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Review Article

SIMULATION OF SOFT COLONOSCOPE HAVING MULTIPLE CONTROL CHAMBER

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ABSTRACT

Colorectal cancer is considered to be one of the most common cause of death related to cancer in world. In overall rankings of cancer related deaths colorectal cancer is placed second in the world. Colonoscopy is important tool for early detection of colorectal cancer and also to remove polyps in early stage. As colonoscopy advances, it requires highly skilled colonoscopist that requires significant amount of training without experience causes discomfort and high pain to patient. In this paper an attempt is made to simulate multichamber colonoscope made of silicone rubber. As traditional colonoscope consist scope that is made of semi-flexible tube, this results painful insertion in colon. This developed scope is highly flexible as well as soft and hydrostatic pressure operated.

INTRODUCTION

Recently many researchers have attempted to develop locomotive endoscope system for less discomfort feeling of the patients based on the propulsive inchworm mechanism. And the inchworm robots can be used in many medical tasks. The pneumatic rubber actuators, which can be designed as multidegree- freedom structures, are widely used in the flexible robot system. Generally, there are three types of pneumatic actuators: cylinders, muscles and bellows. Usually bellows are elastic structures made out of a rubber tube. Suzomori *et al.* proposed a fiberless flexible microactuator (FMA) with isotropic material through cross section design. The conventional FMA has three internal chambers where the internal pressures are controlled independently through flexible pneumatic tubes. Appropriate pressure in each chamber enables three-degrees-freedom motion of the robots. This locomotion is adaptable to many miniature robotic mechanisms. Highly advanced colonoscopes (‘scope[s]’) are used to screen the human colon for diseases and abnormalities, and also for treatment. A scope is an endoscope with a 1.2 m to 1.6 m long flexible but torsionally stiff shaft. Its distal end (‘tip’) can be bent in four directions by twisting control wheels on a grip at the proximal end of the scope.

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A digital camera, light supply fibres and channels for instruments, air and water are embodied in the instrument. The scope is inserted into the anus and pushed into the colon up to the cecum or terminal ileum, while bending the tip to negotiate around colonic bends. The functionally necessary flexibility and length of the scope shaft and the floppy nature of the colon and its attachments hamper, and may prohibit, reaching the cecum and visualizing the entire colon (success rates for experienced endoscopists generally average between 80% and 99%, with some averages <80%) . This results in colonoscopy being a time-consuming procedure and one that is difficult to master. Furthermore, the extensive training in practice that is required to master gastrointestinal endoscopy procedures has a negative effect on endoscopy case throughput and cost . The actions required to perform a full colonoscopy can also be painful for the patient. Sedation is often used to prevent pain, although it increases the risk of complications and lowers patient satisfaction

Related work

In this part mostly nature inspired locomotion of colonoscope is reviewed for problem identification. Based on type of locomotion used in existing colonoscopes there are four type of locomotion techniques is categorized mostly most snake species move by using their ventral scales, the scales on the undersides of their bodies, to pull themselves across rough surfaces.

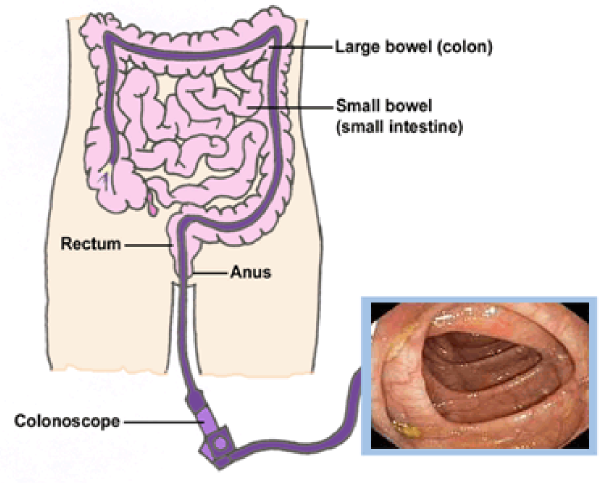

Figure 1. Colonoscopy

They use a serpentine locomotion movement, in which the body assumes a position of a series of S-shaped horizontal loops and each loop pushes against any surface resistance. Vincent *et al*. presented two different electrical actuation solutions for articulated endoscope and developed control scheme for SMA actuators in an antagonist configuration by using steel coils and shape memory alloys for automated locomotion. Peirs *et al*. presented a self propelling micro-robotic arm and associated micro-tools to be used in colonoscopy made of superelastic CuAlNi alloy.

