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RESEARCH HIGHLIGHT

Conclusions in Theory and Practice for Advancing the Applications of Cable-Driven Mechanisms

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The theoretical research of cable-driven mechanisms is developed with its broad applications. The first prototype of cable-driven mechanisms is RoboCrane, which was developed by the National Institute of Standards and Technology (NIST). Then many excellent properties were developed and they have a variety of applications such as aerospace, aircraft and automobile industries [1]. Example application for RoboCrane in the field of aircraft maintenance is equipped with a quick-change mechanism to remove the robot arm remotely.

Subsequently, more and more researchers started to study the features of cable-driven mechanisms. Based on the summary of existed researches, cable-driven mechanisms have advantages of large workspace, low inertia, simplicity in structure, reconfigurability, transportability and fully remote actuation [2].

However, there is a critical issue for cable-driven mechanisms, which is the unidirectional nature of forces exerted by cables. This nature requires that each cable remain in tension while performing tasks. In other words, force closure condition of the end actuator is existed when the forces are redundant. Therefore a minimum of n + 1 cables are required for fully controlling of a cable-driven mechanism with n degrees-of-freedom (DOFs). The objective is to guarantee all cables to be in tension at any point in the workspace. Although this characteristic restricts its scopes of applications, the mechanisms driven by cables only are widely applied in all trades and professions.

Following RoboCrane, a variety of cable-driven mechanisms with different configurations were developed and applied. The common characteristics of such fields are large work volume, precision maneuverability and enhanced crane capabilities required [3].

Sousa, et al [4] developed a cable-driven mechanism called SPIDERobot for on-site construction in architecture. The SPIDERobot is developed to perform assembly operations in the process of building print based on a vision system. Compared with the early robots applied in architecture, SPIDERobot can deal with the complexity and the scale of building construction in architecture. And the applications of SPIDERobot in practice can also foster the vision of different and complementary robotic construction technologies cooperating in on-site construction of architectural buildings.

A large scale 3D printer with a cable-driven mechanism was developed by Barnett and Gosselin [5]. Although a statue was printed successfully, the performance of printer can be improved in the future. Accuracy, robustness and speed are the main keys in the development of printer.

Five-hundred-meter Aperture Spherical radio Telescope (FAST, see Fig. 1) is one of the most successful applications of cable-driven mechanisms [6]. It is located in Pingtang County, Guizhou Province, the southwest of China. The feed cabin is moved by six cables, and the motive precision is difficult to guarantee for large span cable-driven mechanisms. Thus, Chinese researchers put the receiving antennas on a Stewart platform, which provides fine position control and compensates for disturbances like wind motion. And they have made a thorough research on dynamics of large span cable-driven mechanisms.

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Fig. 1 Five-hundred-meter Aperture Spherical radio Telescope

Examples above show that mechanisms driven by cables only cannot meet all requirements in practice. Thus a variety of mechanisms driven by cables and restricted by others are developed and applied. The constraints include links, springs, mechanisms and other actuators like pneumatic artificial muscles [7]. With these constraints, the new cable-driven mechanisms get more characteristics and they are widely applied.

Such mechanisms can provide many desirable advantages such as improved accuracy, moment resistance at the end-effector and reduced out-of-plane compliance compared to traditional cable robots. And various forms of movements are available. Thus, their potential applications are fantastic. At present, hybrid cable-serial robots have achieved some successful cases in industry field. Because of the critical role in the dynamic performance analysis and development of control systems, global dynamic modeling should be studied thoroughly [8].

Trevisani [9] developed a cable-suspended repetitive workspace robot for painting large surfaces like a ship's flank. This cable-driven robot is equipped with a 2-link passive serial manipulator. It has a very large workspace area compared to its cost, and it could be made efficiently.

DeltaBot, which is developed and manufactured by AEMK Systems, Inc., has entered the commercial stage. It has a kinematic architecture similar to the Delta configuration and it further reduces the moving inertia by its innovative use of light cables in kinematic chains.

Moreover, hybrid cable-serial robots are also applied in the fields of rehabilitation robotics and biomimetics due to their unidirectional nature of forces exerted by cables, which is similar as biological muscles. And the bones are considered as links when analyzed. The first rehabilitation robot driven by cables is STRING-man, which was presented by Surdilovic et al. for assisting the locomotion recovery therapy and training [10]. It is driven by seven cables. But there are some major drawbacks existed. On one hand, the cable-driven mechanism are often more difficult to design (e.g. it may be difficult to avoid cable-interference) and more expensive to build and maintain when the number of cables and actuators are higher. On the other hand, the arrangement of cables should be more difficult in view of the recover patient's safety. Therefore, the number of cables can be down to a reasonable number if possible. For this reason, some researcher study the effect on performance of cable-driven mechanisms by adding springs.

And the differences of actuation dynamics in cables and muscles should be considered. Lau, et al [11] analyzed the human shoulder as a cable-driven robot that possesses cables with the actuation characteristics of physiological muscles.

Bionic robots driven by cables are developed with new materials generally [12]. Taking an example of continuum robots, Dong, et al [13] developed a novel continuum robot using twin-pivot compliant joints, which is beneficial in applications due to their high flexibility and small diameter/length ratio.

In the light of these researches and applications, large-scale cable-driven mechanisms are used in the fields that lower accuracy required. For the future, the dynamic and precise control should be studied more deeply. At the same time, it will raise new problems such as the placement of sensors and signal processing in practice.

In the future, in the field of rehabilitation robotics and biomechatronics, position control with higher precision needs to be developed. And with the appearances of new technologies and materials, the new robots with high performances can be developed. Referring to the industrial robots and the configurations themselves, modular design is beneficial for applications in a wide range of fields. Until now, the modular robots driven by cables are existed, while the numbers and arrangements of cables and actuators existed are regular [14]. The numbers and arrangements of cables and actuators existed are regular. Thus, enlightened by the type synthesis of Classical rigid parallel robot, the integration of theories about cable-driven mechanisms with irregular arrangements and different configurations should be studied. Modular reconfigurable cable-driven robots will obtain large-scale applications and promotions.

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