Design of a Peristaltic Robot Trajectory Control System Based on Hydrodynamic Technology

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Abstract. Peristaltic robots are a type of bionic robot with a wide range of applications in industrial production, fire services and everyday life. Due to its small size, modularity, cold resistance, easy sealing and other characteristics, the peristaltic robot based on hydrodynamic technology can check working conditions and troubleshoot in very narrow occasions or pipelines; and due to its stealthy nature, it also has good prospects for application in anti-terrorism and military fields. Therefore, the research in this area has important practical application value and social significance. This paper begins with the general design and gait planning of the creeping robot. Based on an in-depth study of the locomotor mechanism of lower organisms, the overall design and gait planning of the peristaltic robot is based on a simulated locomotion of a biological mole cricket.

Keywords: Peristaltic robots · Hydrodynamic technology · Control systems

1 Introduction

With the rapid development of industrial robotics, there is a growing need for robots not only in the industrial manufacturing sector, but also in the non-industrial sector, which is showing great interest in robots. In industries such as agriculture, the use of atomic energy and space and marine exploration, there is an urgent need for robots that can travel over complex surfaces. But the need for robots that can move autonomously in such diverse and complex environments requires the development of highly intelligent mobility technologies for robots. Industrial production and everyday life often require robots to check conditions and troubleshoot in very narrow situations or pipelines; finding missing victims in natural disasters or war-torn buildings also requires a small, flexible walking device suitable for use in such special situations; in the field of counter-terrorism and the military there is also a need for stealthy reconnaissance robots. Creeping robots are an effective system proposed to meet this requirement.

On Earth, creeping is a form of movement possessed by reptilian lower organisms such as parasites, worms, insect larvae etc. The characteristics of their form and movement make these lower organisms suitable for movement in small spaces and long, narrow pipes. As a result, creeping robots that mimic these organisms have a wide range of adaptations [1]. At present, domestic and foreign research in this area has been carried out in many aspects, in summary, the main characteristics of these studies are: the drive

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device is mostly servo motors or electromagnetic mechanism; motion structure is generally wheeled and suction cup type. These peristaltic robots have some insurmountable shortcomings, mainly in the motor-driven peristaltic robot size is large, not easy to seal, not suitable for low-temperature operations and small pipeline operations, etc. This type of robot is difficult to carry out normal work in the above environment. Therefore, this paper is based on hydrodynamic technology for the design of a peristaltic robot trajectory control system, which can achieve bi-directional linear motion, turning motion, etc. Because of its small size, cold resistance and easy sealing, this peristaltic robot has extraordinary application prospects, such as polar exploration, military reconnaissance, undersea operations, pipeline inspection and disaster rescue and other extreme environments.

2 Overall Design of the Peristaltic Robot

2.1 Biological Prototype

The design of the peristaltic robot is based on the idea of imitating a living creature, which is a form of movement possessed by reptilian lower organisms. The peristaltic systems of these lower organisms (e.g. parasites, worms, insects, etc.) can be classified as follows:

(1) Pedal Movement. Pedal movement is a typical continuous slow gliding over water, mostly found in flatworms, cnidarians and gastropod molluscs. It is propelled by contraction waves transmitted by the abdominal musculature attached to its undersurface. The contraction waves are both direct and retrograde, with the direct waves causing the muscles to contract and raise part of the body, which is placed forward. In this way, the body in contact with the bottom does not actually contract. In contrast, a corresponding contraction occurs in the retrograde wave approach, which causes the adjacent part to contract and extend upwards, with the contracted part acting as a fulcrum and pulling the whole body forward.

(2) Sinusoidal Movement. The interactive contraction and relaxation of the longitudinal muscles on either side of the soft-bodied segmented lateral foot organism produces a form of movement known as sinusoidal movement. Such organisms, as shown in Fig. 1, usually have well-established lateral feet through which they derive reaction forces from the substrate. Each pair of lateral feet works heterophasically, with the particular lateral foot in the drive phase when it is on the crest of a wave and the corresponding lateral foot on the other side in the recovery phase [2].

