Development of Multi-Legged Walking Robot Using Reconfigurable Modular Design and Biomimetic Control Architecture*

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Abstract
This paper focuses on the design of a modular multi-legged walking robot MiniQuad-I, which can be reconfigured into variety configurations, including quadruped and hexapod configurations for different tasks by changing the layout of modules. Critical design considerations when taking the adaptability, maintainability and extensibility in count simultaneously are discussed and then detailed designs of each module are presented. The biomimetic control architecture of MiniQuad-I is proposed, which can improve the capability of agility and independence of the robot. Simulations and experiments on crawling, object picking and obstacle avoiding are performed to verify functions of the MiniQuad-I.

Key words: Multi-Legged Walking Robot, Development and Design, Reconfigurable Module, Biomimetic Control Architecture, Simulation and Experiment

1. Introduction
Recently, interest in the development of mobile robots has grown markedly. Mobile robots capable of overcoming various unstructured environments and carrying instruments to perform the required tasks are expected to work as locomotion platforms for constructions, agriculture and forestry, fire emergency, disaster prevention, etc. Among various forms of robots, the legged walking robots have the best environment adaptability and provide the most cost-effective solution to work in the unstructured environment by performing legged locomotion.

Up to now, many researches have been done on the legged walking robot aimed at getting good adaptability to complex terrain and function, high flexibility and high extensibility. Both of them depend on the robot configuration and control architecture. Robot configuration includes the layout of joints, the range of joint angles, the number of legs and the body structure etc and the control architecture is the time and space mode of intelligence, behaviors, information and control of a multi-legged walking robot system.

To improve the terrain adaptability, many researchers focus on enlarge the range of joint angles by carefully mechanism design. Arikawa deployed an enhanced wire driven mechanism in TITAN-VIII to enlarge the working space (1). Tee (2) and Zielinska (3) also developed legs with large workspace by using worm gear driver and differential gear drive mechanism respectively. Those robots are complex machines difficult for manufacturing.
Other researches chose an alternative way to gain better adaptability. They tried to build a kind of reconfigurable modular robot to gain functional extensibility by changing its shape or structure. Modular manipulators\(^4\) and cellular robots\(^5\) are first kinds of such modular robots, which are composed by homogeneous or heterogeneous modules. Some researchers develop the metamorphic robotic hand using metamorphic mechanism\(^6\). Due to modularity, the cost for manufacturing was reduced and the maintainability was improved by replacing broken modules or adding new modules without major changes. However early modular robots emphasized autonomy of modules. They were complex in structure and poor in loading capacity, which are not suitable for outdoor tasks at all. In recent years, some researchers applied modular methods in developing legged robots looking forward to integrate advantages of modular robots and walking robots. P. Gonzalez de Santos et al. deployed a modular leg structure for a quadruped robot named SILO-04 to improve the maintainability and reduce its costs\(^7\). When developing a landmine sweeping robot, Hirose\(^8\) developed a modular knee mechanism in TITAN-IX for quick replacement of legs damaged by explosion. Chatterjee\(^9\) designed a generic limb module to build a 3-limb robot unit. Odashima\(^10\) developed a general leg module called MoNOLeg, hoping to improve the terrain adaptability by changing the number or the placement of leg modules. However those robots are not fully modularized yet, SILO-04 and TITAN-IV have a fixed number of legs in their body and MoNOLeg has a fixed joint layout in each leg module, e.g.

In this paper, we develop a reconfigurable and functional extendable modular walking robot, called MiniQuad(Mini Quadruped Robot)-I as shown in Fig. 1. We would apply modular design in both leg and body structure to gain better adaptability, maintainability and extensibility simultaneously. We proposed the biomimetic control architecture suitable to multi-legged walking robots, which can realize the reconfiguration. We will borrow the thinking and behavior characteristics of multiped animals and their control ways of behavior, study on the biomimetic control principle and method of multi-legged walking robots, and construct the robot architecture with biomimetic characters.

The outline of the paper is as followed: The design principles and considerations are discussed in Section II. Section III describes the detailed design of each module in MiniQuad-I. Section IV describes and explains the biomimetic control architecture. Section V shows the simulation and experimental results. Finally, Section VI discusses some of conclusion and future work.

