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Innovative methods of control and design of continuum robots

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Abstract. This article discusses the latest methods of control and design of continuum robots, including adaptive control, visual control, the use of hybrid materials and the integration of artificial intelligence. Solutions for improving the accuracy and maneuverability of robotic systems, such as hybrid controllers, fuzzy controllers, singularity avoidance algorithms and dynamic modeling methods, are described. Innovative approaches to stiffness management, the use of biomimetic principles and flexible materials, as well as adaptive trajectory planning are also discussed. Practical applications in the medical field, such as fetoscopic operations and minimally invasive neurosurgical procedures, are considered. Examples of experimental studies demonstrating the effectiveness of the proposed methods and technologies to improve the functionality and adaptability of continuum robots are given.

Keywords: continuum robots, adaptive control, visual control, hybrid materials, artificial intelligence.

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Introduction

Most of the articles focus on solving control problems and optimizing the operation of robotic systems in conditions of complex and changing parameters. The article [1] discusses methods of adaptive control of non-stationary robots using online training aimed at eliminating problems associated with limited and changing ranges of motion. The focus is on developing an adaptive approach to managing non-stationary robots, using the online learning method to handle changing parameters and uncertainty. The article [2] presents the continuum manipulator, which improves the controllability and predictability of movement using a flexible design and analytical methods for precise bending control. The design of the continuum manipulator is presented, which provides precise linear movement and controllability thanks to innovative materials and analytical methods. Both works emphasize the importance of precise control and adaptation of robots to changing conditions in order to achieve optimal performance. The article [3] describes a fuzzy controller that simplifies the control of continuum manipulators and reduces computational requirements, providing effective trajectory tracking. In the article [4], a hybrid position control model for the continuum robot was developed, taking into account interaction with the environment, combining kinematics and dynamics. In the article [5], a planning and management methodology for continuum multi-sectional robots is proposed, taking into account uncertainty and interference. Simulation results are presented to demonstrate the effectiveness of planning and management.

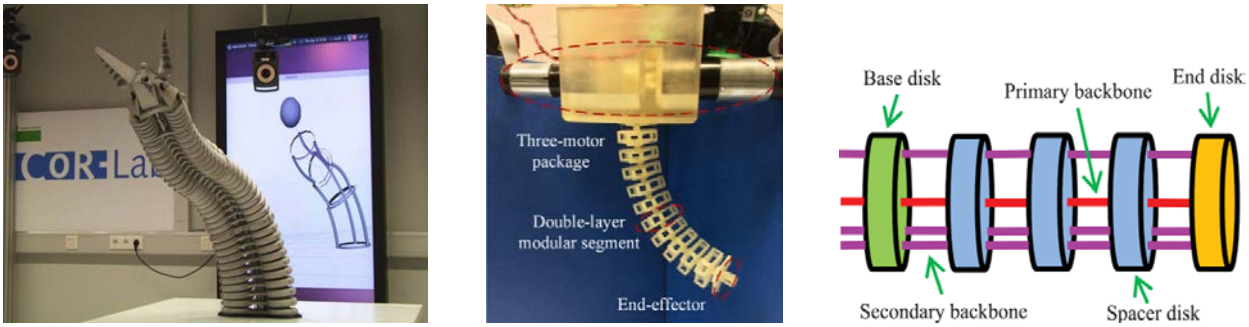

Figure 1

a) BHA mimics an elephant trunk [1]

b) A prototype of the proposed concept of a continuous manipulator [2]

c) The simplified structure of the continuum robot [4]

In developing and improving control and simulation methods for complex robotic systems in conditions of high uncertainty and instability, the authors propose the integration of various methods and technologies to improve the accuracy and controllability of robotic systems.

The article [6] uses a combination of a kinematic model, a Gaussian process regression (GPR) method and a ground-penetrating radar to correct errors and improve control accuracy. The effectiveness of the method has been confirmed by experiments with a real stand.

The article [7] proposes the integration of a continuous robotic arm for airspace control using a modified theory and an adaptive approach. The test was performed in a simulated environment. In the article [8], neural networks, an analytical model and a cascade controller are combined to control a multi-segment manipulator with a pneumatic drive. The results were confirmed by experiments on a real manipulator.

In the article [9], an improved model with piecewise constant curvature and a sliding mode controller for controlling continuous robots are proposed, which includes interference suppression and uncertainty estimation. Stability analysis and numerical modeling are carried out. In the article [10], a mathematical interpretation of VAR is given and a new method for adapting VOR is proposed. This study of adaptive control based on the cerebellum, complemented by a reference model, provides a potential general solution for robot control. If the reference model is not used, it will be difficult for an installation with more poles than zeros to respond immediately. The reference model determines the behavior of the robot. Its response at a high frequency with a small time constant shows a decline, low-frequency signals remain unchanged. To test the proposed method of neural control of image stabilization using a reference model, the authors first briefly present it, and then use it for modeling and experiments in Matlab and Simulink. The described cerebellar algorithm can potentially become a modular controller for soft robots.

