

Design and Implementation of Bionic Spider Intelligent Companion Robot

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ABSTRACT: Aiming at the problems of homogenized appearance, high operation threshold and insufficient expandability of current household companion intelligent devices, this paper designs and implements a lightweight bionic hexapod spider intelligent companion robot named "Spirit-Spider Companion". The system adopts SG90 micro-servos as power actuators, and fabricates the bionic mechanical body with PLA consumables via 3D printing. Based on the Arduino single-chip microcomputer, the hardware platform builds a wireless control system combined with the ESP8266 WiFi wireless communication module. On the software side, a mobile graphical interactive interface is developed to realize functions including motion control, anthropomorphic fun interaction and music-rhythm dance performance. The bionic hexapod structure endows the robot with favorable ground adaptability. Compact in size and supporting secondary development, it can serve not only as an entertainment carrier for family emotional companionship but also as a practical teaching tool for STEAM education. According to comprehensive prototype tests, the robot runs with stable gaits, responds promptly to instructions and completes movements with high fidelity. Combined with existing research achievements in the bionic robot industry, this paper analyzes the advantages and limitations of the scheme and puts forward multi-dimensional improvement suggestions, which provides certain reference value for the research and development of small desktop bionic companion robots.

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I. INTRODUCTION

With the continuous iteration of robot technology and embedded Internet-of-Things (IoT) technology, intelligent companion robots are gradually entering the mass consumer market. Their application scenarios have expanded from traditional elderly care and children's early-age education to diversified fields such as home entertainment and popular science innovation. At present, most mainstream consumer-grade companion robots on the market adopt wheeled or humanoid structures. Wheeled robots feature flexible movement yet poor obstacle-surmounting capacity and can only work on flat hard ground. Humanoid robots deliver good anthropomorphic effects, but they are equipped with complex mechanical structures, difficult control algorithms and generally high selling prices, which are unaffordable for ordinary families and student groups. Some simple bionic robots can only realize basic walking, lacking emotional interaction design, entertainment performance and companionship experience.

Bionic hexapod robots draw on the limb structures of spiders and insects in nature. Relying on multi-degree-of-freedom legs to achieve multi-posture movement, they possess strong static walking stability and favorable terrain adaptability, making them a hot research direction for small-sized robots. A large number of domestic universities and science-and-technology enthusiasts have carried out extensive research on hexapod robots. Nevertheless, most projects focus on inspection and detection functions, while few landing products target consumer scenarios such as daily family companionship and entertaining interaction.

Against the above-mentioned industry status, this paper designs the "Spirit-Spider Companion" bionic-spider intelligent companion robot. The project integrates bionic machinery, wireless IoT communication and anthropomorphic action interaction, with three core design goals: humanized interaction, multi-function integration and emotional companionship. It lowers the barrier to use: users can complete full control through a mobile graphical interface without mastering programming knowledge. Meanwhile, the open-source hardware supports secondary modification and development, satisfying dual demands of home entertainment and science-and-technology innovation learning for teenagers.

II. Overall Product Scheme Design

2.1 Core Design Concepts

Many traditional robots require complex parameter configuration and command memorization, creating high barriers for ordinary users. This product abandons complicated configuration procedures and adopts button-based graphical interaction on mobile phones. All functions are visualized, and action commands can be issued by clicking buttons. Human-computer interaction is simplified into intuitive command selection, enabling the elderly and children to get started quickly.

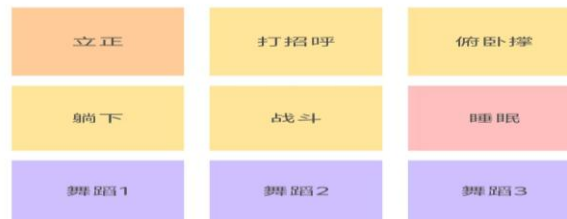


Figure 2.1 Overall Design Concept

The hardware platform integrates multiple capabilities including basic movement, social actions, fitness demonstration and dance performance. A single robot covers various scenarios such as home entertainment, guest reception, show performance and science experiments, avoiding low utilization of single-function devices.

Pure mechanical movement cannot achieve satisfactory companionship effects. This product simulates emotional states through body postures: the "sleep" state represents rest, the "combat" mode simulates excitement, and the "greeting" function delivers social feedback. Body language constructs mimetic emotion so that the robot is more than a mechanical device but a feedback-enabled household partner.

2.2 Appearance and Mechanical-Structure Design

The robot adopts a bionic-spider hexapod layout, and each mechanical leg is equipped with multiple movable joints. The multi-degree-of-freedom structure serves as the physical basis for translation, leg-lifting and complex posture transformation. All structural components of the robot are 3D-printed with eco-friendly PLA materials. PLA features convenient forming, light weight, decent toughness and impact resistance, which suits desktop small-sized robots. Furthermore, the 3D model can be modified for users to independently adjust the appearance of shells and legs for personalized customized modification.

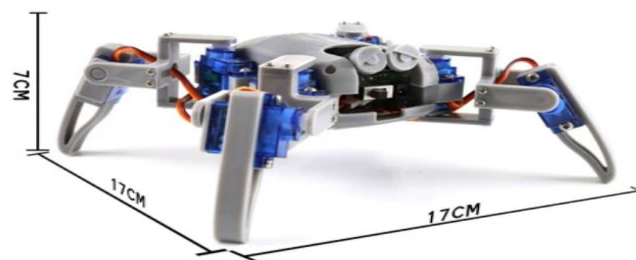


Figure 2.2 Physical dimension drawing of the robot

Overall physical dimensions: length 17 cm, width 17 cm, height 7 cm, classified as a desktop miniature robot. Its compact body allows free movement on desks, tea tables and household floors. The streamlined shell balances technological aesthetics, and the robot can be displayed as a tech ornament when idle.

