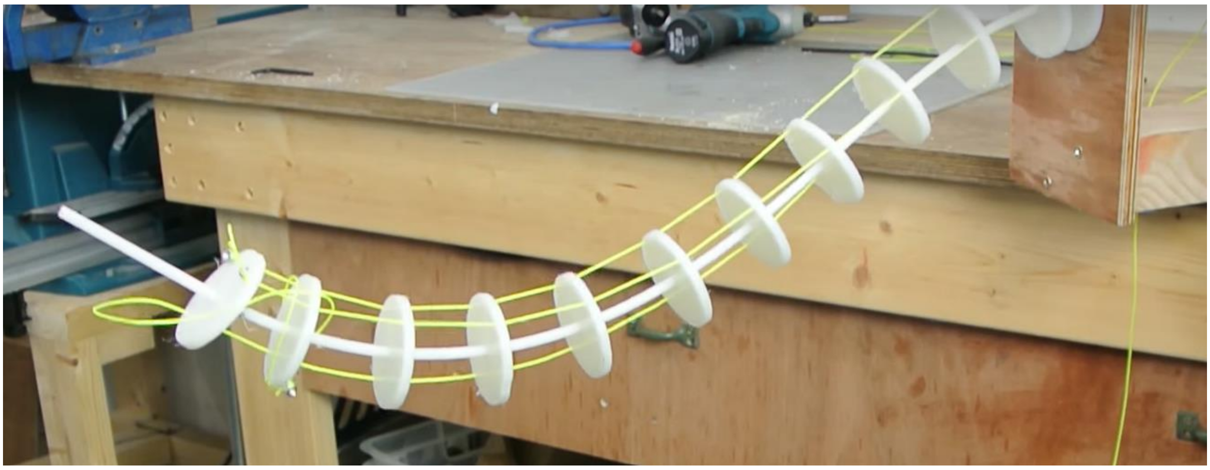


Figure 7 elephant trunk experiment, source: https://www.youtube.com/watch?v=EUEp-AfvvzE

Muscles with memory form

Some materials, like Nitinol, can store a specific form and restore it, if changed, under specific conditions.

Nitinol wire can be heated to a high temp (approx. 500C) and shaped at this temperature, this shape is “memorised”. When cooled it is compliant and flexible, but when heated to a lower temperature (approx. 50C), it reforms back into the “memorised” shape. The heating can be done quickly by passing a current through it. However, cooling can be slow, even with fans and heatsinks. The wire can be shaped into a spring or a mesh to give a pulling force when current is passed through. Nitinol is commonly purchased as a wire or spring, but you can also buy it in other shapes such as linear actuators, meshes or plates. Two or more opposing wires can be used to pull the trunk in different directions. Or a spring / gravity can oppose the wire to pull it to another form when the wire is cool. A lot of information on Nitinol can be found here: https://www.kelloggsresearchlabs.com/nitinol-in-plain-language/. There are three ways we could use the wire (see below).

The main drawbacks are: cooling can be slow so the wire can be stuck in its memorised shape for a while; the wire slowly fatigues and will no longer remember its shape after approx. 1,000,000 cycles; heating the wire could be difficult to monitor and there could be a serious safety/fire risk if the heating is not stopped before the wire reaches a very high temperature.

Linear – the wire is embedded into the core of the trunk and shaped into the desired trunk shape so, when heated, it bends to this desired shape pulling the trunk geometry with it.

Figure 8 a Nitinol muscle, source: https://www.youtube.com/watch?v=JudjfDWhOA4

Mesh – the wire is shaped into a mesh that moves to the desired shape. This is usually used for medical purposes such as expanding blood vesicles. We could maybe use this to form the outside of the trunk (directly wrapped in skin) or be to form a structural core similar to the linear shape.

