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Bio-Inspired Robots Imitating Human Organs with Embodied Intelligence Behaviour

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Bio-Inspired Robots Imitating Human Organs with Embodied Intelligence Behaviour

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Abstract. Soft robotics is an emerging field that introduces promising engineering methods that replicate biological behaviours. Soft robotics aims to obtain a delicate interaction with their environment and be adaptable in different situations. Using the morphology and materials in robotics design is recognised as an embodied intelligence of the system. This method provides new ideas other than classic engineering strategies; it can translate biological behaviour into an engineering context. Embodied intelligence introduces potential ways to replicate human organs' motor activities with soft-bodied simulators. Researchers are looking for a test environment that imitates the complex human organs functionalities to advance the knowledge of the human body. Many recent diseases were discovered, such as stomach dysrhythmia. It is believed that a test environment that can replicate such illnesses can introduce a faster solution to patients suffering from those illnesses. This chapter will discuss soft robots that emulate human organs using embodied intelligence in their morphology for simpler control systems and continuous actuation behaviour.

1. Introduction

Embodied intelligence is a term that was introduced to look at the robotics system from a different perspective. Generally, the robotics system is viewed as the robot body where the motion occurs, and the controller where all the programming and signal interaction with the robot body; These two sections are usually separate. However, the embodied intelligence concept combines both sections as an integrated system to achieve a task [1]. A robot body can be intelligent to manage some tasks without needing a signal from a controller. In this method, the controller of a robot can be simplified dramatically to achieve complex tasks. For example, the adaptation of the robot body to a surrounding environment can be considered an intelligent behaviour. In nature, the structure of a living organism (brain and body) is usually coupled to perform mobilities and other essential chores [2]. Human organs are an example of an embodiment in a human body, which they have complex behaviour that is still under research. For example, the interaction of the esophagus and the stomach between their body and the food shows a high level of adaptation with embodied intelligence behaviour. In order to develop robots that can simulate the adaptation, compliant materials with adequate morphologies are needed.

Soft robotics is a sub-field of robotics that proposes robots composed of soft materials that are comparable with biological forms [3]. The ability of the biological responses to their heterogeneous environment stimulates soft roboticists' inspiration [4]. This ability is observed in the living organisms' elasticity and manoeuvre to their surroundings as a daily activity. The observations of the living organisms' behaviour can be interpreted and applied in the engineering domain to obtain a method that classical robotics cannot solve. Soft roboticists are investigating the behaviour of living organisms, where identifying nature's functions can be efficient and effective in engineering. Soft robotics techniques aim to recognise the living system's perpetual and compliant functionalities by engineering procedures and communicate the abstracted knowledge into the robotic domain.

Biomimicry presents inspiring approaches to the engineering field through the quantitative examination of biological functions (adaptation, actuation, and sensation) [5]. These processes can be represented by mimicking a living system, such as human organs' responses. By linking concepts from diverse frameworks, multidisciplinary soft robotics can help researchers increase their biological functions' knowledge through robotic systems (see figure 1 (a)). Soft robots inherit unique features relative to the human organ's properties. Soft robots can be formed in a complex configuration that presents more pragmatic geometry than inflexible robots. Additionally, soft materials are analogous to biological behaviour regarding elasticity and adaptation to the surrounding conditions, essential for achieving embodied intelligence in the robotic context. It is possible to develop soft robots that offer bio-mimicking human organs' motor functionalities with soft robotics techniques.