The metodology

Many papers explore various aspects of the design, control and simulation of continuum robots. The main topics include the use of biological analogues to improve the functionality of robots, the development of adaptive control methods to solve problems with changing parameters, and optimization of modeling for more accurate and effective control. Attention is paid to both innovative design solutions (for example, the use of soft and hard materials, dynamic switching between states) and advanced methods of control and trajectory planning.

The article discusses the use of biomimetic principles and the combination of various structural elements to create a robot with high flexibility and the ability to capture objects. The article [11] discusses adaptive gripping using flexible and rigid materials based on origami design. These articles emphasize the importance of creating structures that can effectively cope with various manipulative tasks and adapt to different conditions.

Figure 2. Underactuated cable-driven robotic gripper with three compliant fingers fully open (left) and closed (right) [11]

The article proposes an approach to pose planning and robot control continuum, which takes into account excessive degrees of freedom and flexibility. New methods such as simulation and adaptive control are used to achieve stability and optimize trajectories. All three articles explore methods aimed at improving the adaptability and accuracy of robots in changing conditions. These articles combine a focus on the development and optimization of continuum robot designs using both new materials and control methods to enhance their functionality.

Some articles are devoted to the development and improvement of continuum manipulators and robots with an emphasis on flexibility, adaptability and control accuracy. The article describes a mechanism that combines rigidity and flexibility through switching between discrete and continuous states, which improves the functionality of the manipulator. This expands the range of applications of continuum robots, allowing them to combine the advantages of rigid and flexible structures. In the article, methods of dynamic modeling of continuum robots are proposed, including the use of Cosserat rods and the development of a MATLAB code package for simulation. This highlights the importance of accurate modeling to optimize design and control. The article discusses the use of a MAML-based controller (Model-Agnostic Meta-Learning) for precise positioning of the continuum manipulator under varying loads. This illustrates the importance of adaptive management and minimizing data volumes for effective management and accuracy.

Other articles focus on the development and improvement of continuum robots with an emphasis on stiffness and adaptability management. The article discusses a variable stiffness manipulator that combines elements of rigid and flexible structural design. Modeling and experimental tests confirm the effectiveness of this design. The article presents the concept of improving the rigidity of continuum robots with cable drive using additional cables. This allows you to increase the rigidity of the structure and reduce unwanted deformations. The article discusses OctRobot-I, which regulates stiffness in various directions. Theoretical models are being investigated and experimental tests are being conducted, demonstrating significant improvements in the rigidity and performance of the robot.

Some authors focus on improving the functionality and adaptability of continuum robots through the integration of various technologies and control methods. The article proposes a hybrid controller with an error compensation function to improve tracking accuracy. A hybrid controller is used that combines visual data and sensory information for precise positioning and improved control in conditions of limited visibility. The focus is on error compensation and improved tracking through data processing algorithms.

The article discusses the use of distributed artificial intelligence to increase the autonomy and stability of robots. Methods of autonomous control based on distributed intelligence are being studied in order to provide the continuum robot with the ability to perform autonomous actions. Focuses on distributed artificial intelligence and autonomy, using examples of bioengineered solutions to improve the robustness and autonomy of Continuum robots. Explores the distribution of intelligence and autonomous solutions inspired by biological systems to enhance sustainability.

The article presents a combination of hard and soft components for stiffness control and proprioceptive perception of the robot. A stiffness control system and three-dimensional positioning using spring and soft elements are described. It is focused on a combination of hard and soft components for stiffness adjustment and control, including experimental characteristics

and module control. Focuses on stiffness management and proprioceptive perception through a combination of hard and soft elements.

The article describes a robotic continuum system using contact-compatible mechanisms (CACMs) to solve problems of torsion and loss of stability, which improves rigidity and morphological accuracy. Considers mechanical design and modeling to solve torsion and wear problems, using contact-compatible mechanisms to improve stiffness and stability.

These articles show a variety of approaches to improving continuum robots, from integrating sensory data and AI to innovative design solutions and improving mechanical properties.

Findings/Discussion

These articles demonstrate a wide range of methods and approaches for improving continuum robots, ranging from mechanical and structural solutions to control and planning algorithms in complex environments.

The article [12] describes the mechatronic design of a device for precise fetoscopic surgery, using the integration of a controlled tube and a manipulator with a remote displacement center. The focus is on improving the maneuverability and stability of imaging through the use of a stereoscopic camera and electromagnetic sensors.