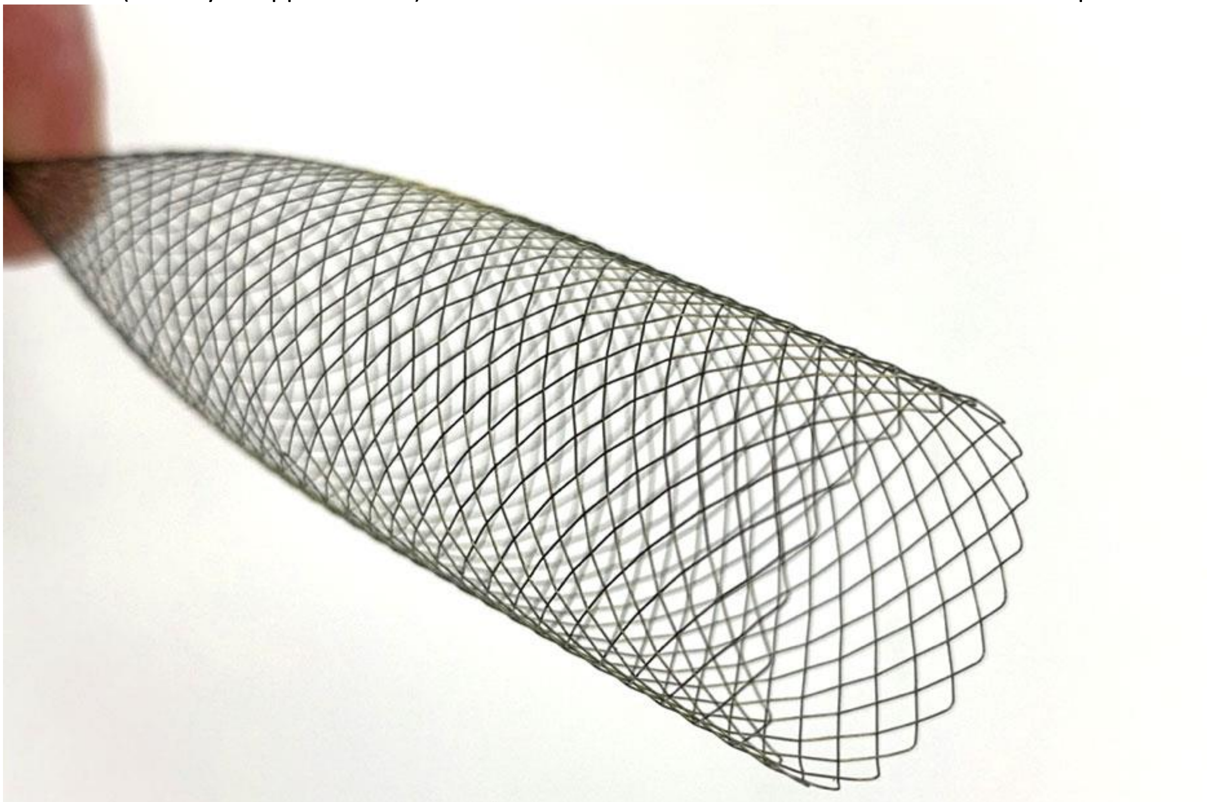


Figure 9 A Nitinol mesh, source: Nitinol Devices (oxdevice.com)

Spring – The wire acts like a spring, contracting when heated. This can then be used as a linear actuator pulling a tendon or as individual springs between joints.

Figure 10 a Nitinol spring, source: https://www.youtube.com/watch?v=65r6Ztxi0EQ

Soft robotics – inflation

Inflating a tube placed along one side of the trunk causes the trunk to bend away from that side. This could be paired with another inflatable to enable bending in two directions or 3 inflatables to enable bending in 3D. These can be controlled with servos pushing syringes.

Single Inflation – One inflatable that runs along the length of the whole trunk. Simple to make but it only allows simple movements.

Figure 11 soft robotic tentacle, source: https://www.youtube.com/watch?v=gPYjo-W2ctU&t=138s

Multiple Inflation – segments of the trunk can be inflated independently, bending each segment separately. This has the potential to be very complicated.