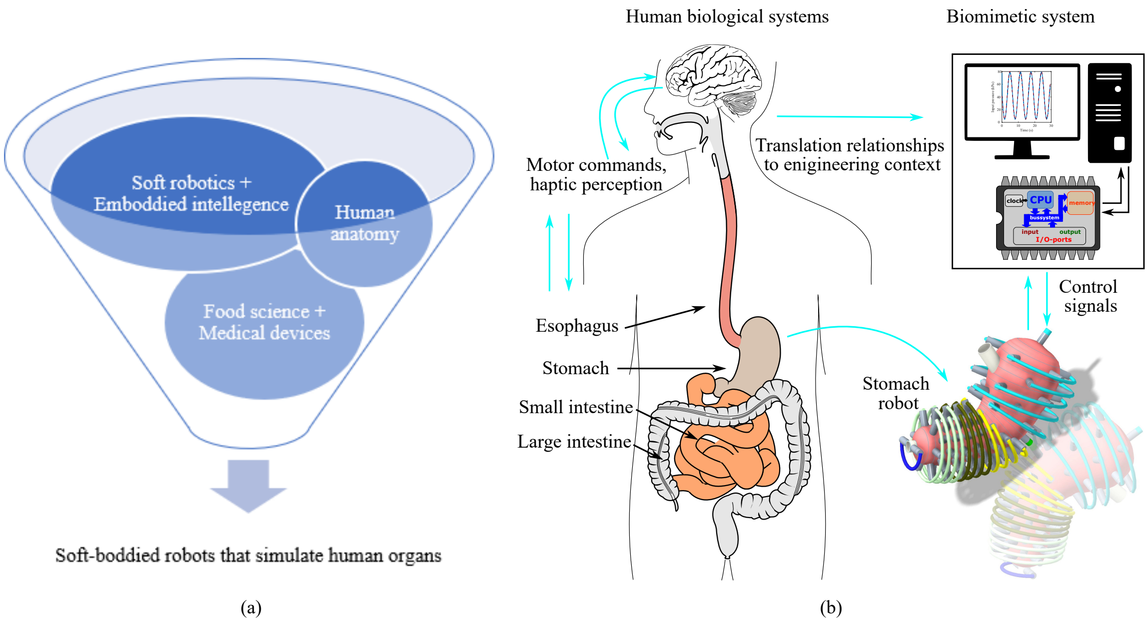

Figure 1. (a) The embodiment occurs in the human biological systems and the translation of the related relationship toward the engineering systems. The brain generates command signals to the biological systems that stimulate the motor functionalities in the smooth muscles of the gastrointestinal tract. Haptic perceptions send signals back to the brain. A PC represents the translation of the biological system in the engineering context for generating control architecture that corresponds bidirectionally with a controller. For example, a stomach robot that can mimic the behaviour of a biological stomach is shown with a set of multiple actuators to perform the motor functionality. These actuators can be in a pneumatic form which communicates with the controller. To achieve the haptic perception in the soft robot, it is required to have a sensory system capable of measuring the deformation of the motor functionality and investigating the rheological behaviour. (b) The soft robotic human organs simulators links and integrates concepts from three areas: stomach anatomy, soft robotics, and food science.

Embodied intelligence assists in promoting different techniques to robotics that can be applied to simulate biological motor functionalities such as human organs. Manufacturing human organs in physical devices aid in the exploration of the organ's behaviour and related illnesses. Several studies have attempted to mimic human organs with the biomimetic method [6]. Computer-based studies on the properties of stomach functionalities have been carried out utilising numerous procedures, such as finite element analysis simulations [7, 8]. Assumptions were used to overcome many limitations that occurred in the simulation studies. Ferrua et al. advised that a dynamic soft robot can be a practical method for experimenting and validating the conduct theories [7]. For example, the swallowing robot was constructed from compliant materials and actuated by a pneumatic system to emulate a human esophagus [9]. Recent soft robots present inspiration and a step forward toward embodied intelligent robots that are adaptive to the unknown or variant environment, such as the swallowing robot [10], stomach robot [11, 12], and heart actuator [6]. The interaction between these robots and their environment is challenging to control. Nevertheless, what if the morphology of the robots can handle the interaction? In this case, we can see the benefit of embodied intelligence in reducing the control complexity and allowing a closer step for developing complex robots that simulate human organs.

In this chapter, we discuss three examples of soft robots that possess embodied intelligence through their body responses and simple control system: esophagus and stomach robots that bio-mimicking human organs functionalities and a ring actuator that simulates the contraction of the gastrointestinal tract (GI). A brief introduction from the medical perspective is communicated and followed by the relevant robotic systems. The discussion presents what has been done, the current state, and what will we need to move forward concerning a biologically inspired robot that simulates human organs.