(3) Earthworm Peristalsis. Alternating waves of contraction of the longitudinal and transverse muscles, conducted from head to tail, form the earthworm wriggle. The longitudinal contraction waves of earthworm peristalsis are conducted backwards and are replaced one by one by the transverse contraction waves. During movement, the front end of the earthworm slowly elongates, driving the head further into the surface of the earth, before the head begins to swell and act as an anchor and subsequent longitudinal muscle contractions begin. The repetition of this action acquires a forward movement; the reverse contraction wave conduction leads to a backward movement.

Fig. 1. Sinusoidal motion

2.2 Overall Structural Design of the Mechanical System

In order to structure the peristaltic robot in such a way as to better simulate the movement of the looper, the following requirements must be considered:

(1) Continuity constraints (the volume of the organism remains constant) require the peristaltic robot to have flexible connections for the purpose of cushioning external forces and increasing resilience to the outside world.
(2) Friction factors require a frictional difference between the front and rear feet of the peristaltic robot and the support surface, and the greater the better;
(3) The creeping gait requires the creeping robot to mimic the creeping of an inchworm, achieving creeping in both forward and backward directions.

The overall structure of the peristaltic robot is designed according to these three design requirements, as shown in Fig. 2, which is a schematic diagram of the overall structure of the single-joint peristaltic robot, where 1 is the support plate to which the guide bar, stud and rubber ring are fixed; 2 is the rubber ring, which acts as the back foot of the support plate and has a friction difference with the front foot of the UHMW-PE material; 3 is the SMA tension spring, which acts as the drive element, and 4 is the a cylindrical compression spring, as biasing element, which combines four SMA tension springs arranged symmetrically with a cylindrical compression spring to form a biased memory alloy double-range actuator; 5 is a guide rod to hold the compression spring in place and at the same time prevent it from becoming unstable [3].

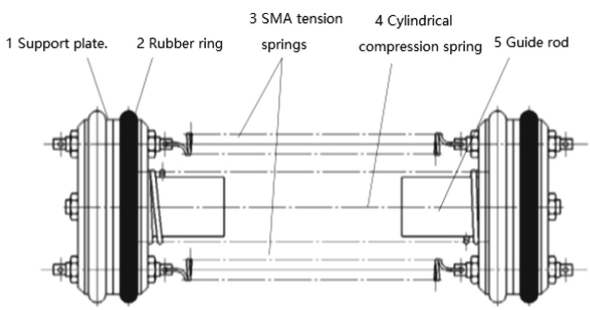

Fig. 2. Diagram of the wiggle robot joints

3 Design of the Peristaltic Robot Trajectory Control System

3.1 Control System Hardware Design

The hardware circuit designed in this paper uses a microcontroller system. The design idea is that the microcontroller generates a set of pulses with a defined duty cycle and then controls the corresponding semiconductor power device to drive the SMA spring.

The semiconductor power devices can be used in two ways: the linear amplification drive method and the switching drive method. The linear amplification driving method is to make the semiconductor power device work in the linear region. This method has a simple control principle, small output fluctuations and good linearity, but the power device will consume most of the electrical power when working in the linear zone due to the heat generated, and the efficiency and heat dissipation problems are serious. Therefore, this paper adopts the semiconductor switch drive method, using the field effect tube as a switching element (the source and drain of the field effect tube between the drive voltage, the gate is controlled by the microcontroller), through the microcontroller control of the field effect tube to turn on or off the SMA spring drive circuit.

The control system circuit schematic is shown in Fig. 3.