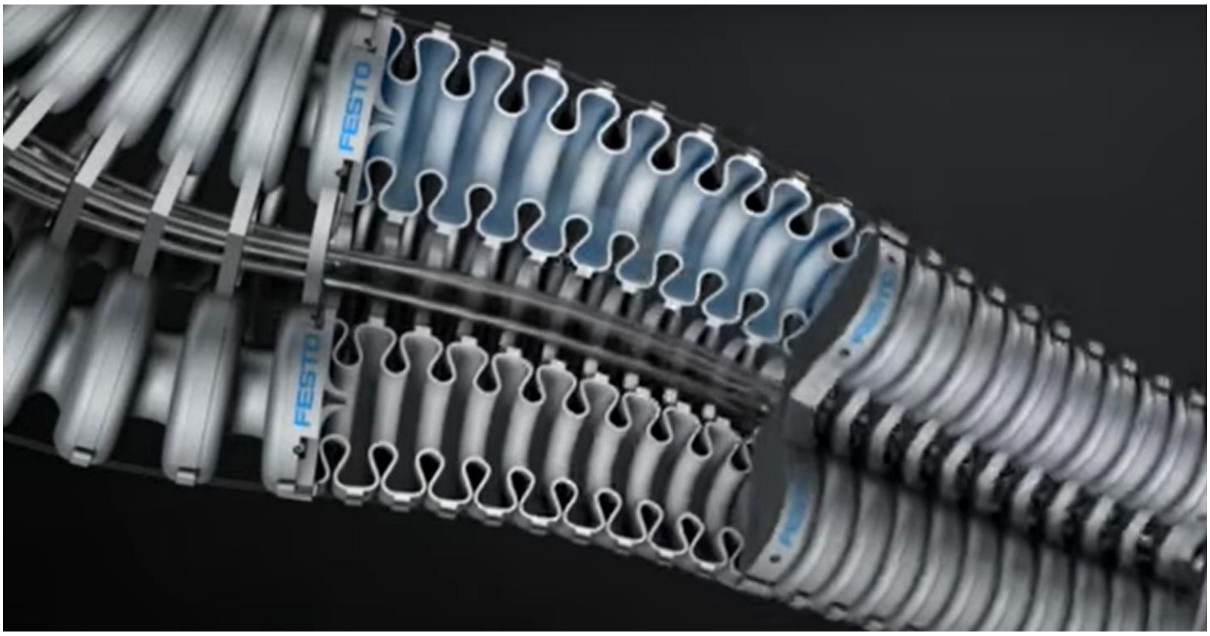
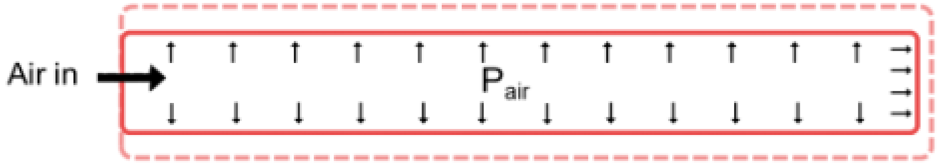
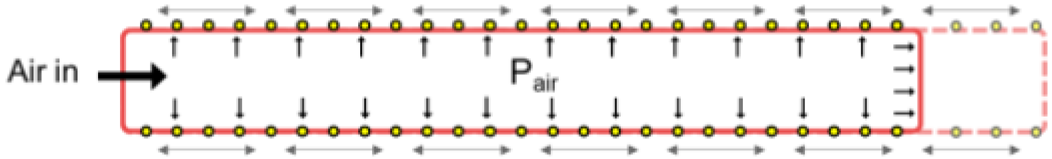
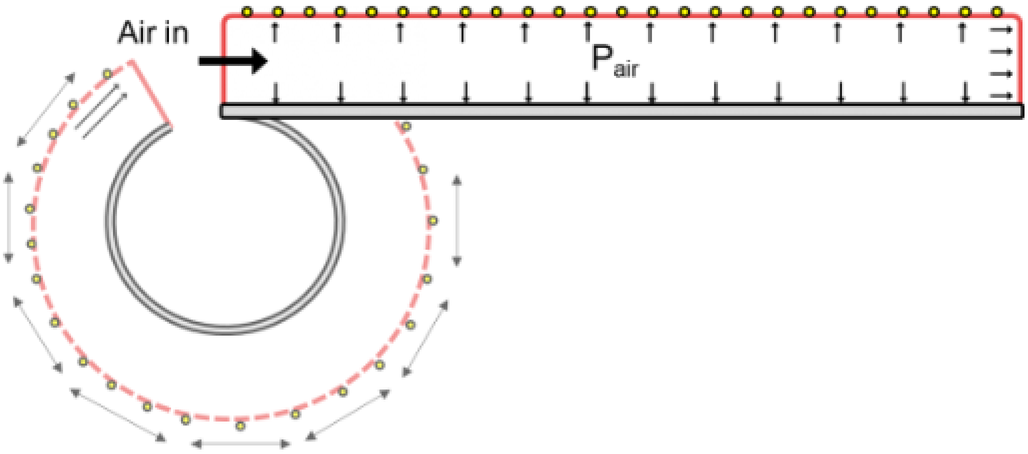