2. Bio-inspired esophagus robots

In this section, we will introduce the swallowing functionality in a human body with the related muscular behaviour of the organ. The second half of this section illustrates the robotic system that simulates the swallowing functionalities.

2.1. Swallowing process in medicine

The feeding process is initiated to obtain nutrition for growth and body functions. It is a conventional manner and is essential to the continuance of living. Feeding includes the ingestion of solid and liquid foods conveyed to the digestive system where the nutrients can be derived.

Swallowing is the process between chewing and gastric digestion by allowing food to pass through the pharynx [13]. Swallowing or deglutition is classified physiologically into four phases: oral preparation, oral, pharyngeal, and esophageal phase [14]. The oral preparation and oral phases are under deliberate control to chew food to boluses [15]. The pharyngeal and esophageal phases are under involuntary control that continuously progresses when initiated [16]. These phases are coordinated to successfully transport boluses from the mouth to the stomach (see Table 1). The esophagus is a tubular hollow organ that connects the pharynx to the stomach and locates in front of the spine.

Dysphagia is a common disorder that affects the swallowing process [17]. It results from many major diseases, including stroke and cancer, usually shown among the elderly [18]. Patients with dysphagia struggle to ingest solid food and thick liquids. A practical treatment suggests modifying patients' diet to adjust bolus viscosity, which can be challenging to maintain. The investigation of dysphagia is limited by the complexity of testing on patients and the limited number of in-vitro devices. Food scientists usually initiate the simulation of the swallowing process with in-vitro devices to investigate the response of boluses in the esophagus, which aid in developing a solution for patients.

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Table 1. Digestive process.

Gastrointestinal tract	Mechanical movement	Digestive juices
Mouth	Chewing	Saliva
Esophagus	Swallowing/Peristalsis	N/A
Stomach	Upper muscles & lower muscles peristalsis	Acids
Small intestine	Peristalsis	digestive juices
Large intestine	Peristalsis/bowel	N/A

2.2. *Swallowing process in robotics*

Biologically inspired swallowing robots were introduced as an in vitro solution for investigating food boluses and their response to dysphagia disorders [19]. These robots aim to mechanically simulate the peristaltic wave in the esophagus by empirically validating the motion. Therefore, the specifications of the esophagus are used to provide a correct esophagus-like robot. Specifying

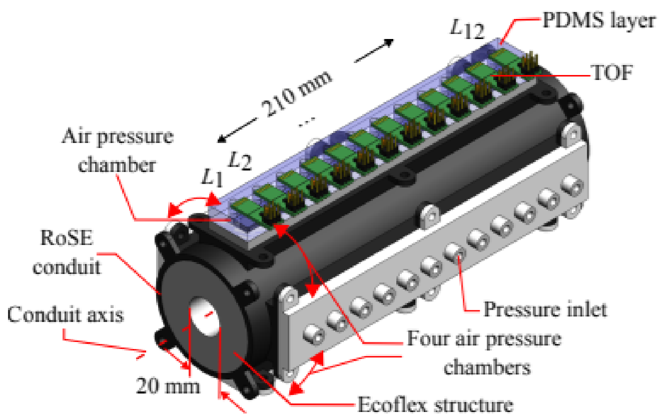


Figure 2. RoSEv2.0: a swallowing robot for simulating the esophageal behaviour and testing stent migration [20, 21].

the esophagus contractions and peristaltic waves is essential for developing an apparatus that simulates these biological behaviours. Anatomically, the esophagus can be considered a tubular organ extending 200 mm in length with a bore diameter between 18 to 23 mm [22]. The peristaltic wave in the esophags usually transfers boluses to the stomach within 3-10 s [14]. This period can be varied depending on the viscosity of the intake bolus, such as water; it can be transferred faster between 2-5 s with the help of gravity. The peristaltic wave is usually started slower in velocity, shallower in amplitude, and progresses faster and higher in the human organs. The amplitude and velocity of the peristaltic wave over the conduit are varied and divided into two sections: the first third of the tube length and the rest two-thirds [23]. The average amplitude in the first third is 53.4 ± 9.0 mmHg, while a larger amplitude occurs in the two-thirds at 69.5 ± 12.1 mmHg. The velocity also changes over the esophagus, starting at 2.92 cm/s and traversing down to 4.98 cm/s in the lower part.

