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A NOVEL METHOD FOR BIO-INSPIRED COMPLIANT MECHANISMS IN MEDICAL APPLICATIONS

Yarrapragada K S S Rao

Professor, Dept. of Mechanical Engineering, Aditya College of Engineering, Surampalem, E.G.Dt, A.P - 533437, India

ABSTRACT: Compliant mechanisms are very flexible and have a monolithic construction, making them popular in the design of medical robots and gadgets. Since biological creatures' structures occasionally provide a better answer than those of conventional mechanisms, several compliant mechanisms take inspiration for their designs from nature. However, the geometries of bio-inspired structures are typically quite complicated, making it difficult to model and evaluate them using conventional techniques. In this study, we provide a unique modeling framework in Matlab, based on the Finite Element Method (FEM), for analyzing the mechanics of various bio-inspired compliant devices. A non-linear FEM formulation that incorporates the modeling of large displacements, tendon-driven mechanisms, and contact problems was implemented in the proposed framework to overcome the limitations of the basic linear FEM formulation, which can only be used to model small displacements of compliant mechanisms. The suggested framework may also be utilized to optimize the structural characteristics of bio-inspired compliant systems. Hence, this results shows better results interms of accuracy and efficiency.

KEYWORDS: Finite Element Method (FEM), Compliant Mechanism, Biomimetics.

I. INTRODUCTION

Rigid-joint mechanisms are widely employed in medical robotic systems and traditional medical devices to provide motion transfer. Despite their stability and robustness, rigid linkages nevertheless have a lot of drawbacks, such a complicated construction procedure and tiny joint gaps that make sterilizing medical equipment challenging and costly[1]. Medical device systems are equipped with compliance procedures to address these issues .

In contrast to traditional rigid-joint mechanisms, compliant mechanisms get at least some of their mobility from flexible members' deflection as opposed to only from moveable joints. forceps with flytrap and fin-ray effect inspired adaptable gripper. The prototypes of the three bio-inspired compliant mechanisms are displayed. These are made at our institute utilizing various 3D printers.

Surgical forceps are an important tool for grasping, retracting and stabilizing tissues or organs in various medical applications. Conventional surgical forceps are usually made of metal and can be reused after reprocessing and resterilization. Since the contamination of reusable medical devices is an important factor that leads to the spread of infectious diseases, disposable plastic forceps are often used to prevent device-related infections [2]. In current state of the art, disposable forceps have mainly two kinds of mechanisms, the rigid-joint mechanism and the compliant mechanism.

In recent decades, we have witnessed the fast development of compliant mechanisms in the mechanical, electrical and biomedical engineering. Unlike the conventional rigid-joint mechanisms, the compliant mechanisms gain at least some of their mobility from the deflection of flexible members rather than only from movable joints. With this interesting feature, the total number of mechanical components with movable joints can be greatly reduced in a compliant mechanism, which helps to reduce the friction during the motion and also simplify the assembly work after fabrication [3]. In the design of microscale biomedical or electrical devices, the compliant mechanisms are also preferred because the conventional rigid-joint mechanisms are difficult to fabricate at the micro level and have in that case low accuracy. Since the flexible property of compliant mechanisms are quite close to the nature of some living creatures like snakes or flowers, many compliant mechanisms have a bio-inspired design. However, it is not easy to analyze and design such a bio-inspired compliant mechanism with the traditional methods. The classic rigid-body mechanism theory cannot be directly used since the parts in the compliant mechanisms are deformable continua and they cannot simply be treated as rigid bodies. The Pseudo-Rigid-Body Model (PRBM) and Finite Element Method (FEM) are two methods which are often used to analyze compliant mechanisms. With the PRBM method, the flexible parts in a compliant mechanism with large deflections are modelled as a combination of torsional springs and rigid joints. In this way, the classic rigid-body mechanism theory can also be used to analyze compliant mechanisms [4]. Although the PRBM method provides good results in calculating the final tip position of a compliant mechanism, the detailed stress distribution in the structure of the mechanism cannot be calculated due to model simplification. This disadvantage can be overcome by using the FE method since the detailed stress distribution in the compliant mechanism can be calculated with the help of the structure discretization by the FE-method. However, the original linear FE-method is only suitable for analyzing small-displacement compliant mechanisms since the linear equations in the calculation are no longer valid by large deflections. Therefore, geometrically non-linear FE method should be developed to achieve plausible analysis results of the large-deflection compliant mechanisms. The FEM tool presented in this paper is such an extension of the linear FE method to realize plausible nonlinear analysis of the bio-inspired compliant mechanisms [5].