Figure 12 soft robotic gripper inspired by an elephant trunk, source: https://asknature.org/innovation/flexible-gripper-inspired-by-the-elephant-trunk/

Reinforced Bending Actuator – An elastomer bladder tube is lined with a material that prevents it from expanding outwards (radially), causing it to expand forwards (axially) when inflated. One side of the tube can be restricted from growing causing it to bend instead of linearly expand.







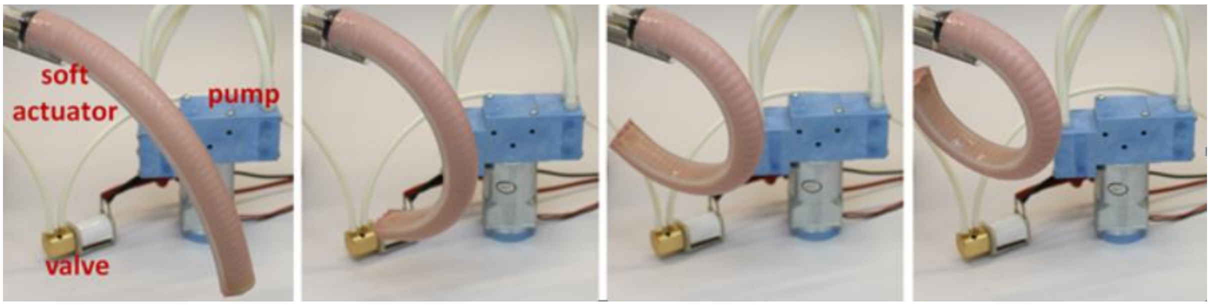


Figure 13 a nice tutorial on the subject, source: Robotic Arm Inspired by the Elephant Trunk — Innovation — AskNature

Really good instructions of how to make a bending actuator here:
We have tried to replicate it and to couple back-to-back to allow movement in two directions.
The amount of air needed is surprisingly high, and the use of a pump could bring noise and require a lot of energy. We also tried a linear actuator with a syringe. The syringe will probably leak air over time so we could try a water or oil instead, but it still looks like the system will require a lot of energy to work.

Prototypes

We have tested two of the precedent solutions examined in the context review.

Both a soft robotic approach and the tendon system have worked, with different notes.

Figure 14 two different approaches: top - tendon, bottom - soft air

Approach 1 – Silicon Trunk using air pressure

The first tests we conducted were to produce a hollow silicone trunk that could bend via air or water pressure. We followed the open-source instruction produced by Soft Robotics Toolkit to create this prototype.