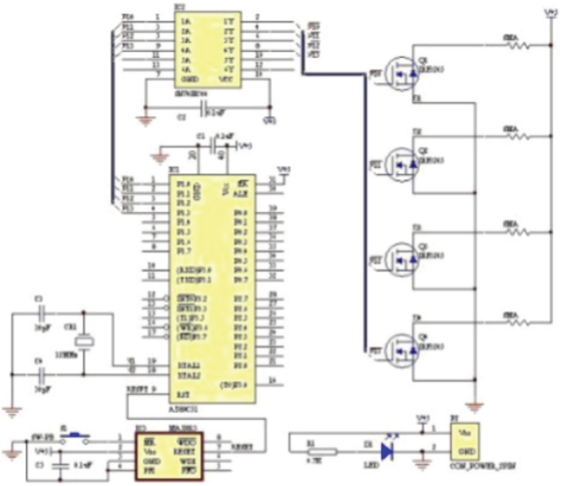

Fig. 3. Circuit diagram of control system

Here, the microcontroller is the ATMEL AT89C51, whose on-chip 4K program memory is a FLASH process and can be instantly erased or rewritten, making this microcontroller a very low requirement for development equipment and greatly reducing development time. Here the P1 port of the AT89C51 is chosen to control the gate of the field effect tube. The main considerations for the selection of FETs are maximum voltage, maximum current, maximum power and form factor requirements. In this paper, the model IRF3205 field effect tube is selected, its maximum voltage is 55 V, the maximum current is 98 A, the maximum power is 150 W, the switching voltage and the microcontroller pin output level match. The power supply uses a constant voltage source of 5 V, with a maximum current of 50 A, to meet the energisation requirements of the SMA spring, and to match the voltage control element of an effect tube [4].

3.2 Control System Software Design

For single-joint creep robots, each of the four SMA springs needs to be controlled. In this paper, the SMA springs are driven by electrical heating. The hardware circuit has already determined the on and off conditions of the SMA springs, so it is only necessary to control the duty cycle of each SMA spring in a certain time sequence. The size of the duty cycle will be determined experimentally. Once the minimum duty cycle of the SMA springs has been determined, the heating time of the individual SMA springs can be controlled by means of a time delay subroutine. The program flow diagram is shown in Fig. 4.

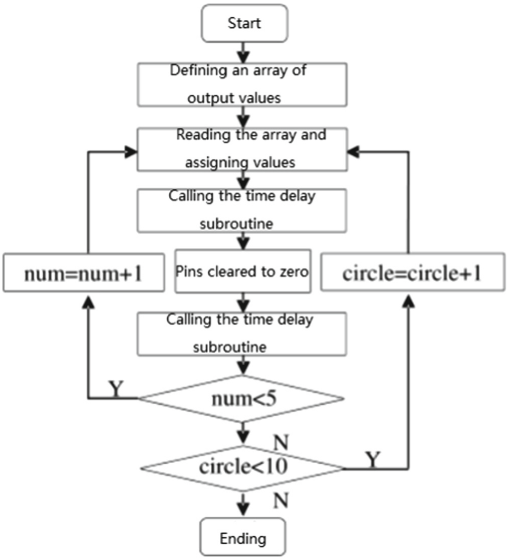

Fig. 4. Flow chart of program

According to the design of the hardware circuit it can be seen that the pulse sequence sent by the microcontroller is active low, i.e. the low level controls the SMA spring to energise the heating and the high level controls the SMA spring to disconnect the cooling. Here an array approach is used to control the pulse sequence output from the P1 port. According to the gait planning of single-joint creep robots, a motion cycle can be divided into a number of beats. Here, "1" is used to indicate a high level and "0" a low level, and the output required by the P1 port for each beat can be regarded as a set of binary numbers. This set of binary numbers is converted into hexadecimal form and formed into an array according to the sequence, and then the elements of these arrays are assigned to the P1 port in chronological order to achieve the purpose of controlling the peristaltic robot.

After the last array has been output, the first array is re-cycled to achieve multi-cycle control.

The number of elements in the array is determined by the number of beats required for a working cycle. The control process is simplified here by dividing one working cycle into five beats, which are controlled by the integer variable nun. When the program is initialised, this array is first defined, then every time unit, the next element is taken and assigned to the P1 port, and after the fifth beat it is judged whether to restart the cycle. In the running process, let the microcontroller repeatedly execute these five beats in order to achieve the loop, the number of cycles is controlled by the integer variable circle.

4 Conclusion

This paper has developed a control system for a peristaltic robot based on the design of the structure, actuator and trajectory control system of the peristaltic robot based on hydrodynamic technology. The control system uses a combination of electric heating and natural cooling with pulse width modulation control of the SMA spring current. The use of software control of the pulse signal duty cycle reduces the complexity of the hardware circuit and enhances the operability of the experiment. The control circuit is simple and reliable.

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