An inchworm moves by alternately extending and distending sections of its body to produce peristaltic waves that drive it through the soil. This type of locomotion is particularly suited to unstructured or even hostile environments where wheels and tracks fail. Young *et al*. proposed a bio-mimetic micro robot in order to create an autonomous free mobility inspired by earthworm. A two-way linear actuator using shape memory alloy (SMA) spring and silicone bellows is applied to the micro robot. The speed of robot is 10mm/min and shape memory alloy is used for actuation. Menciassi *et al*. designed and fabricated high-stroke prototype inchworm locomotion based colonoscopy robot consists of a pneumatic bellow (the extensor) and two clamping mechanisms which suck the tissue and then grasp it by closing two opposite jaws. The theoretical speed of navigation obtained is 18.65 cm/min and elongation ratio is 200%. The developed model is made of silicone bellow and it uses pneumatic air for actuation.

Another class of locomotion in colonoscope is caterpillar or legged locomotion. This type of colonoscopic robot crawled inside colon with the help of legs. The advantage of legged locomotion is that legs can move on a rough surface and if they are having adhesive power then they stick to colon for locomotion. Valdastri *et al.* designed a novel mechanism for robotic legged locomotion at the mesoscale that enables a small robot to traverse a compliant, slippery, tubular environment, even while climbing against gravity. The developed robot is 11 mm in diameter and 25 mm in length. The body of robot is made of aluminium and lead screw mechanism is used for locomotion, for actuation battery is used. Kim *et al*. fabricated an insect-like robot and tested the developed robot as a new locomotion to move in colon that is flexible, slippery and has dramatic diameter change.

Length of developed robot is 125mm and diameter is 30mm. Average crawling speed obtained is 2.5 mm/s. The last class of robot is continuum robots that have attracted much interest from robotics researchers during the last decades. These kinds of systems are characterized by the fact that their mechanical components do not have rigid links and discrete joints in contrast with traditional robots. The locomotion of these robots was inspired by the movements of natural animals such as tongues, elephant trunks and squid tentacles etc. Chen *et al*. developed COLOBOT made of silicone rubber tube and present a sensor-based guidance control and proposed circumscribed circle that is to approximate the central position in real-time based on three sensor readings. The developed robot is pneumatically operated. Haiyan *et al*. developed continuum robot for colonoscopy of length 300 mm and diameter 20 mm and discussed its structural design, kinematic model and control system for continuum robot i.e. made of polyeruthene and is electrically driven. Suzumori *et al*. designed silicone rubber tube actuator based on static analysis using non-linear finite element method, in which geometrical and material non-linearity are considered. They used Mooney–Rivlin model for modeling and MARC Software for simulation. The developed robot is made of silicone rubber and is pneumatically operated.

Hyper-elastic Finite Element Model

Due to use of high non-linear hyper elastic material, a constitutive derivation for rubber deformation was not solved, instead models were created and analysed using Finite Element Analysis in ABAQUS 6.10. Many mathematical models have been explored and established for modelling high non-linear elastomer. Hyper elastic material models are highly capable of representing the non-linear response and nearly incompressibility of Rubber. By mechanically testing a particular rubber and analyzing the data one can choose a material model which would be well reproducing the mechanical response and allow for convergence and satiability of solution process. The Mooney-Rivlin Model was chosen for this high non-linear simulation from several constitutive models based on strain energy potential for incompressible and isotropic materials. The Mooney-Rivlin model can be used for small, moderate and large strain, respectively up to 200%. The strain energy density function for an incompressible M-R model is described as

$$W = \sum_{p,q=0}^{N} C_{pq}(\bar{I}_1 - 3)^p(\bar{I}_2 - 3)^q + \sum_{m=1}^{M} D_m(J-1)^{2m}$$

With $C_{00} = 0$ Where C_{pq} are material constants related to the distortion response and D_m are material constant related to the volumetric response. For a compressible Moony-Rivlin material.

If $N = 1, C_{01} = C_2,\ C_{11} = 0,\ C_{10} = C_1$, M=1

For consistency with linear elasticity in small strain,

$K = \frac{2(C_{01}+C_{10})}{1-2\vartheta}$, $\mu = 2(C_{01} + C_{10})$
K= initial bulk modulus
μ= Initial shear Modulus
ϑ =Poissons ratio (≅ .499 for rubber)
and as rubber is treated as incompressible material Like rubber J=1

Then

W= $C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3)$

C_{10} , C_{01} are material constant determined empirically and $\bar{I}_1$, $\bar{I}_2$ are first and second Invariant of deviatoric component of the left Cauchy-Green deformation tensor.

$$\bar{I}_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2$$
$$\bar{I}_2 = \lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_3^2\lambda_1^2$$

Rubber has a highly nonlinear property. Generally, it is, therefore, difficult to analyze its deformation, especially if it includes large deformation. In the present study, utilizing nonlinear FEM software (ABAQUS 6.10), this is an engineering analysis software package with extended capabilities necessary to analyze the mechanical behaviour of rubber materials. The goal of FEA simulation is to check both the behaviour of geometry and estimate the pneumatic pressure to produce a bending capability in Rubber tube and also handles material nonlinearity and geometrical nonlinearity including large deformations, analyses were carried out to find the most efficient design of a rubber pneumatic actuator. Room temperature vulcanization (RTV) silicone rubber was used as the actuator material and a material test was conducted according to International Organization for Standardization 37 (‘Rubber, vulcanized or thermoplastic - determination of tensile stress-strain properties’). For meshing the entire tube C3D4: A 4-node linear tetrahedron element is used with seeds size .0035.