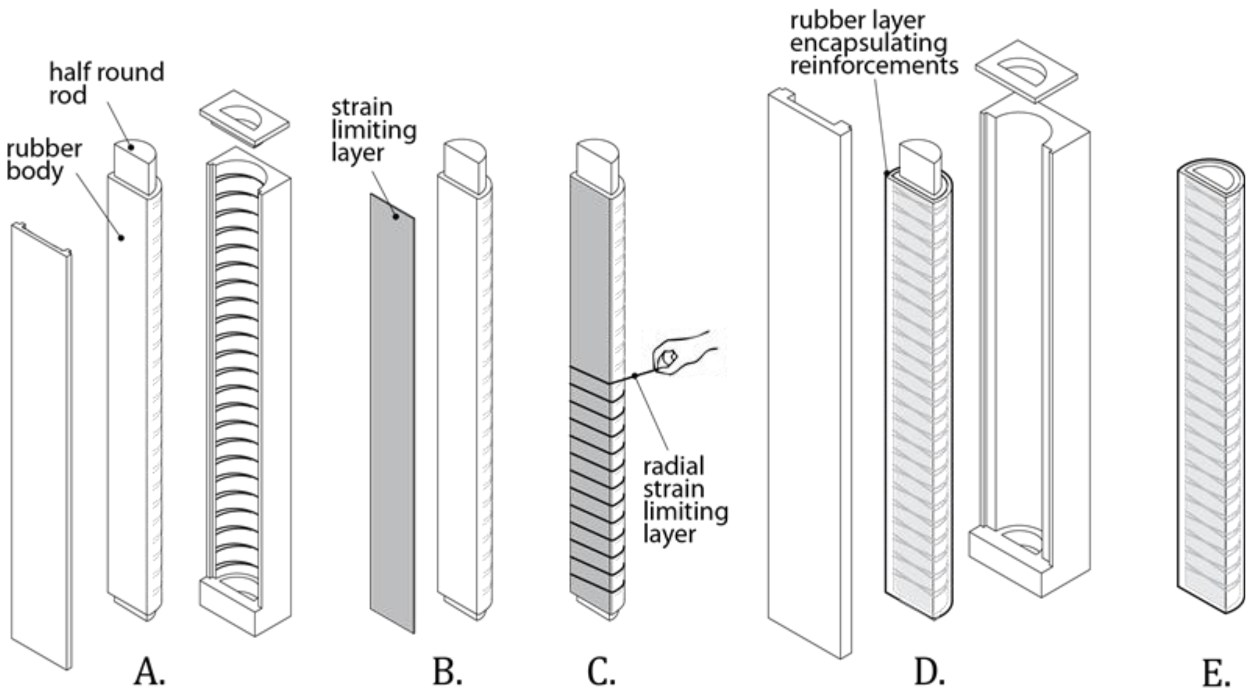


Figure 15 fiber reinforced actuator, source: https://softroboticstoolkit.com/book/fr-design

It was made from basic readily available materials and components, the moulds to cast the silicon trunk where 3D printed. The silicon used for this prototype is robust and strong and suitable for a children's toys.

Figure 16 silicon materials used for the mold

The movement of this prototype was promising and mimicked that of a real elephant but there were several concerns.

- The trucks neutral/resting position was out straight and not relaxed looking
- The movement for this prototype was only in one direction
- The air pressure required to get a full movement was high
- Over time the air could leak and maintaining a tight seal with the air pressure required for movement was difficult

Figure 17 the trunk in a relaxed position

Figure 18 minimum bend

Figure 19 half bend

Figure 20 the trunk, fully closed

To address the concerns, we produced a second trunk. We looked to create a trunk with thinner walls, so would require less air pressure to create the desired movement, and with two air chambers to allow for movement in two directions. To do this we used latex instead of silicon and used a dipping process instead of casting in a mould. There was potential in this design, but the latex was not the correct material, it broke after a few uses and the dipping technique was problematic.

