Crawling into motion: Design optimization of Soft Crawling Robot (SCR)

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ABSTRACT – This paper discussed the design optimization of soft crawling robot for crawling locomotion. Robots are generally built by connecting rigid links and they have inadequate degree-of-freedom. The design of conventional rigid robots that are inadequate for the degree-of-freedom renders them unsafe for human dealings. Unlike this conventional robot, Soft Crawling Robots (SCR) having unique adaptive characteristics makes the robots fit in a confined space and make delicate movements. The SCR proposed design was created using the SolidWorks software. The SCR design has two variants which are (a) Quadrupedal SCR and (b) Inchworm SCR. The parameters of both kinds of robots are assessed by manipulating the base thickness, chamber gap distance, number of chamber and the air chamber width. Both designs are optimized using the FEM (finite element method). Assessment and optimization are carried out by using Abaqus software to assess the robot's performance with regards to the pressurised air. The Inchworm SCR achieved 130.4mm bending motion in compared to Quadrupedal SCR, with 44.06mm bending motion.

1. INTRODUCTION

Research on animal movements has been carried out for a long period by the experts. It was the crawling without limbs that caught their attention as an efficient way of movement and in a delicate way. The soft crawling robots (SCRs) are always composed of soft materials [1]. The soft and simple design makes them more reliable and safe so that they can be used effectively in real life situations [1]. Majority of the designs of the soft robots are derived from the movements of animals such as the insects. These creatures do not have stiff body and skeleton so they are able to move freely [2]. These soft robots can even move in a confined space place in a much better way in comparison to the conventional rigid robots [3]. Many kinds of actuators and constituents have been examined by the scholar for making these soft robots with the best design. Some of the latest designs created by the researcher focus on enabling the robots to adhere, stick or slip as per the requirements.

Soft crawling robots (SCRs) are the kind of robots that use soft actuators for movement. Majority of the robots of this kind employ pneumatics actuators due to high efficiency but require several accessories, therefore making them difficult to control. These soft robots can sustain huge distortions with vast degree-of-freedom which makes them more suitable to be employed in unstructured location compared to the conventional rigid robots. Unlike the soft robots, the conventional rigid robots cannot be employed in situations where precision is required such as medical purposes, thus making the soft robots preferable. Basically, robots are employed to provide higher safety to the humans as they lower the possibility of harm to the humans by working in a hazardous environment in place of the humans. The main problem with the conventional rigid robots is that they are not flexible enough which renders them less safe for human dealings. In this research, two types of design of SCRs (soft crawling robots), which are quadrupedal and inchworm, were assessed and enhanced to be employed for general applications.

2. SOFT CRAWLING ROBOT DESIGN

In this research two design was selected; i.e.: (a) Inchworm soft crawling robot and (b) Quadrupedal soft crawling robot design. For both design, their parameters were optimize for motion elongation. The body of the robot is made up of chambers that undergo expansion under pressure. The chambers' lower parts are equipped with air gap holes. These holes are connected in such a way that when there is pressure applied, every chamber will be included. The robot will then move via the contraction and expansion of the chambers. Figure 1 illustrates the Inchworm Soft Crawling Robot.

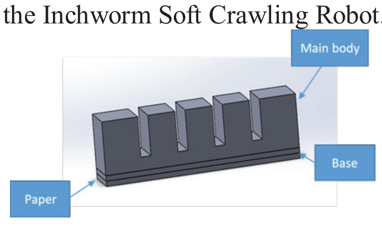

Figure 1 Inchworm soft crawling robot design

The Quadrupedal Soft Crawling Robot refers to a soft robot with four legs and one body. Within the robot are chambers that expand under pressure. The robot's base is also made up of paper that allows it to bend. Figure 2 illustrates the Quadrupedal Soft Crawling Robot.

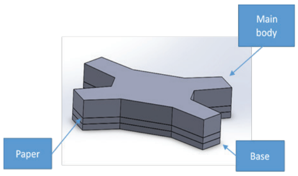

Figure 2 Quadrupedal soft crawling robot design

3. RESULTS AND DISCUSSION

The design for the Soft Crawling robot is conducted by utilising the SolidWorks software, and the stress and bending analysis outcomes are achieved through the Abaqus software. The pressure employed ranges from 1psi to 8psi. The fixed side is at the back actuator. The initial dimensions for the inchworm designs are: gap of chamber 2mm, thickness of base 2mm, and width of air chamber 2mm. An example of optimization for Inchworm SCR is shown in Figure 3 and Figure 4 depict the outcomes of pressure against displacement and stress for the 'thickness of base' parameter. The base thickness is varied as 2mm, 4mm and 6mm.

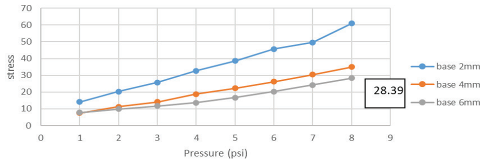

Figure 3 Pressure vs. stress graph for parameter thickness of base.

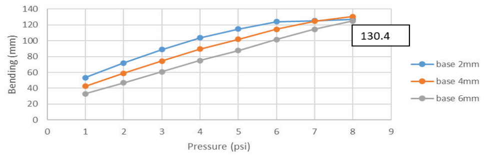

Figure 4 Pressure vs. bending graph for parameter thickness of base.

Regarding SCR, the aspect of bending is more significant in comparison to stress, as the movement of SCR progresses according to bending values. Therefore, the superior scheme is selected with reference to the bending values. From Table 1, the highest bending observed is for the inchworm soft actuator at a value of 130.4mm. The optimized parameters for this comprise 4mm base thickness, 5mm chamber gap, and 2mm width for the air chamber. Table 2 shows the scheme of the quadrupedal soft actuator features a lower bending values compared to the Inchworm SCR. From the preceding Table 1 and Table 2, it can be summarised that of both types, the better design is for the Inchworm SCR, with its optimized higher bending value.

4. CONCLUSIONS

Based on the results of the FEM analysis for the two designs; the design, optimization, and analysis of two soft crawling robots were validated. The optimized design that was selected is the Inchworm SCR, with optimized parameters that were examined and determined to comprise 4mm base thickness, 5mm chamber gap, and 2mm width for the air chamber, with the bending value 130.4mm. Future studies are suggested by fabricating both designs of soft crawling actuator to further verify the designs and performances of the soft crawling actuator.

Table 1 Summary of optimization for Inchworm SCR

Actuator	**Optimized value (min stress and max bending)**			
	Optimized parameter	**Stress (N/m^2)**	**Optimized parameter**	**Bending (mm)**
Inchworm soft actuator	Thickness of base= 6mm Gap of chamber = 5mm Width of air chamber = 2mm	28.39	Thickness of base = 4mm Gap of chamber = 5mm Width of air chamber = 2mm	130.4

Table 2 Summary of optimization for Quadrupedal SCR

Actuator	**Optimized value (min stress and max bending)**			
	Optimized parameter	**Stress (N/m^2)**	**Optimized parameter**	**Bending (mm)**
Quadrupedal soft actuator	Number of chamber = 1 gap Thickness of the base = 2mm Width of air chamber = 2mm	80.73	Number of chamber = 1 gap Thickness of the base = 2mm Width of air chamber = 2mm	44.06

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