Finite Element Model

In this analysis silicone rubber tube is used as central member for colonoscope, the tube have radius of .011 m as inner diameter and with thickness 1.5 mm. The length of tube is taken as .7 m.

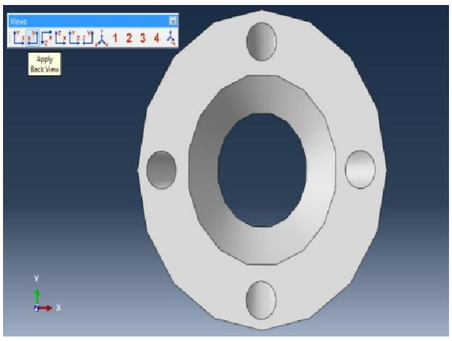

Figure 2. Front View with hole of developed model

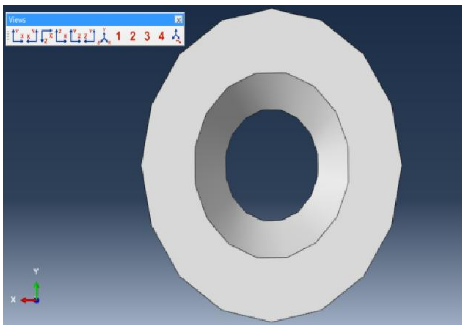

Figure 3. Back View of developed model

Figure 4. Isometric view of developed model

Table 1. Hyperelastic Material Properties of silicone rubber

Co-efficient	Value
C_{10}	86349.7 Pa
C_{01}	62134.8 Pa

The four circular hole have been generated for application of pressure to control the locomotion of tube. The material properties of hyper elastic silicone rubber are used by obtaining stress-strain data experimentally. The Mooney-Rivlin hyperelastic material model is used for Finite Element analysis and the material properties used are shown in below table 1. Poison ratio of rubber is taken as .499. For meshing C34R linear tetrahedron element is chosen with element sixe .0039 m. The mass density of rubber is taken as 1208 kg/m^3 and dynamic Explicit step is chosen for analysis. The analysis is carried out in 2 steps, First step is default stress and in second step hydrostatic pressure of 6 kPa is applied inside generated on tube. The cross-sections of model are in circular shape. When air pressure is applied to the model, the rubber tube is inflated upto some extent. And after applying more pressure the rubber tube bend.

RESULTS AND DISCUSSION

In this analysis results have been obtained the von-mises stress, Nodal displacement and logarithmic strain. For obtaining the results tube was divided in three equal part and from each part extreme node is selected ie, Node number 86 was selected for first part which is at origin, then .233m from origin another node 20202 is selected and data have been extracted, then .466 m from origin node number 22181 was selected and last node at .7 m distance from origin node number 92 is selected for data analysis. Graphs have been plotted for each node with different colours. Figure 5 shows the von-mises stress generated in tube while applying hydrostatic pressure from four created chambers. It is clearly shown in graph as the nodal distance increases the stress increases. This von-mises stress distribution can be helpful to designer for development of colononscope. In Figure 6 the resultant displacement for selected four nodes is plotted and is clearly seen that as nodal distance increases the deflection in tube increases and w.r.t. time the tube is deflected in sinusoidal path. Figure 7-9 shows the nodal displacement in X, Y, Z direction respectively. U1 and U2 is vanquished and only in Z direction it shows resultant values that follows a sinusoidal path which can helps the tube to locomote inside colon as colon have very complex geometry.

