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Development of a Bionic Hexapod Robot for Walking on Unstructured Terrain

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Abstract

This paper reports the design methodology and control strategy in the development of a novel hexapod robot HITCR-II that is suitable for walking on unstructured terrain. First, the entire sensor system is designed to equip the robot with the perception of external environment and its internal states. The structure parameters are optimized for improving the dexterity of the robot. Second, a foot-force distribution model and a compensation model are built to achieve posture control. The two models are capable of effectively improving the stability of hexapod walking on unstructured terrain. Finally, the Posture Control strategy based on Force Distribution and Compensation (PCFDC) is applied to the HITCR-II hexapod robot. The experimental results show that the robot can effectively restrain the vibration of trunk and keep stable while walking and crossing over the unstructured terrains.

Keywords: hexapod robot, structure optimization, posture control, force distribution, force compensation

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1 Introduction

The locomotion of a multi-legged robot is highly complex[1,2]. The hexapod robot which is typically multi-legged is characterized by its climbing capability and fault-tolerance for walking on unstructured terrain. It is particularly suitable for tasks in complex environment[3], such as exploration (SpaceClimber)[4] or transportation (Athlete)[5] in outer space, detection in the wild (Dylema)[6,7] and for operation in extreme environment (Lemur)[8] where high reliability is essential. Thus the development of a hexapod robot capable of walking on unstructured terrain is of practical importance.

Much research work has been devoted to the generation method of free gait. This includes the method based on Central Pattern Generators (CPG)[9,10,11] applied in robot Scorpion[12] and Cruse′s Walknet[13–15] which is used in the design of several robots[16]. The free gait brings autonomic coordination between the legs into effect. The research efforts have been expanded to improve the stability of hexapod walking on unstructured terrain since the compliance control of the legs was proposed. This strategy is successfully applied in robots LAURON[17] and DLR-Crawler[18] that is based on the force sensors in locating their legs. Under the compliance control, the disturbance due to state transition between swing and stance is restrained and the stability of walking is improved. The purpose of research on hexapod robot is to achieve its autonomous and stable walking on unstructured terrain. A large stability margin is necessary for its broad adaption to unstructured terrain. The posture adjustment is an effective approach to achieve this. The technique for posture prediction, applied in robot RHex[19] and Robot III[20], adjusts the posture by computing the position of projection of Center of Gravity (COG) in Support Polygon (SP). The kinematic calculation is complex as the structure is series-parallel and there are 18 degrees of freedom (DOFs). The problem of foot-force distribution of hexapod robot during locomotion on a vertical surface has been discussed in Ref. [21]. This paper proposes a strategy called Posture Control strategy based on Force Distribution and Compensation (PCFDC). The distributed foot-force is used as a feedback for posture control to avoid computing the position of COG, and

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also is combined with compensative foot-force to restrain the vibration of trunk.

The hexapod robot HITCR-II is developed for walking in complex environment. The vision, force and other sensors are designed for the robot to realize the perception of environment and its own state for successfully crossing over unstructured terrain. The walking of hexapod with free gait on flat terrain is successful for the first generation robot, HITCR-I[22]. The compliance control based on 3-DOF force sensor on a leg of the second generation hexapod robot HITCR-II[23] is also investigated. The free gait provides the robot independent walking ability, and the compliance control of leg improves robot's adaptability to slightly rough terrain. The work reported in this paper is to enhance the stability margin of walking of the robot by posture control strategy, which is a key technology for crossing over unstructured terrain and even for climbing over the obstacles.

In this paper, a novel hexapod robot HITCR-II suitable for walking on unstructured terrain is proposed (as shown in Fig. 1). It is characterized by high-integration and control with multi-sensors. An objective function is formulated to optimize the parameters of structure to improve the dexterity. Using the sensing information of the force sensors and pose sensor, the PCFDC strategy is proposed to improve the stability margin of hexapod walking. Firstly, the foot-force distribution model is developed to obtain the desired distributed foot-force of all stance legs in any gait pattern. Secondly, the foot-force compensation model is created to obtain the compensation value of foot force, with the aim to restrain the vibration of trunk while the robot walks on unstructured terrain. The method proposed in this paper is verified by comparing the simulation and experimental results.

Fig. 1 The hexapod robot HITCR-II walking on unstructured terrain.

2 Design of the hexapod robot HITCR-II

The design of HITCR-II is based on three objectives. The first objective is to provide enough motion-promoting force for its walking, and to realize a small-scale highly-integrated structure. The second objective is to design complete sensor system within the structure of robot so that the robot has the perception of environment and its own state. The third objective is to improve motion dexterity by optimizing its structural parameters.

2.1 Structure, sensors and transmission agent of HITCR-II

The outline of the body of HITCR-II and the distribution of its six limbs are designed as oval-shaped to improve the stability of walking as well as to reduce the possibility of interference between the legs during movement. As shown in Fig. 2, the length of trunk is 320 mm, and the width of anterior and posterior parts are 136 mm and 196 mm respectively. Binocular stereo vision is developed to select the route and the support point of the foot. The pose sensor is installed at the geometric center, which is equidistant to all the six foot-ends to perceive the posture on-line.

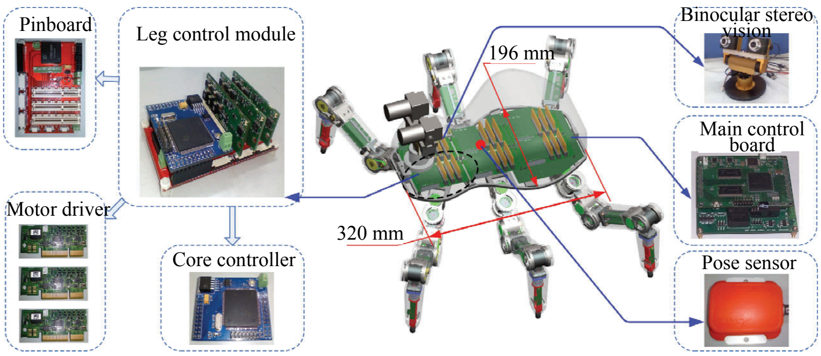

Fig. 2 Structure of HITCR-II's trunk.