Conceptual design of a modular snake origami robot

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Conceptual Design of a Modular Snake Origami Robot

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***Abstract*— This work shows the conceptual design of a modular snake robot using modules built from a folded paper structure. Module interconnection scheme and their design specifications are based on existing modular snake robot technology, simplifying the control of the whole robot. Module concept design, size and scaling, followed by the paper sheet folding procedure and its interconnection are explained. The modeling of the folded module's bending behavior is compared with a rigid one, validating its implementation convenience. The main objective of this work is to seize the emerging technology of programmable sheets, to produce a real soft robot application.**

I. Introduction

Nowadays, it is a fact that the robotics community has accepted the modular, snake and other redundant type of robots as potential tools for several applications, namely search and rescue, infrastructure inspection, first response, environment monitoring and so on [1]–[3], not to mention medical applications like probes [4]. Particular examples of the modular snake robots usage can be found [2], demonstrating their multi-mode locomotion capabilities. Such diversity of gaits is achieved by simplifying the robot's locomotion by means of parameterized motions governed by cyclic functions [5]. The motion is relied to the time changing configuration space (i.e joint angles).

Our Modular Snake Robots are commonly constructed using 16 modules. Modules are composed of a rigid body (the actuator) and a holding structure to attach it to the next identical module. A lack of space to add components as sensors, power and tools became a problem. On the other hand, our current research has given us an insight to the necessity of adding a body and actuator compliance to negotiate in a better way terrain non-homogeneities. For that reason, our research goal aims to improve our current structural and actuation technologies. However, we keep both, our robot architecture [6] and the locomotion controlling scheme. In other words, maintaining the modular snake robot concept.

Consequently, a new proposal of soft robot called "origami robot" is taken into account. These robots, currently implemented as a proof of concept at MIT-CSAIL, Harvard-Wiss institute and EPFL-Reconfigurable Robotics Lab, are based on a planar sheet that by consecutive foldings, becomes a spatial structure [7]. This novel kind of robots serves as a starting point for the viability of the concept proposed here.

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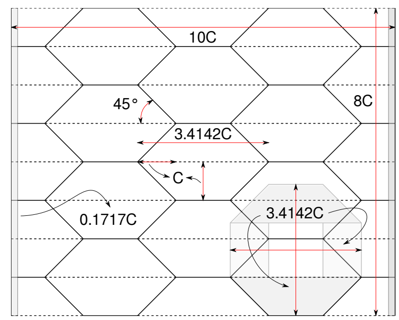


Fig. 1: $10C \times 8C$ sheet, mountain and valley folding pattern.

II. Preliminary Specifications

In order to keep same functionality and control schemes as previous Modular Snake Robot technology [5], some requirements must be accomplished in the design of the folded sheet module. As the control of a modular snake robot relies only on the joint angles bending capabilities, this is our primary design parameter. Our current robot controllers constrain the module bending angle operation up to $\frac{\pi}{3} rad$ for safety purposes [8]. However, the robot bends each module up to $\frac{\pi}{2} rad$ if needed. We consider that the module proposed here must present the same bending capabilities. Additionally, as we know, the folded module proposed presents several sub-bending due to its construction nature, a single angle command value must drive all the folded module to a desired final bending angle. Finally, modularity must be exploited to allow future shape re-configurations.

III. Module Design: Scaling and Procedure

Dimensions are normalized with *tesserae* characteristic length C to make our design scalable for several sizes. Fig. 1, shows the pattern required to convert a single paper sheet of $8C \times 10C$ into a bending folded module using the procedure in Fig. 2. An octagonal cross-section module is obtained (see Figs. 1 and 2-11). Sheet borders excess of $0.1717C$ remains, allowing convergent faces to overlap and be fixed.

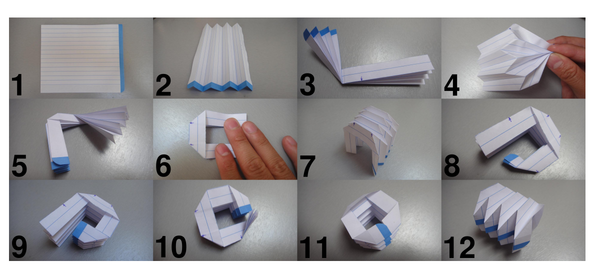


Fig. 2: Sheet folding procedure of bending folded module.

