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An Active Bending Endoscope using Smart Materials

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Abstract: ***Actual endoscopes which are used in industry and in minimal invasive surgery, have certain demerits, mainly due to their minimal mobility. The technical constraints for this kind of application are space constraints and torque and angular constraints. The primary solution consists of a two degree of freedom structure driven by two pairs of antagonist shape memory alloy wires. The dimensions and preloading for such actuators follow an analytical approach. A perfect solution to this problem is realizing endoscopes driven through smart materials integrated actuators. The possibility of using nanomaterials in endoscopy and other medical applications is yet to be explored in depth and provides a vast platform of opportunities and research. Nanomaterial based instruments have become vital in generating images of high resolution and high contrast which are very much needed in precision diagnostics and surgical operations. The principle of smart materials actuation, combined with an initial approach to their design, control and materials used and proposed material alternatives is presented in this paper.***

Keywords: Endoscope, Shape Memory Alloys, Actuation, Design, Materials

1. Introduction

Endoscope is a clinical instrument used for minimal invasive surgeries. It mainly consists of a flexible shaft with provisions to traverse air, water, electric wires and other minute instruments. At one end of the shaft, there is a steerable tip with camera chips, LEDs and exit for exhausts and electrical connections. On one end, there is a grip with regulatory mechanisms which are used to bend the tip. Bending motions in a conventional endoscope is controlled externally by wire traction. The main advantage of flexible endoscope is that it enables traversing complicated trajectories and reaching anatomical regions with minimal invasion. But this flexibility curtails the functionality of the endoscope. This brings the stiffness of the endoscope as the most important design parameter while designing and developing a flexible endoscope. The endoscope should be developed in such a way that there should be a balance such that the scope is rigid to advance the endoscope and being flexible enough to traverse complex and curved trajectories. This makes the scope too flexible to fully prevent it from non-desirable bending and too rigid to regulate it from deforming the trajectory.

Research studies have suggested the use of various smart materials and polymer metallic composites in the design and development of active endoscopes. Smart materials are of primary focus because of their innovative use in practical applications. Primary examples of the smart materials are shape memory alloys which are extensively used in modern day applications.

Smart material actuators are activated by thermal resources, thermal conduction can result in unwanted actuation of other actuators in proximity which leads to unwanted bending in these proximity actuators. This leads to causalities to the patient when the inner organs collide with the instrument. An elastic backbone was utilised to realise the bending and to act as a spring for the Smart materials. Bending happens due to the heating of actuators, leading to the contraction and bending of the instrument. [10].

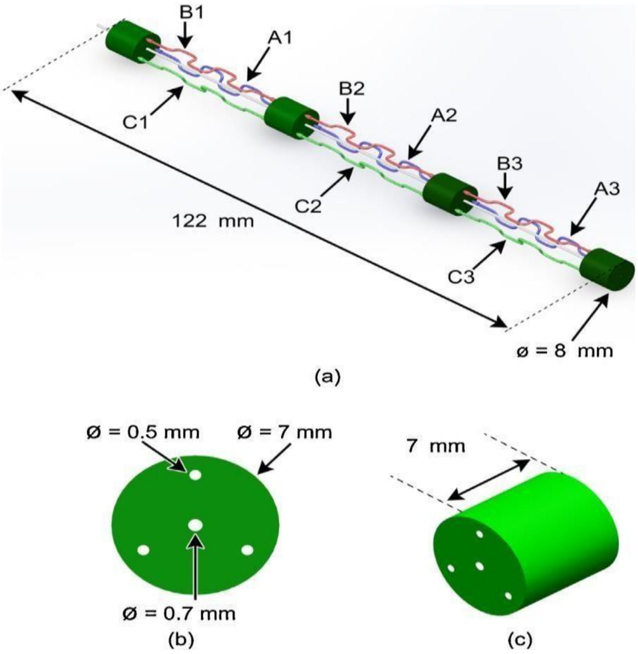

Figure 1: a) Endoscope instrument design with specifications b) Elevation c) Isometric dimension

Localized blood pressure measurement and injection of medicine is done through a catheter which is a small tube with high flexibility. The process of catheterization helps doctors to access infected sites to be monitored and treated through a blood vessel. Doctors regulate the edge point of the catheter by controlling its proximity part externally. With reference to blood vessel dimensions, the catheters are in the range of 1.0-3.0 mm diameter and 1.25 m length. As doctors must ensure the regulation of the tip of the catheter from externally, actions with catheters demands considerable skillset, particularly when the blood vessel has complicate mechanism. Thus, the current scenario demands an active catheter which has high flexibility and mobility [1].