Clinical trials on patients might cause discomfort and ethical issues, limiting medical studies on the swallowing process. Unlike medical practices, a swallowing robot can test the behaviour of dysphagia without including patients. A robot simulating the esophagus should determine the specification of the contraction waves reported above. In an esophageal stent method, a meshed tube is installed in an esophagus suffering from dysphagia to remain a blocked region open. This method allows patients to swallow solids and liquids food. Stents usually migrate in the esophagus within time. Researchers who work on stent development are interested in swallowing robots as an experimentation method for the stent migration (see Fig. 2) [21]. The interaction between a stent and a robot presents an embodiment intelligent environment, and understanding the migration of the stent is highly related to the embodiment of the robot body. The effect of continuous peristaltic waves can also influence the stent state. This is still under research, and the analysis of this behaviour is yet to come.

2.3. Peristaltic wave in esophagus robot

How can we create a peristaltic wave that simulates GI behaviour, and how is it possible in the engineering context? Figure 3 shows a segment of the swallowing robot with a travelling peristaltic wave at the inner surface of the conduit. The conduit has four embedded chambers in each layer (12 layers in total). As the conduit is soft, applying pressure to inflate these chambers cause the conduit to contract. The peristaltic wave in the esophagus is a sinewave-like that has been already specified in the literature [20]. Inflating three layers in the robot conduit produces a sine wave that can be controllable. The compliance of material allows this simple-control complex-response relationship. By altering the inflation between the chambers, the robot can produce contractions. For example, simulation of the peristaltic wave in the stomach (see fig. 3, or the segmental contractions in the small intestine. The sinewave characteristics such as amplitude and wavelength are controllable. Different control methods can be applied to achieve a desired sine wave inside the conduit either by open-loop control for generating spatiotemporal waves [21] or with closed-loop through nonlinear model predictive control [20]. The ability to control the peristaltic wave opens the door to simulate many behaviours, such as dysphagia. Also, swallowing robots can be used for other applications such as industrial pumps, and by varying the peristaltic wave parameters, the robot can change the speed of pumping various contents.

In a robot that simulates the GI tract, adaptive behaviour is critical for generating the

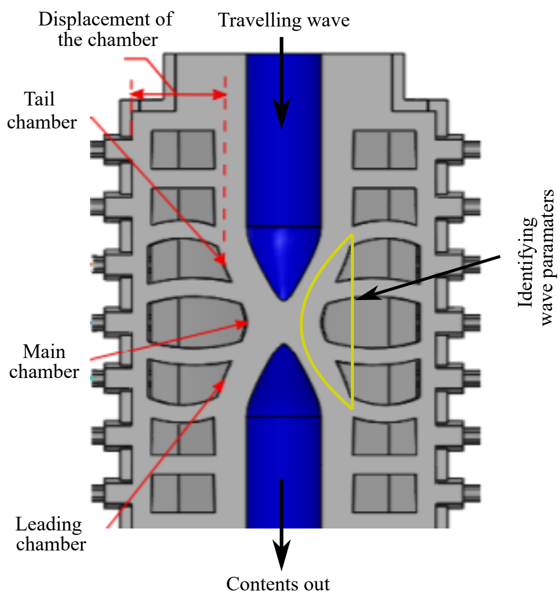


Figure 3. A section of RoSEv2.0 in a cross-section view that illustrate a travelling peristaltic wave from top to bottom (adapted from [20, 21]).

peristaltic wave. The morphology and material properties should inherit specifications similar to the biological example, such as stretchability and compliance. Adaptive behaviour considers intelligence behaviour as seen in nature. It is possible to generate a complex motion such as the peristaltic waves in a robot with simple control methods. Developing robots that mimic biological behaviour is essential for a set of applications, but also, the process of development provokes many questions about how biological motion exists. By developing such robots, we discover exciting and inspiring behaviours from nature [24], advancing knowledge in many disciplines.

3. Technology of Stomach Robots

In this section, we will present the behaviour of the human stomach and its essential role in the digestion process. After that, we depict the robotic system that mimics the peristaltic waves of a human stomach.