2. Philosophy of Design

2.1. Modular Division

The design models of a multi-legged robot in different configurations are shown in Fig. 2. It can be seemed that robots with different configurations differ in the number and the layout of legs in the body, as well as the number and the layout of joints in legs. Hence, we can divide the whole robot into two modules, leg modules and the body module.

The mechanism designs of leg modules have a direct impact on the robot functions and performance. To achieve complex operations, the large working space is desired. Several
basic configurations for walking robots including insect leg, pantograph mechanism and leg with prismatic joints have been developed so far. The joints in pantograph and prismatic mechanism can be decoupled with each other by carefully design, which ease the gait controlling. But considering the limitation in joint angle of both pantograph and prismatic mechanism, we choose the insect leg as the configuration of leg modules in MiniQuad-I. We divided the leg module into three joint modules based on the functional and structural similarities exist in the joints.

The design of body module aims at the decision on the number, locations and the symmetry of legs. The number of legs influences the speed, stability and load capacity of the locomotion. The locations and symmetry of legs impact on the complexity and stability of gaits.

Obviously, different application environments require different choices of robot configurations. Compared to existing robot which only apply modular design in part of them, MiniQuad-I was composed by joint modules, leg modules and body module, and hence reconfigurable in both body and leg level. The thoroughly modularization brings better adaptability, maintainability and extensibility to MiniQuad-I simultaneously.

2.2. Determination of Joint Ranges

In order to enlarge the workspace and to simplify the control of the robot, the decision on joint range angles is one of the most critical issues in the design. In this section, the working environments of MiniQuad-I are classifying into several groups. Then, the required joint angles to negotiate environmental conditions are determined. As preliminary steps for analysis, following assumptions are set in advance.

Assumption 1: The robot always keeps its body parallel to the surface during locomotion. For the case of walking over a sloped terrain, the body of the robot can obtain better stability margin when tilting forward in parallel with the terrain surface. For the case of walking over the even terrain, the gait planning and control of the robot is simplified because the robot does not need to change the orientation of the body.

Assumption 2: Assuming that the body of the MiniQuad-I is a rectangle and the length, width and height of the body are denoted as , and , respectively. The angle of joint of leg can be denoted as . The lengths of the hip link, thigh link and tibia link are described as , and . Leg modules are placed on the body regularly with specific intervals in both longitudinal and lateral direction. The longitudinal interval is denoted as , and the literal one can be denoted as .

1) Standing and hibernating on plain surface: Plain surface can be defined as a surface without obstacles. During walking on a plain surface, the posture of the robot can be represented as A, B and C as illustrated in Fig. 3. Here, the state A denotes the standing phase and the state C means the hibernating phase. All other postures exist in between two
extreme phases, typically such as the state B which is often selected as the normal posture for crawl gaits. Thus, considering the size of the robot body, joint ranges for moving on a plain surface can be derived as follows.

2) Crawling and turning on plain surface: For a specific robot performing a regular and symmetric crawling gait, the distance between leg reachable space origins and the centre of the body has no effect on the stability margin and the stride length. But the robot which has larger leg reachable space can gain larger stability and stride length. For rotary gaits, the robot larger in reachable space has larger maximum rotary angle. Therefore, to gain better performance in walking, the reachable space of each leg should be designed as larger as possible.

3) Stepping over obstacles: Procedures to go over an obstacle is successively described from step 1 to step 4 as shown in Fig. 4.

In step 3 shown in Fig. 4, the relation between joint angles and the maximum height of the obstacle are obtained. When the robot is moving at step 3, front legs and rear legs coincide with the state A and C of Fig. 3, respectively. Consequently, the height of the largest obstacle that can be stepped over by the robot can be delivered as follows.

\[ H_o = L_1 + L_3 - h/2 \]  

And joint angle ranges should satisfy following conditions.

\[ -90^\circ \leq \theta_1 \leq \phi \]

\[ -90^\circ + \phi \leq \theta_3 \leq 0^\circ \]

Where,

\[ \phi = \arcsin\left(\frac{L_4 - h/2}{L_2}\right) \]

It can be seen that conditions for stepping over obstacles have the same as that of the plain surface.