Former works on smart micro devices has used bulk titanium nickel based smart materials sin the form of sheets or wires. As mentioned in **[2]**, when the titanium nickel based smart material is used, the size minimizing is confined to the least sizeof microns and since intricate assembly work for micro components is crucial, it leads to low productivity. The titanium nickel film was deposited by the radio frequency magnetron sputtering system JEOL JEC-SP360M with Ž. two separate Titanium and Nickel targets purity of both, 99 % in Ž and low pressure Argongas as a medium for sputtering. The dependence of ratio of composition of the film on RF power applied to each target was probed to find the optimum conditions suitable for sputtering.

The first smart material cardio vascular device used was the Inferior Vena cava filter. It is utilised for interruptions in blood vessel for curtailing pulmonary embolism by placing in the vena cava as mentioned in [3]. The device is fabricated of smart material wire curved in such a way that it traps the clots which are dissolved in time using the bloodstream. The device exploits the shape memory effect for insertion i.e. the original form in the martensitic stage is transformed and modified into a catheter. When the device is released, thermal effect of the body aides the filter to return to its predetermined shape.

Studies on smart materials have witnessed significant growth because these materials possess both sensing and actuating functions which points to many potential applications **[4].**Correlating the properties of smart materials with other materials can create intelligent or smart composites by utilizing the unique properties of shape memory alloys and other smart materials like shape memory effect, pseudo-elasticity and higher damping . Now a days, Smart material wires have also become available on a commercial basis for the design of smart composite structures because smart material wires with minimum diameter fibers and particles can be produced at ease.

2. Design and Principle of operation

The endoscope is made with nine actuators bounded each other and separated by rings. The separator rings were designed to keep the instrument's shape by acting as a housing for the actuators. Physically and thermally isolating them from one another was also a function of the separator rings. Heat conduction can cause undesired actuation of other neighbouring actuators, resulting in unwanted bending from the other actuators, because the SMA actuators are actuated by thermal energy. As a result of the tool colliding with the patient's inner organs, the patient may get harm. To aid in the bending process and act as a bias spring for the SMA, a pseudo-elastic backbone was used. The instrument bends when one of the SMA actuators is heated, causing it to contract and allowing the instrument to bend. The overall structure is shown in Fig. 1, together with labelling for the different actuators and separator ring diameters.

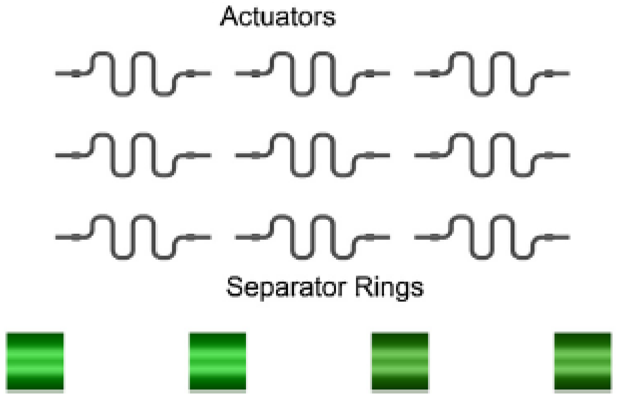

Figure 2: Actuators and Separator ring

The instrument was made up of three pieces, each with three different actuators that allowed for three different degrees of bending freedom. Sections A, B, and C imply actuators in the same plane, while actuators 1, 2, and 3 denote actuators in the instrument's front, centre, and back. The arrangement of the actuators with the ac is depicted in Fig. 1. For the sake of simplicity, one-way SMAs were utilised, which necessitated the employment of a bias spring to reorient the SMA actuator to its original shape once it was deactivated. Figure 2 depicts the overall organisation of each instrument component. When one of the actuators is heated, it contracts, causing the instrument to bend.

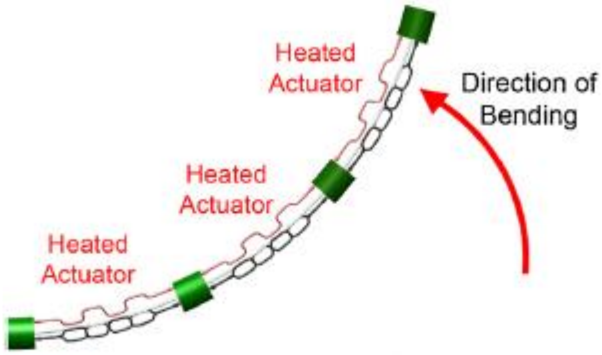

Figure 3: The Actuator bending after heating

3. Results and Discussions

A segmented prototype made of Teflon actuated by shape memory alloy actuators and connected by ball and socket joints was analyzed. Considering on a segmental basis, the two segments selected can be in any of the seven states. The discrete point reached by the edge of the probe is seven which increase geometrically with the rise in the number of segments; the number of states is expressed as 7n–1, where n represents number of segments including the base. The angle made by the top segment with ‘z’ axis was calculated and was found to be approximately 28° for the prototype and may alter depending on the smart material actuation and application. The length of each segment in the model developed was approximately 22 mm; reduction in this length will give more flexibility to the probe.