In our institute, we are developing a toolbox called Solid Geometry (SG) Library in Matlab to achieve automatic design of various medical robots and mechanisms [6]. Those robots and mechanisms can be quickly fabricated by different kinds of 3D printers. We implement our design platform in Matlab since Matlab has integrated many multidisciplinary methods so that we can perform various simulations and analyzes in the same environment without additional data input and output. With this advantage, the design process of robots and mechanisms can be greatly accelerated. Recently, we have also integrated the geometrically non-linear FE method into our toolbox. The implemented FEA tool has extended the linear FEA concept of Matlab's Partial Differential Equation (PDE) Toolbox and can be used to accelerate the design process of the bioinspired compliant mechanisms for medical applications. In this paper, we will present the non-linear algorithm of our FEA tool and several simulation examples of our bio-inspired compliant mechanisms for verification.

II. LITERATURE SURVEY

S. Çıklaçandır and Y. İşler, et.al [7] Laser is becoming widespread in medical applications. Many types of lasers and applications are available in a variety of ways. Nowadays, laser applications are made by hand. However, the time to be applied and the area to be applied sometimes cannot be implemented suitably and safely. In this work, a mechanism is designed to apply the laser correctly and safely. The mechanism moves the laser in two directions. At the same time, the laser can be sent at a certain angle to the field to be applied. It is sent to the drawing control

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card which is drawn through the program via the computer. In this system, where many parameters can be changed in the interface, the LabVIEW program makes the visualization easier. It is seen that the drawing from the computer is done successfully with the laser.

Y. Sun, Y. Liu, L. Xu and T. C. Lueth, et.al [8] propose a novel disposable compliant forceps for general open surgical applications, developed using topology optimization techniques. Compliant mechanisms are much easier to sterilize than rigid-joint-based mechanisms, hence they are often used in the design of disposable medical forceps for preventing the spread of diseases from reusable medical devices. However, it is time consuming and inefficient to use empirical methods for designing compliant forceps. To simplify the design process, topology optimization techniques are employed in this paper to automatically synthesize the shape of compliant forceps. The entire design process was performed in Matlab. The designed forceps was quickly fabricated with selective laser sintering (SLS) and can be disposed of after single-use. The clamping capability of the proposed forceps was evaluated by a series of simulations and experiments. Results showed that the forceps is reliable and robust under different loads in open surgical tasks. With the work presented in this paper, we can achieve automatic synthesis of disposable compliant forceps with high performance

W. S. Rone and P. Ben-Tzvi, et.al [9] virtual-power-based method proposed and it can also achieve accurate modeling of the shape of snake-like robots, they are still focused on continuum robots. From this point of view, these methods cannot be directly used for analyzing other types of compliant mechanisms with irregular geometries and different actuation principles.

K. -J. Chiu, Y. -T. Huang, Y. -M. Huang, K. -Y. Tai, S. -D. Wang and T. -S. Chen,et.al [10] advance of information network makes lots of users start to store personal or corporately confidential documents in network environments digitally. In this case, it is necessary to effectively prevent data from being stolen through the authority management. In the past years, some chief medical institutions start to apply e-database system to store and collect medical information, including patients' personal data and medical confidential information. Aiming at patient's electronic medical record data, the greatest advantage of mobile agents is the use. In the virtual network, we can legally collect patients' medical information in various medical institutions and share patient's information among medical institutions. Furthermore, public key cryptosystem and Lagrange interpolation are utilized for proposing a key management and data access mechanism to effectively maintain the confidentiality and security of medical information sharing. With the constraint for specific users to acquire the decryption key for encrypted data at a specific time, the mechanism proposed in this study can largely enhance the difficulty for illegal users or external attackers to steal secret keys. It provides a brand-new solution for the management of medical information.