Common gaits for hexapod robots include tripod gait and alternating gait. This robot adopts an improved tripod gait for basic walking logic. At least three legs support the fuselage during movement to guarantee stability and reduce roll-over risks.

2.3 Research and Test Process

This study strictly follows the scientific process of "demand orientation - technology research and development - test optimization - landing promotion". First, through questionnaire survey, field visits and expert interviews, the core needs of users and management parties are clarified. Then, the hardware system development is completed, including sensor selection, hardware integration and box structure design, and the software system research and development is carried out at the same time. Then, through laboratory tests and field pilot verification, the equipment performance and user experience are continuously optimized. Finally, large-scale operation is promoted to realize the actual landing of technical achievements.

III. System Test and Problem Analysis

3.1 Basic-Movement Test

The robot stably completes forward, backward and turning movements. The unique translation gait supports left-right lateral movement without changing orientation, allowing it to pass through narrow gaps. The improved tripod gait is adopted during walking for alternating switch of supporting legs. The fuselage vibrates slightly without roll-over.

3.2 Anthropomorphic-Interaction Action Test

All preset postures including standing at attention, greeting, push-ups and sleeping can be fully reproduced with coherent and smooth movements. Different simulated states can be directly distinguished by body postures, realizing mimetic emotional expression.

3.3 Dance and Beat-Following Test

Three preset dance programs run completely. After receiving music signals, the robot identifies beats and adjusts dancing speed along with music tempo, achieving favorable performance effects.

3.4 Power-Supply-Stability Test

During continuous high-load actions such as dynamic dances and push-ups, energy-storage capacitors on the mainboard effectively suppress voltage drop. Servo jitter, disordered movements and protective shutdown do not occur, and the overall operational stability is improved.

Deficiencies of the prototype are discovered through tests, which are also common pain points for small-sized hexapod robots:

- 1.No environmental-perception sensors are equipped on the prototype; autonomous obstacle avoidance is unavailable and all movements rely on manually-issued commands.
- 2.The 400 mAh lithium-ion battery has limited capacity, leading to short continuous working time under high-load dance modes.
- 3.Gait algorithms are only optimized for hard flat ground, and movement performance degrades on carpets and grounds with uneven friction.
- 4.Only button-based mobile-phone control is supported at present; intelligent capabilities such as voice interaction and autonomous emotion generation are absent.

IV. Application Scenarios and Expansion Prospects

4.1 Major Application Scenarios

As a household entertainment-oriented companion device, the robot can realize visitor-reception, posture performance and music-accompanied dancing, enriching leisure activities and family parties. Anthropomorphic limb interaction provides interesting playmates for children.

The complete system adopts open-source hardware. 3D-printing models and control codes can be secondarily modified. It is suitable for bionic-robot teaching in primary-and-secondary schools and maker labs. Students can acquire knowledge including mechanical-structure design, 3D modeling, servo control, Arduino programming and WiFi IoT communication. They can practice debugging of bionic gait algorithms and cultivate hands-on abilities and programming thinking.

4.2 Follow-up Function Expansion Directions

Combined with the current development trend of bionic companion robots, the prototype can be iteratively upgraded from three dimensions: hardware, algorithm and intelligence.

Hardware-Sensor Expansion: Install ultrasonic sensors and infrared obstacle-avoidance sensors to realize autonomous obstacle avoidance and cruise. Add RGB light modules to assist emotional expression via light colors. Equip microphones and loudspeakers for voice broadcast.

Voice-Interaction Enhancement: Access voice-recognition modules to support direct robot control by voice commands, getting rid of mobile-phone operation and further improving human-computer interaction experience.

Power-Supply and Mechanical Optimization: Adopt higher-capacity lithium-ion batteries to extend endurance. Optimize leg connecting-rod structures and add leg buffer structures to improve movement adaptability on complex ground such as carpets.

Intelligent-Algorithm Upgrade: Introduce simple emotion-logic algorithms to realize autonomous switching of action postures according to trigger conditions and achieve man-machine interaction without manual control. Optimize gait algorithms to further reduce fuselage vibration during movement.

V. CONCLUSION

This paper completes the full-scale design and prototype realization of the "Spirit-Spider Companion" bionic-spider intelligent companion robot. Mechanical-structure design, hardware selection and assembly, software programming and debugging are finished. Functions including wireless graphical control, bionic walking, anthropomorphic interaction and music-accompanied dancing are realized. Targeting desktop small-sized bionic companion robots, this product delivers controllable hardware costs and strong expandability, with values for both home entertainment companionship and science-and-technology innovation teaching.

The consumer-grade bionic companion-robot industry is still in rapid development. Integrating bionic mechanical structures with emotional human-computer interaction constitutes a vital development direction. The prototype still suffers from insufficient intelligence and limited endurance. Its intelligence level can be further enhanced by installing additional sensors, introducing voice interaction and optimizing gait algorithms, providing practical references for the productization of household small-sized bionic companion robots.

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