3.1. Medical background of a stomach

The digestion of intake food is a routine activity in various species to sustain living and growth. Inside the human body, regular digestion involves the rule of a churning movement and chemical breakdown of the food to chyme in a stomach [13]. Gastric motility provides mechanical motor functionalities. Related fields specialists declared that the motility cycles and motion strongly impact the digestion rule [8, 11]. The antral contraction wave (ACW) is the motor peristalsis activity that appears in the smooth muscles of a human gut [25]. More investigation on the ACW is required for analysing the performance, but few apparatuses are available as test environments that simulate the ACW [26, 27]. The state-of-the-art instruments are rigid forms, and inflexible actuators perform the actuation. These robots' motion and anatomy are unrealistic when contrasted with the perceived biological stomach. Acknowledging the gaps mentioned above has resulted in several soft-bodied stomach emulators that mimic human stomach motility and anatomy.

A significant known disease in the gut is dysrhythmias. This condition causes disorder in the stomach ACW rhythmic behaviour such as the direction frequency of the peristaltic wave [28]. Dysrhythmias cause difficulties in the normal digestion of food and liquids in a patient. A clinical solution that can identify a solution for dysrhythmias requires the examination of a specialist with an invasive technique.

The medical understanding of the digestion rule from the perspective of anatomical and physiological characteristics has improved lately, which has assisted in examining dysrhythmias. The knowledge of normal digestive processes can be known from healthy participants, but the diversity in participants' stomachs anatomy and situation introduce uncertainties for forming standardised measurements. Another challenge in the medical field is to provide ongoing nourishment to patients with dysrhythmia. The in vivo testing of the digestive process remain restricted through related complexity in the invasiveness methods [15].

Dysrhythmia can be examined in a test environment; a soft robot mimics the human stomach motility and can replicate dysrhythmia. The replication of GI motor functionality (healthy and ill) explains the causes of unhealthy behaviour. Furthermore, the Electrogastrogram (EGG) is the abstracted signal from the stomach, an example of a GI organ, which can also be used to simulate any irregular behaviour. Biomedical engineers have studied the EGG signals to identify stomach behaviour in healthy and unhealthy situations. It is proposed that the investigation of the EGG signals from a sick stomach can be implemented in a computer simulation, and signals can be examined with a stomach robot [29].

3.2. In-vitro stomach simulator

An in vitro soft-bodied robot mimicking the ACW of a stomach is needed for related research [30, 8, 26]. The motivation that drives this research can be exhibited in advancing the exploration of the digestion behaviour in both healthy and unhealthy stomachs. This exploration is plausible by an in vitro stomach robot. With an in vitro device, many studies can be conducted, such as the investigation of newly developed food and drugs that are related to the fields of food science [31]. Another application is represented by testing newly developed medical devices, such as micro-endoscopic capsules [11]. From these examples, we can see that a soft-bodied stomach robot inherits multi-disciplinary nature combining medical, engineering and food technology fields (Fig. 1).

Medical literature benefits the development of the in vitro device with the fundamental knowledge of the human stomach's anatomy and motility. The engineering input is correlated to the soft robotics methods, which can achieve a behaviour compared to biological responses. The material's behaviour introduces an adaptation capacity to the working environment. Another associated field in this study is food technology. Researchers from this field are highly interested in stomach robots to carry out their research, and a realistic stomach model will significantly impact the quality of quantitative food research. A stomach robot provides a test environment with repetitive, safe, and animal-free testing. Currently, the state-of-the-art rigid stomach robot is the backbone of stomach robot research and a source of inspiration to move the current state forward. The multi-disciplinary character of bio-inspired robots that simulate human organs proposes new opportunities for looking further than robots tailored for specific tasks.

It is challenging to develop soft robots that replicate the human stomach's motility, and state-of-the-art stomach robots perform ACW with rigid components. In such robots, there is no embodiment in the robot body, which either makes the controller very challenging or the overall functionality of the robot very simple. Therefore, an imitation of the human stomach motility by the soft robotics actuation techniques is necessitated for more versatile behaviour to generate peristaltic waves that can present embodied intelligent behaviour. The peristaltic wave data obtained from the medical field must be applied to the controller of the stomach simulator to provide a realistic stomach-like robot.