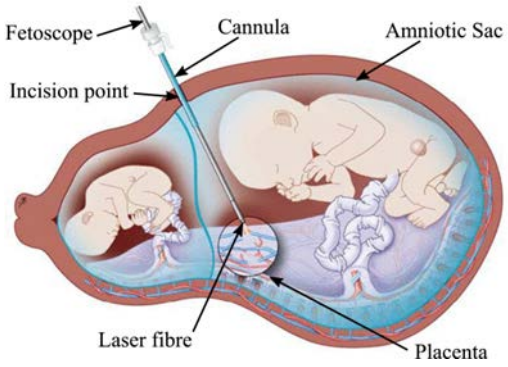

Figure 3 – Schematic diagram of the FLP procedure for the treatment of TTTS showing with the endoscope positioned to coagulate the placental vessel anastomosis [12]

In the article [13], the authors consider visual control for continuum robots, including algorithms based on Jacobian optimization, in order to avoid singularities and provide control in closed environments without prior calibration. The article [14] focuses on the control and modeling of continuum manipulators, taking into account mechanical parameters and constant curvature. The authors of the article [15] present the design and optimization of a robot with concentric tubes for minimally invasive operations, with customization for a specific patient and the use of preoperative MRI data. The article describes motion planning and a dynamic drag control method for a two-section continuum robot in a dynamic environment using motion capture systems and simulation planning.

These articles show a variety of approaches to improving continuum robots, from integrating sensory data and AI to innovative design solutions and improving mechanical properties.

Conclusions

This article summarizes the achievements in the field of control and design of continuum robots, emphasizing the importance of integrating adaptive control methods, the use of hybrid materials and the use of artificial intelligence. The approaches described in this paper, including hybrid and fuzzy controllers, singularity avoidance algorithms and dynamic modeling methods, demonstrate significant progress in improving the accuracy, maneuverability and stability of robotic systems. Design innovations such as the use of biomimetic principles and flexible materials, as well as adaptive trajectory planning, open up new possibilities for the application of continuum robots in various fields, including the medical field. Practical examples, including fetoscopic operations and minimally invasive neurosurgical procedures, confirm the effectiveness of the proposed solutions. Overall, the article highlights the importance of continuing research and development in the field of continuum robots in order to maximize their potential in complex and dynamic environments.

Confirmations

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The contribution of the authors

Kalekeyeva M.E. – made a significant contribution to the collection and analysis of literature on continuous robotic manipulators inspired by biological models. His work focuses on the study of the current state of this technology, its application and management issues, which contributes to the development of more flexible and adaptive robotic systems.

Muratbekova G.V. – participated in the development of the concept of work and writing the text of the article with the presentation of analytical data, ensuring the integrity of all parts of the article.

Konakbay Z.E. – participated in the critical revision of the content of the article and in the approval of the final version for publication

Gozhakhmetova M.A., Vakhitova L.V. – participated in the development of the concept of work and writing the text of the article with the presentation of analytical data, ensuring the integrity of all parts of the article. References

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Инновационные методы управления и проектирования роботов континуум

Аннотация. В этой статье рассматриваются новейшие методы управления и проектирования роботов continuum, включая адаптивное управление, визуальный контроль, использование гибридных материалов и интеграцию искусственного интеллекта. Описаны решения для

повышения точности и маневренности робототехнических систем, таких, как гибридные контроллеры, нечеткие контроллеры, алгоритмы предотвращения сингулярностей и методы динамического моделирования. Также обсуждаются инновационные подходы к управлению жесткостью, использование биомиметических принципов и гибких материалов, а также адаптивное планирование траектории. Рассмотрены практические применения в области медицины, такие, как фетоскопические операции и малоинвазивные нейрохирургические процедуры. Приведены примеры экспериментальных исследований, демонстрирующих эффективность предлагаемых методов и технологий для улучшения функциональности и адаптивности роботов континуум.

Ключевые слова: континуальные роботы, адаптивное управление, визуальный контроль, гибридные материалы, искусственный интеллект.

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Континуум роботтарын басқарудың және жобалаудың инновациялық әдістері

Аңдатпа. Бұл мақалада адаптивті басқару, визуалды бақылау, гибридті материалдарды пайдалану және жасанды интеллект интеграциясын қоса алғанда, continuum роботтарын басқару мен жобалаудың соңғы әдістері қарастырылады. Гибридті контроллерлер, анық емес контроллерлер, сингулярлықтың алдын алу алгоритмдері және динамикалық модельдеу әдістері сияқты робототехникалық жүйелердің дәлдігі мен маневрін жақсартуға арналған шешімдер сипатталған. Сондай-ақ қаттылықты басқарудың инновациялық тәсілдері, биомиметикалық принциптер мен икемді материалдарды пайдалану және адаптивті траекторияны жоспарлау талқыланады. Фетоскопиялық операциялар және аз инвазивті нейрохирургиялық процедуралар сияқты медицина саласындағы практикалық қолданбалар қарастырылады. Continuum роботтарының функционалдығы мен бейімделуін жақсарту үшін ұсынылған әдістер мен технологиялардың тиімділігін көрсететін эксперименттік зерттеулердің мысалдары келтірілген.

Түйін сөздер: үздіксіз роботтар, адаптивті басқару, визуалды бақылау, гибридті материалдар, жасанды интеллект

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