Y. Yang and T. Chen,et.al [11] development of information technology, the informationization of the medical industry is also constantly developing rapidly, and medical data is growing exponentially. In the context of “Big Data +”, people began to study the application of data visualization to medical data. Data visualization can make full use of the human sensory vision system to guide users through data analysis and present information hidden behind the data in an intuitive and easy-to-use manner. This paper first introduces the workflow of

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DBN, a deep learning algorithm, and summarizes the computational characteristics of the algorithm. The classification function is translated into an assembler using an instruction set-based assembly language, and the program is evaluated for performance. Secondly, based on the Hadoop ecosystem, this paper analyzes the BDMISS system for big data medical information resource sharing. Based on the system's requirements and functional positioning, from the medical information collection and sharing, data mining and knowledge management level, the big data medical service system is constructed. Based on the semantic network and ontology theory, big data mining technology and the design of "medical cloud", the resource sharing mechanism is analyzed. Based on the Spring MVC framework, using Echarts, HCharts and other data visualization technology, according to the design of specific modules, the visualization and display of medical data is realized, which has certain promotion effect on the research and development of medical big data visualization analysis.

C. Baek, K. Yoon, and D.-N. Kim et al. [12] have modeled the large deflections of Concentric Tube Robots (CTR) using the FEM software ADINA. The structure of CTR was triangulated into shell elements, which is appropriate for the thin tubular structure but not applicable for general 3D structures.

G. Runge, M. Wiese, L. Gunther, and A. Raatz, et.al [13] developed a modeling framework for soft material robots in Abaqus and Matlab which uses the general tetrahedral elements to mesh the structure. However, the proposed framework was mainly developed for analyzing snake-like soft robots, in which the FEM was employed only to extend the PCCM method

Y. Hu, L. Zhang, W. Li, and G. Yang, et.al [14] software SolidWorks was used as a solid modeling and FEM tool to calculate the displacement and stress of a single section of a tendon-driven snake-like surgical robot. Although the proposed FEM approach was more general, the load applied to the tendon-driven section was oversimplified as a force couple on the top of the section, which neglected the influence of the tensile force on the inner surface.

E. Coevoet, A. Escande, and C. Duriez, et al.[15] integrated contact modeling into the FEM-based models of soft robots the contact search method proposed based on predefined contact node pairs, which is inefficient for modeling surface contact problems with complicated geometries.

III. METHODOLOGY

In this section, we will present several FEM examples of our bio-inspired compliant mechanisms to show the applications of the non-linear FEM method in our automatic design. The proposed FEM-based modeling framework was applied in the design and simulation of three kinds of bio-inspired compliant mechanisms for medical applications. The simulation results were compared with the 3D-printed prototypes of the mechanisms to demonstrate the performance of the proposed modeling methods. All the calculations were executed on a computer with an Intel Core i7 CPU at 2.9 GHz

Snake-like Soft Robot In our institute, we are developing 3D printable robotic systems for minimally invasive surgery. The snake-like robots are used in our applications because of their high flexibility and tangible benefits to the patients (see Fig. 1). The flexibility of the snake-like robots is gained from the flexure hinges. To analyze the flexure-hinge-based compliant mechanisms, the PRBM method is usually used due to the short calculation time. In our applications, we also use the non-linear FEM method to analyze the snake-like robot since it is

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difficult to calculate the stress distribution of a continuous body by using the PRBM method. And the stress distribution is important for the fatigue and fracture analysis of the soft robots.