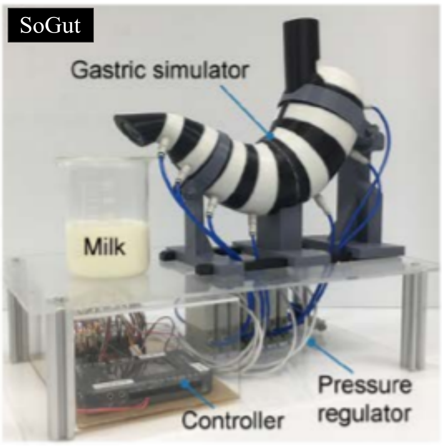


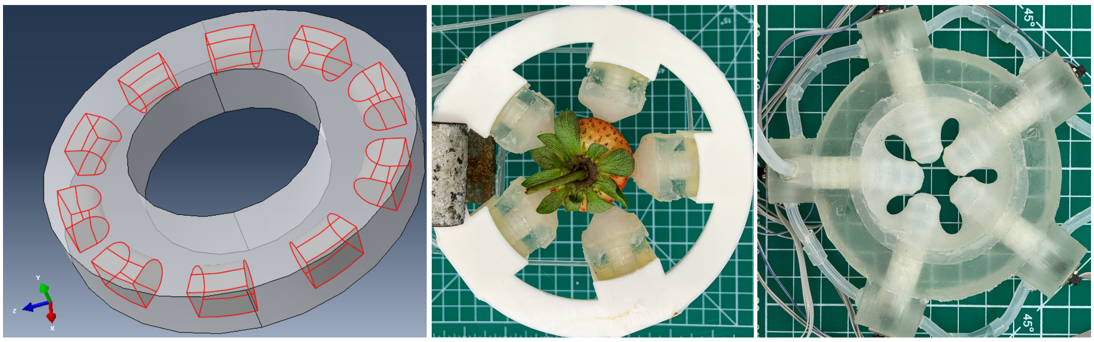
Figure 4. SoGut; soft robot stomach simulator with discrete soft actuators [12]

4. Soft ring actuator

4.1. Background

Bio-mimicry of the GI tract is essential to improve medical knowledge by testing on a physical robot, such as investigating dysphagia. As discussed in the stomach and esophagus sections, these organs' contraction waves are challenging to emulate. Other organs in the GI tract have a typical tubular shape and motor behaviour, a peristaltic wave of rhythmic contractions. It is the radial contraction that is generated by the smooth muscles. These contractions differ between organs in sequence, frequency, and velocity. Rather than designing a specific soft robot to mimic a targeted organ, we can create a generic soft ring actuator as a small section that can be modified to simulate any organ in the GI tract.

There are very few ring actuators that have been built for this purpose (see Fig. 5). Soft ring actuators are usually soft-bodied with embedded chambers that are pneumatically actuated. They emulate the contraction of a segment in the GI tract, tubular organs with different anatomy. Dang et al. presented a ring actuator to simulate a segment of the stomach [30]. It consists of one material with a single cylindrical chamber that inflates to produce a contraction. The same concept of the actuator is later used to construct a soft stomach robot. This ring actuator is simple to design, fabricate and control. However, the resulting contraction was not satisfactory for the significant contraction of the stomach, where a complete occlusion inside the soft ring is required. We previously presented an FEA study on a soft ring with multiple chambers with different designs to identify how the design parameters influence the contraction behaviour. Using a single material to construct the entire ring actuator presents unsatisfactory results compared to the biological body. Another ring actuator was developed from composite silicone to solve the large deformation issue in a soft ring actuator by emulating a segment of GI [32]. The same actuator was also used to build a full soft robotic stomach simulator with a continuous robot conduit to perform a mechanical peristaltic wave. Such an actuator can be employed to simulate other GI organs such as the esophagus and intestine.



(a) (b) (c)

Figure 5. Four examples of soft ring robots, (a) Finite element analysis for ring actuator of the same material with multiple chambers [33], (b) Bellows-driven soft pneumatic actuator that can be formed as a ring shape to simulate the peristaltic contractions and also serves as a gripper (gripping a strawberry) [34], (c) Entirely soft ring actuator that simulates a segment of the gastrointestinal tract with soft fingers [32].