We believe there could be a possible solution given more time by combining the two tests above. By firstly casting the trunk in silicon with a thinner wall to reduce the air pressure needed for movement and secondly casting it with two hollow chambers to allow movement in both directions. The remaining concern is the neutral/resting position will still look unnatural but a solution could be to cast the trunk in a bent position, so it is already bent. A great advantage of casting in silicon is that the fell and look works well for the elephant trunk and the desired form, texture and colour could be achieved through the silicon and mould it is cast into.

Approach 2 - Hinged trunk using a tendon

The use of movement via a tendon is a well-documented approach and is the current approach used by Anibotics for their current prototype, we have looked to differ from their current design in two ways. Firstly, the new designed trunk is hinged on pivot points whereas their current design is a living hinge style design. This new pivot point hinge gives more movement with less force needed from the tendon, also the design can be tweaked to give different movements at each hinge. Secondly, we have experimented with the use of a single tendon which is ridged but also flexible enough to achieve both the up and down movements required for the trunk. An advantage of using a single tendon is it will only require one motor to control the movement reducing electronics and space required to control the trunk so all this could be incorporated into the elephant head. This design also gives a realistic look in both the movement and in the natural/resting position. The design has been created with catches on the opposite side to the tendon to stop it over extended/curling.

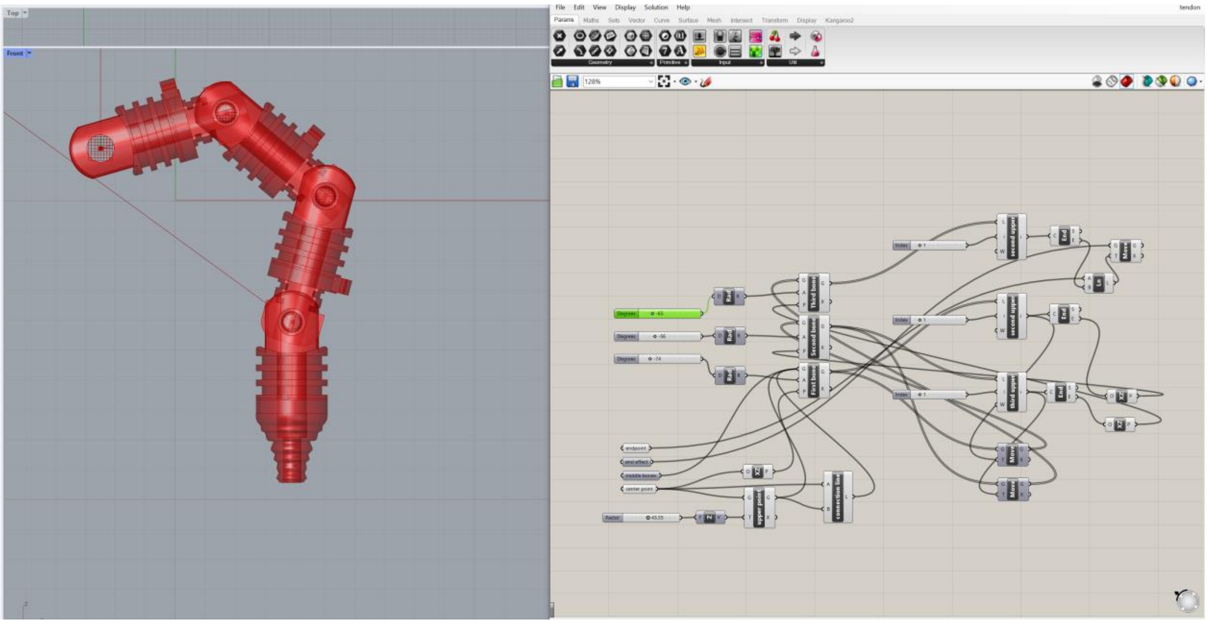


Figure 21 parametric modeling using Grasshopper

Figure 22 the 3d printed prototype from Grasshopper

Figure 23 the 3d printed prototype from Grasshopper

Our hinged trunk has been 3D printed using a Forlabs SLA 3D printer in a robust resin. This type of printing creates high resolution accurate models which is perfect for developing the trunk and possible for small production numbers, if wanting to increase production it would be possible to switch to higher volume producing methods such injection moulding. With further development a thin silicon skin could be potentially cast over the hinged mechanism to give the desired finish, texture detail and colour required. Pictured below is the printing and processing of a trunk design which is tapered to be a more realistic shape of an elephant trunk.