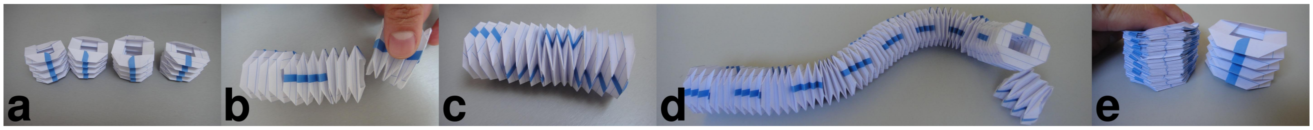
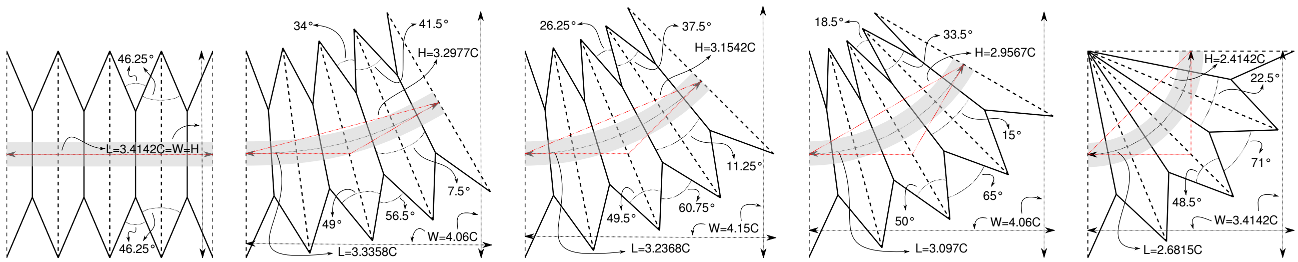


Fig. 3: Module Interconnection. “Pocket” detail (b). Robot structure with 16-modules stretched (d) and compressed (e).



(a) $\theta = 0\ rad$ (b) $\theta = \frac{\pi}{6} rad$ (c) $\theta = \frac{\pi}{4} rad$ (d) $\theta = \frac{\pi}{3} rad$ (e) $\theta = \frac{\pi}{2} rad$

Fig. 4: Bending analysis of the folded module at different θ values.

Module interconnection is self allowed. A sort of “pockets” are created in the folded module allowing the consecutive modules to be attached as shown in Fig. 3b. An interesting emerging capability of this conceptual design is its compression into a minimal volume (Fig.3e). An advantage for future transportation and deployment purposes.

IV. Modeling and Validation

Geometric analysis of the angles needed in each vertex (external/internal) of the folded module for a given whole bending angle was carried out. Results are shown in Figs. 4a to 4e. For controlling purposes, good resolution in the actuation angle span is expected. There is a notable variation of the external angles in both inbound and outbound sides in the analyzed angle span compared to the internal one. This higher resolution suggests the use of these external angles (i.e most inner folded edge of the module) as actuation points, and keep the internal angles passive seizing the compliance of the material. Additionally, the use of these internal edges is convenient because in situations like the extreme bending of $\frac{\pi}{2} rad$, there is no physical room for an actuator or wiring to control the internal module angle. It is worth to mention that in a whole span $(-\frac{\pi}{2} rad \leq \theta \leq \frac{\pi}{2} rad)$, the relationship with the external angles found (Fig. 4) is linear (not shown here), matching the design assumption of controlling the module's folded vertex angles by using single joint values per module.

A further analysis (not shown here), of relationships between the folded module arc length L and the hypotenuse H of the triangle composed by virtual rigid body modules (red lines in Fig. 4), leads to a strong consistency of the bending capabilities of the proposed modules with the current modular snake robot technology.

V. Concluding Remarks

We envision the use of programmable sheets to create modular snake origami robots. This design fulfills preliminary specifications, allowing it to be implemented with real active structures and test its locomotion capabilities (Fig.5).

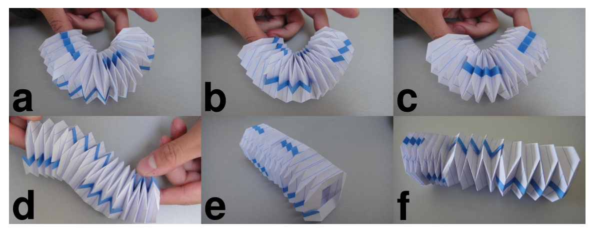


Fig. 5: Expected locomotion capabilities. Lateral Rolling (a)-(c), Sidewinding (d), Linear Prog. (e), and Concertina (f).

Our interest is to share our knowledge on modular snake robots, to find experts in soft-robotics and join efforts to turn this conceptual design into a novel and promissory device.

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