4.2. The functionality of ring actuators

The ring actuator can be considered a fundamental design to develop more functional soft robotics that mimics an organ in the GI tract. In this method, more investigation on the specification of the organ behaviour can be structured with a small section for simplification. Another aspect of using this method is investigating the embedded sensory system for measuring the contraction. A sensory system can be a vital perspective for analysing the interactions between the surface and other elements that might influence the contraction. Though, it is very challenging to design an embedded sensor that can deform largely to accommodate the contraction of the soft ring actuators [35]—solving this problem by introducing sensors that adapt to the large deformation without influencing the performance of the robots. Embedded sensors in robots can present the forces that occur from the interactions, which aid in understanding the embodied intelligence and quantifying its performance.

Although soft ring actuators are constructed to mimic the contraction of the GI organ, they can be used in other applications such as gripping [30], in-hand manipulation [36], and industrial pumps [37]. The morphology of these actuators illustrates the adaptation to different environments and the applicability of using the same model for various applications, which is considered embodied intelligence. The self-organisation concept can also be seen in the in-hand manipulation application. The ring actuator consists of multiple fingers and can achieve manipulation without directly controlling the finger's bending motion. The break of symmetry concept determines the direction of the manipulation. Changing the frequency can influence the rotation of the manipulated object.

5. Discussion and conclusion

5.1. Embodied intelligence in organ simulators

The embodied intelligence can be seen in organ simulators by looking at the soft robots' behaviour that simulates peristaltic waves. The peristaltic waves require a self-organisation concept to be accomplished with the soft actuator. The material properties of soft robots, such as Ecoflex, achieve high strain/stress cycles with a simple control system. a series of embedded chambers in a tubular structure can be actuated in a sequence to achieve peristaltic waves. The deformation of a chamber influence the neighbouring chambers, which provide a continuous deformable surface rather than a discrete contraction. This aspect simplifies the control strategies and provides a more realistic deformable surface than biological behaviour. Self-organisation is one of the essential advantages of bio-inspired robotics, where rigid robots fail to mechanically simulate a movement like the smooth muscles in a human body. The three examples mentioned above used this technique (see Table 2).

The embodied intelligence can also be found in various applications that a soft robot can achieve. In the swallowing robot example, such a robot can serve as a test environment for simulating the swallowing process and an industrial pump. This example implies that the morphology of the swallowing robot is adaptive to a different environment by only altering the control schematic. The morphology of soft robotics can simplify the control complexity of required motion by employing the multi-degree of freedom inherited in their body. Another example is the soft ring actuator. The morphology of such an actuator helps these actuators to behave in many forms, such as simulating organ contractions, a gripper and an in-hand manipulation for industrial robotics applications. The in-hand manipulation method presented a break of symmetry and self-organisation concepts [36]. The symmetry break occurs in manipulating an object to rotate either clockwise or counterclockwise. The bifurcation can be determined by changing the frequency and duty cycles of the applied signals. The self-organisation behaviour is used by the soft fingers in the ring actuator (see Fig. 5) as the rotation of the object is also determined by the touchdown angle of a leader's finger. The other fingers always follow the same direction without an external control signal. This behaviour is specified as an underactuated system with no control over the bending angle of the soft fingers that rotate the contacted manipulated object. The self-organisation method is very beneficial for soft robotics applications. The morphology of the soft actuator is considered intelligent and can be included in the control strategies rather than cancel the useful multi-degree of freedom.

The current state of soft robotics with embodied intelligence presented various techniques and applications that benefited from the embodiment, such as self-organisation. Many robots were designed to accomplish a targeted task. However, improving the design of soft robots allow them to perform tasks in an unknown environment. The morphology plays a significant role in self-organisation. Soft actuators can achieve more adaptable behaviour in a complex work environment when the multi-degree of freedom can be employed in the design and control

Table 2. Summary of the current esophagus, stomach, and ring actuators that simulate the peristaltic waves in a human body.