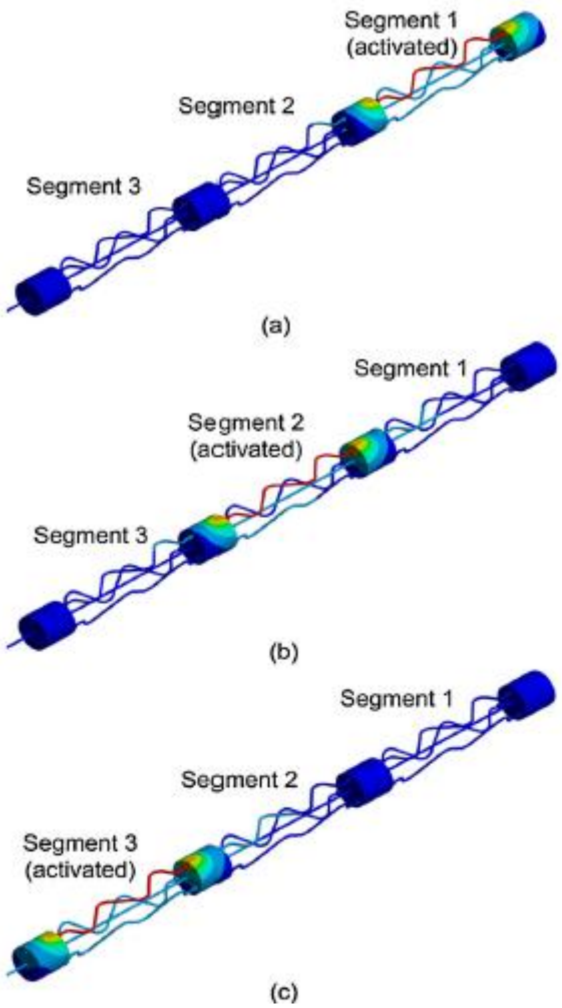

Figure 4: Simulation of Actuator (a) Segment 1 activated. (b) Segment 2 activated, (c) Segment 3 activated

4. Comparative Study

Main comparison was made with reference to the SMA material used for the actuator and the miniature endoscope model. The low actuation frequency of SMAs is a well-known limitation. Miniaturization of the endoscope model with a material other than Teflon with clear magnitude of heat loss and control in bandwidth also needs to be explored without compromising accuracy. A comparison of the materials which is used in active endoscopes now is listed below [4].

The tabular data shown below indicates that Teflon (PTFE) maintains its stability with reference to the dimensions against tension, which along with its biological merits makes Teflon a preferred choice.

Table 1: Comparative study of materials

Suture Material	Immersion Time	Mean	Min	Max	p*	p
PG (Polyglactin)	Baseline Day3 Day7 Day 21	26.67	20.02	30.69	0.18	0.522***
		27.55	25.13	30.20	0.55	
		27.01	22.78	29.76	0.34	
		27.4	6.77	7.92	0.27	
		28.14	6.73	7.49	0.25	
BS (Black silk)	Baseline Day3 Day7 Day 21	14.58	10.12	15.72	0.01	0.001***
		12.81	7.75	15.87	0.33	
		9.91	8.54	11.87	0.27	
		12.87	12.28	14.91	0.01	
		12.54	11.48	14.57	0.11	
PTFE (Teflon)	Baseline Day3 Day7 Day 21	7.52	4.88	8.22	0.01	0.094***
		7.59	7.23	8.10	0.58	
		7.84	7.34	8.21	0.66	
		7.48	6.77	7.92	0.10	
		7.21	6.75	7.49	0.43	