Figure 24 the trunk being printend in one piece, with the working hinges

Figure 25 the complete trunk, washed out to remove the uncured resin

Figure 26 the final structure

The prototype

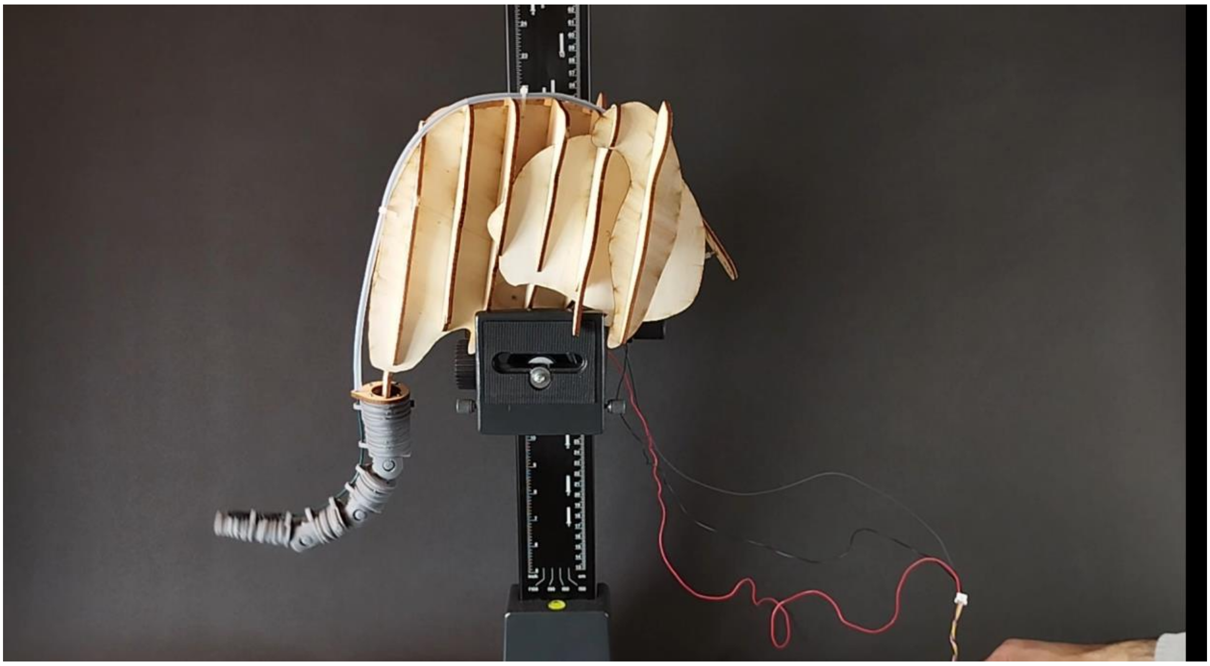


Figure 27 a short video of the tendon experiment

Approach 3 - Hinged trunk using servo motors

A third approach which we were unable to develop past a concept idea was to adapt our hinged trunk design to work with servo motors at each hinged. This may require the truck to be scaled up slightly to accommodate the motors but would give a lot of possibilities with movement and gestures of the trunk. An alternative to having a servo at each joint we considered the use of gearing running through the truck to each hinge there for reducing the space requirements of a servos at each joint.

Systems we are suggesting here are like them used in small opensource 6 axis robot arms and in robotic snakes. The robotic snake idea is perhaps the most interesting and could give the most movement that can be programmed to create additional gestures to the elephant over just the up and down curling movement.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