Name	Body type	Actuation mode
Swallowing robot (RoSE) [21]	Soft body with rigid shell	Peristaltic contractions with pressurised air
Pump robot [38]	Foam conduit	Peristaltic with pressurised air
Artificial-esophagus [39]	Rigid body with soft conduit	Peristaltic contractions with SMA wires
TNO Intestinal Model (TIM-1)[40, 27]	Rigid body with flexible wall	Contractions with pressurised water
Human Gastric Simulator (HGS) [26]	Latex vessel with rigid rollers	Peristaltic with rigid rollers
Dynamic Gastric Model (DGM) [41, 42]	Rigid body	Rigid cylinder
Stomach simulator, [11]	Soft body with rigid actuators	Peristaltic with rigid wires
Soft robotic gastric simulator (SoGut) [12]	Soft body with rigid shell	Peristaltic with soft actuators
Soft robotic stomach simulator (SoRSS) [43]	Entirely soft-bodied	Peristaltic with soft actuators
Ring-shaped actuator [30]	Soft body with rigid shell	Shallow contractions with pressurised air
Ring soft pneumatic actuator (RiSPA) [32]	Entirely soft composite silicone	Large contractions with pressurised air
Soft ring actuator [33]	Entirely soft same material	Shallow contractions with pressurised air

strategies. The biological living organism couple the brain and body as one entity [2]. Following the biological example of embodied intelligence will result in an attractive behaviour in terms of adaptability, simple control, fewer actuation components, and overall intelligent soft robots that can achieve more than a simple task.

5.2. *The challenges and future direction*

The struggle to move forward in soft robotics can be narrowed down to sensing and actuation problems. Although material science provides methods that can be used in soft robotics, soft sensors are still a significant drawback that limits the controllability of soft robotics. Soft sensors suffer from reliable high stress/strain profiles that occur in soft materials. Soft materials stress/strain relationship can deviate with time, and the hysteresis curve might also get affected by materials properties changing with time. Another impediment is soft sensor discontinuity of measurement in large deformable robots. This issue occurs when the sensor stretchability reaches the maximum limit. Improving soft sensor design will solve many challenges the soft robotics control method faces.

The actuation challenge lies in simplifying soft robotics's rigid and bulky tethered system. A soft robot can be a small form but tethered with a sizeable rigid actuation system such as a pneumatic system. Developing a soft actuation system can simplify and provide an entirely soft robot that is untethered. The new generation of soft robotics is expected to employ these techniques to move forward in the soft robotics field. Self-organisation can be an excellent direction with actuation systems that communicate together to achieve a task. In a pneumatically actuated system, a discrete actuation method, a separate pneumatic valve controls each chamber, limiting the possibilities of soft robots' behaviour. A solution to this method is employing self-organisation in the actuation system by controlling the multi-chamber system with a design that communicates to each other by using the material properties and how the material responds to the same applied pressure [44]. We can develop a single input multi-output system with an entirely soft robot's body and actuators for more versatile applications by employing such techniques.

It is challenging to identify and quantify the intelligence of robots simulating organs. It is acknowledged that embodied intelligence exists in the material and morphology used to construct these robots. However, can we call these robots intelligent?. A significant question that researchers are looking to solve. Concepts have been established, such as the Turning test and the Chinese room. Although the robot body can entirely rely on the material embodied intelligence, today's actuation methods are still premature for obtaining such intelligence. An embodied intelligent soft actuator and sensors are an essential research direction that advances this field. Suppose we can develop a fully embodied intelligent soft robot that simulates a human organ (including soft actuators and sensors) with a central pattern generator control method. In that case, one can argue that we can investigate implant strategies and not only use these robots for a test environment. This can be done by closing the human-robot reality gap with embodied intelligent behaviour, which is still in an early stage but is feasible as a research direction.

In this chapter, we discussed embodied intelligence from the perspective of soft robots that simulate human organs. We briefly presented three examples of how soft robots can simulate an organ and why we need such a device. The swallowing robot, stomach robot, and ring actuators simulated the gastrointestinal tract were presented. We discuss the benefit of embodied intelligence to achieve an advanced robot that simulates organs. The current state and the future direction were also communicated.

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