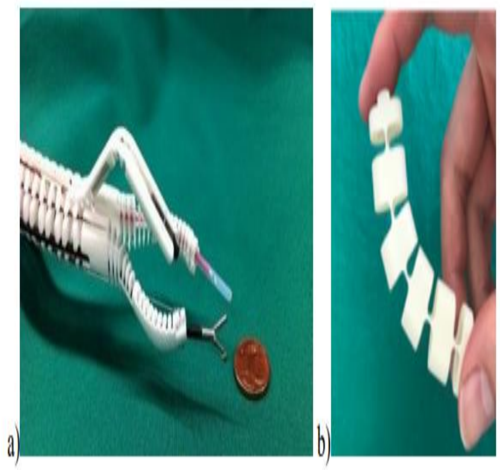

Fig.1: SLS printed snake-like soft robots: a) A tendon-driven multiarm snake-like robot, b) A 6-segment spine of a snake-like robot with flexure hinges

In this example, we use our non-linear FEA tool to analyze the influence of gravity on the snake-like robot. According to the data sheet of our Selective Laser Sintering (SLS) printer FORMIGA P 100, the material of the printed snake-like robots is PA2200 which is a kind of biocompatible polyamide with the density 0.93 g/cm3 and Young's modulus 1700 MPa. The 3D geometry we used is the 6-segment spine of a snake-like robot. In the FEsimulation, the gravitational acceleration is 9.8 m/s2 and the total gravity force is divided into 8 increments with the tolerance etol of 0.001. It shows that the first segment of the spine has the largest rotation angle and also the highest stress. This phenomenon is demonstrated by the SLS printed spine, which shows that the simulation results of our FEM tool is plausible.

IV. RESULT ANALYSIS

In this performance analysis of medical applications for Bio- inspired compliant mechanisms is observed in this section.

Table.1: Performance Analysis

Parameters	Finite element method (FEM)	piecewise constant curvature model (PCCM)
Accuracy	99	89.1
Efficiency	97.5	90.2

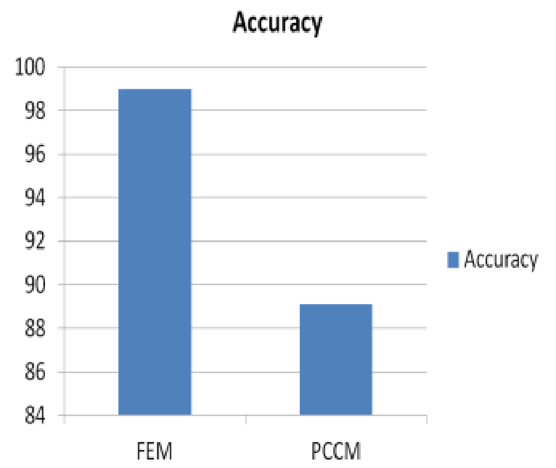

Fig.2: Accuracy Comparison Graph

In Fig.2accuracy comparison graph is observed between FEM and PCCM.

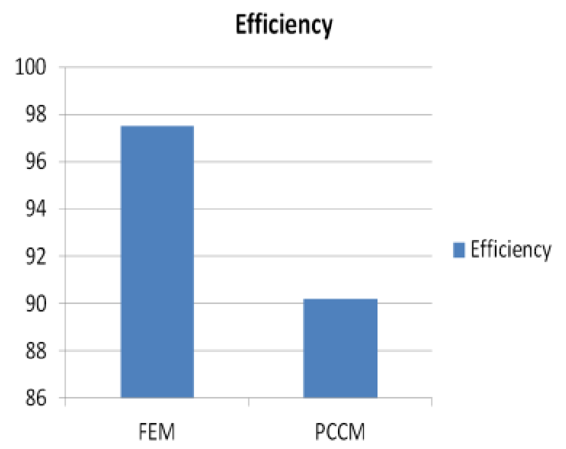

Fig.3: Efficiency Comparison Graph

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In Fig.3 efficiency comparison graph is observed between FEM and PCCM.

V. CONCLUSION

This study analyzing the mechanics of bio-inspired compliant mechanisms using a general and accurate modeling framework. The proposed solution is based on FEM and can achieve high-performance modeling of complex geometries. The novel method is used for simplifying the geometries and the realized modeling frameworks are only applicable to the specific models. Hence, this model achieves better results interms of accuracy and efficiency.

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