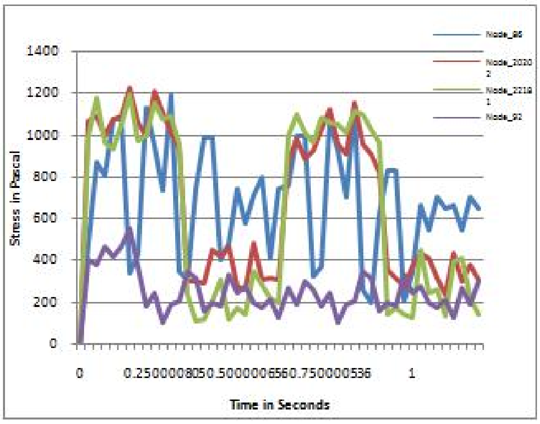

Figure 5. Von-Mises Stress

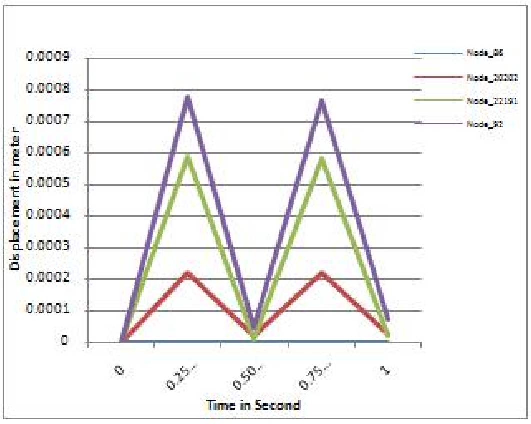

Figure 6. Resultant nodal displacement

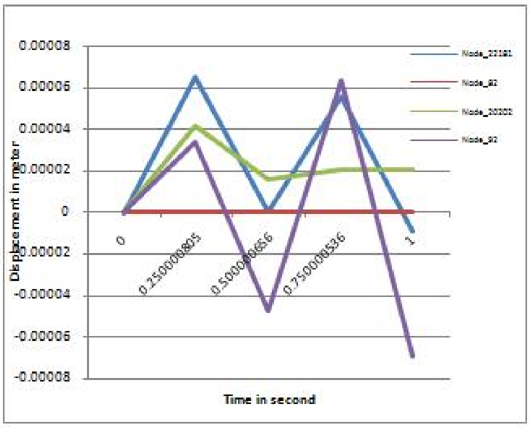

Figure 7 .Nodal Displacement in X-direction

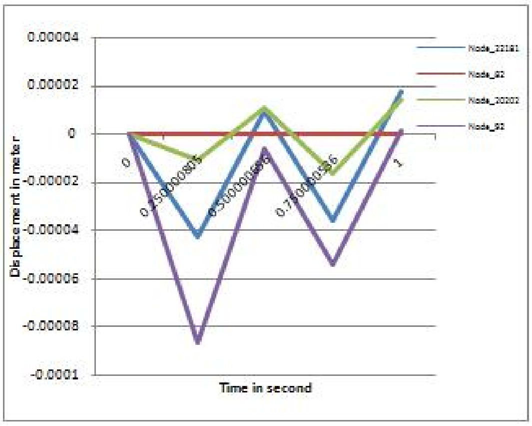

Figure 8. Nodal Direction in Y- Direction

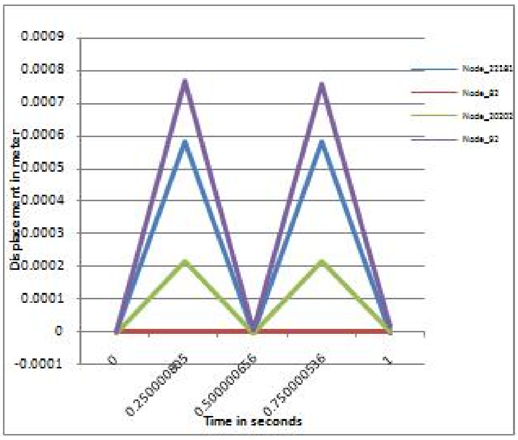

Figure 9. Nodal Displacement in Z-Direction

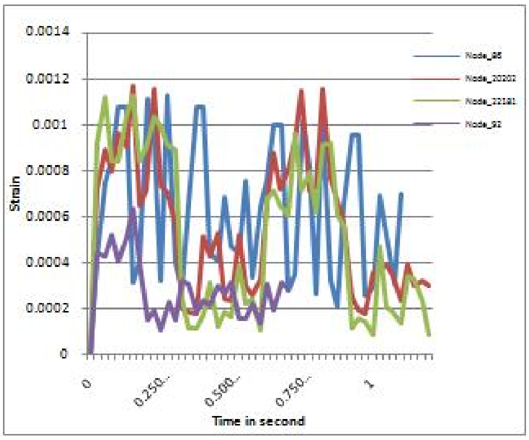

Figure 10. Logarithmic strain

In Figure 10 logarithmic strain value is plotted for different nodes. The graph shows same pattern as von-mises stress w.r.t. time.

Conclusion

In this research work, hydrostatically operated colonoscope made up of soft silicone rubber which is flexible to enter into the complex shaped colon is designed and analysed for its movement using finite element methods. While applying pressure the deflection of tube and stresses induced is computed. The stresses in the body of colonoscope increased linearly w.r.t. step time. This study helps in improving the design of colonoscope tube so that the colonoscope takes desired path in the colon. It is also important to make the colonoscope and test it in-vitro condition. From future prospective researchers may take up design of colonoscope using pneumatically operated devices which are both flexible and cause less pain to the patient.

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