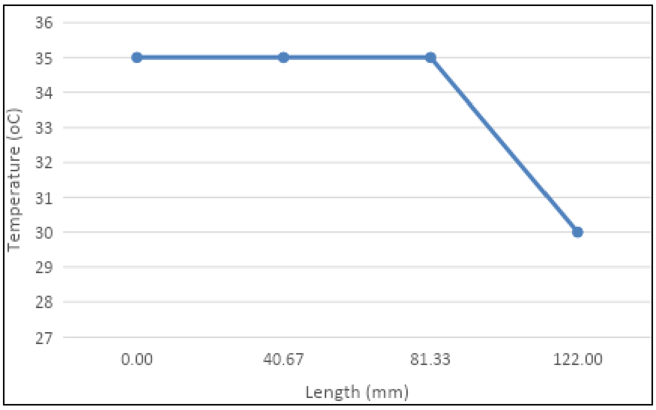

Figure 5: Segmental thermal test bending comparison – End section

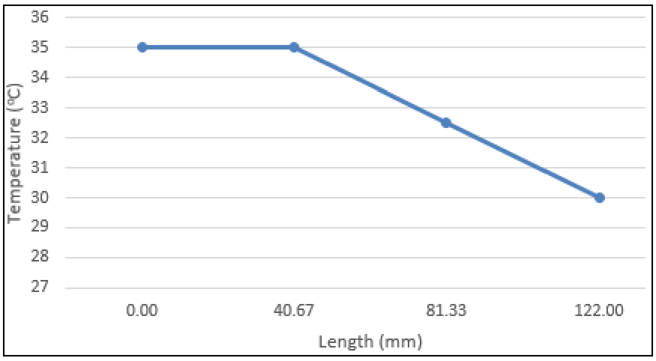

Figure 4: Segment thermal test bending comparison

The figure 2 and 3 indicates the segmental thermal test for the end section and middle section respectively. The maximum bending angle corresponding to the middle section was approximately 33 degrees when the temperature was 35 degree Celsius whereas the maximum bending angle corresponding to the end section was approximately 38 degrees when the temperature was 35 degree Celsius.

Table 2: Comparison of bending and reformation dimensions, time (w.r.t Fig.1)

	A1	A2	A3	B1	B2	B3	C1	C2	C3
Maximum Bending angle	36.16	30.86	37.24	31.96	31.98	19	39.2	36.8	34.36
Bending Time (s)	7.4	9	8.2	7	7.2	10.2	9	9	10.2
Reformation Angle	20.98	13.28	23	15	14.92	10.5	25.32	24.5	21.28
Reformation time (s)	34.1	39	41	34.5	37	41.5	35	43.1	41.6

5. Conclusion

Explorations and works in the field of Nano materials and Nano SMAs as an alternative to Teflon in Endoscopes and boroscopes is proposed. Nanomaterials also give a spark to the research in capsule endoscopy and smart endoscopy. Nano material based wound healing therapeutics is already materialised and applied in medical fields. Miniaturization of the present endoscope structure will be highly beneficial for non-invasive surgery as well which can be realized by the use of Nano material. In addition, Nano SMA based actuation and heat loss calculations may help minimize unwanted bending of the endoscope causing injuries to the patient.

References

[1] Run-xinZhang, Qing-Qing Ni , Toshiaki Natsuki and MasaharuIwamoto “Mechanical Properties of Composites Filled with SMA Particles and Short Fibers”, Composite Structures, Vol.79, No. 1, PP: 90-96 (2007).

[2] Sayaka, the next generation capsule endoscope’, available at http://www.rfamerica.com/ sayaka/ (2012).

[3] ‘Transformation Temperature Measurement Methods Data’, available at http://jmmedical.com/resources/211/Measuring-Transformation-Temperatures-in-Nitinol-Alloys.html (2012).

[4] Bellouard, Y., Clavel, R., Gotthardt, R., Bidaux, J.E. and Sidler, T. “A new concept of monolithic shape memory alloy micro-devices used in micro-robotics”, 6th International Conference on New Actuators, ,p.88 (1998)

[5] Brojan, M., Bombač, D., Kosel, F. and Videnič, T. “Shape memory alloys in medicine”, RMZ – Materials and Geoenvironment, Vol. 55, No. 2,pp.173–189 (2008)

[6] Chang, J.K., Chung, S., Lee, Y., Park, J., Lee, S., Yang, S. et al. “Intravascular micro active catheter for minimal invasive surgery”, 1st Annual InternationalIEEE-EMBS (2000).

[7] Muhammed Raihan and Abdul Khadir “A multi-segmented shape memory alloy-based actuator system for endoscopic applications,”, Sensors and Actuators A: Physical, Vol: 296, No.1, pp: 92-100, (2019).

[8] H. Iro and J. Zenk, "A new device for frontal sinus endoscopy: First clinical report", *Otolaryngology – Head and Neck Surgery*, vol. 125, no. 6, pp. 613-616, (2001)

[9] K. Xu and N. Simaan, "An investigation of the intrinisic force sensing capabilities of continuum robots", *IEEE Trans. Robot*, vol. 24, no. 3, pp. 576-587 (2008).

[10] D.B. Camarillo, C.F. Milne, C.R. Carlson, M.R. Zinn and J.K. Salisbury, "Mechanics modeling of tendon-driven continuum manipulators", *IEEE Trans. Robot*, vol. 24, no. 6, pp. 1262-1273, (2008).

[11] H.-S. Yoon and B.-J. Vi, "A 4-DOF flexible continuum robot using a spring backbone", *IEEE Int. Conf. Mechatronics and Automation*, pp. 1249-1254, (2009).

[12] M. Rilk, D. Kubus, F. M. Wahl, K.W.G. Eichhorn, I. Wagner, F. Bootz, et al., "Demonstration of a prototype for robot assisted endoscopic sinus surgery", Proc. IEEE Int. Conf Robot. Autom, pp. 1090-1091, (2010).