4) Overturning when the robot is flipped over: When topples over and falls down with its back on the ground, the robot which has overturning capabilities can get up and return to the normal posture. This capability is useful for exploration tasks. The overturning movement can be presented as a sequence of leg movements as shown in Fig. 6. Here, in step 6 the length of legs should be sufficient for supporting the rotating body, shown in Fig. 5. According to this, the relationship between joint angle ranges and the size of the robot modules can be calculated as follows.

\[ 0^\circ \leq \theta_4 \leq \phi \]

Where,

\[ \phi = \arccos\left(\frac{L_4 + y_f - L_5}{L_2}\right) \]

5) Picking and placing objects by legs: If the lift angle and the swing angle of legs are large enough, the robot will have a high degree of motion dexterity and can perform picking and placing movements by using legs as manipulators.

Picking object with a couple of front legs is illustrated as Fig. 7. From Fig. 7, it can be seen that the minimum width of the object \( W_{min} \) is restricted by the size of robot body and the angle range of the joint 1, at the assumption that the two operating legs are extended completely. The relationship between the minimum width of the object and the angle range of joint 1 can be calculated as follows.

\[ W_{min} = y_f - 2(L_1 + L_2 + L_3)\cos\theta_{1\text{max}} \]  

3. Module In MiniQuad-I
MiniQuad-I is designed as a reconfigurable modular architecture, which consists of a body module, four leg modules in a quadruped configuration or six leg modules in a hexapod configuration and additional application modules. In order to simplify the structure and to
increase the extensibility of the robot, we focus on structure standardizations and how to subdivide the leg module into joint modules. The details of each module are described in the following subsections.

![Fig. 5 The critical step of overturning movement](image)

### 3.1. Joint Module

In designing leg and joints, attention is given to standardizing part as much as possible and to increasing the joint angle ranges of each joint.

The leg of MiniQuad-I consists of hip module, thigh module, tibia module and outer shells that form the thigh and the tibia. These three joints are all rotatory joints. Considering such similarity, the hip module, thigh module and tibia module share the same structure shown in Fig. 8, which contains a DC servo motor with a rotary optical encoder, a 3 stage 64:1 planetary gear box and a 45:1 worm gear. A potentiometer and an optical encoder are used to sensor joint angle and motor velocity. It should be mentioned that, though all joint modules in one leg are in the same size, DC servo motors may be differ in power because joint modules located in different positions of the robot have different torque demands.

Considering the weight, stiffness, strength and cost, aluminum alloys are chosen as the main material of the mechanical components expect for gears and worms. LY11 (LY stands for duralumin: Al-Cu-Mg alloy) is mainly used for the mechanical parts and LY12 is mainly used for the outer shells of joint modules.

Joint modules are connected with each other by interfaces in the same size so as to make the decomposition and maintenance easy by replacing the broken modules rapidly without major difficulties or expense.

### 3.2. Leg Module

The leg module of MiniQuad-I as shown in Fig. 9 are made up by three joint modules as well as feet-end-tools and supporting frames. To cope with all the environmental conditions discussed above, the joint ranges have been calculated. Based on these results, the specification of joint ranges are determined in Table I. Because of the carefully design of each joint module, the MiniQuad-I has a large reachable space for each leg comparing to other exiting robots. Comparisons of joint angles among most recently walking robot are listed in Table I, and all joint angles are translated into the same joint coordinates used in MiniQuad-I in Fig. 10. The length of the hip, thigh and tibia are 62 [mm], 200 [mm] and...
275 [mm], respectively. The link length was determined by considering the body size and the joint angles. It can be noticed that the designed reachable space is asymmetric. The upper space is designed for legs working as manipulators and the lower one is for locomotion. For the purpose of handling or passing small objects over the body, the upper space is designed larger. Hence, MiniQuad-I can use its legs cooperatively in a similar way as fingers of human hand to catch, pick or hold objects.

In order to achieve both light weight and high stiffness for the leg, MiniQuad-I has an exoskeleton leg structure. The loads applied on the supporting foot are supported by the outer shells of the legs.

### 3.3. Scaleable Body Module

The body module is designed as a scalable supporting frame for other modules as shown in Fig. 9. Leg modules are connected to the body module by extensible connections. When changing configuration of the robot, only a few parts need to be replaced. Additional application modules can be added into MiniQuad-I to meet the further demands of specific tasks, such as camera modular for remotely inspection, special tools for remotely repair tasks, etc.

### 3.4. Configurations of MiniQuad-I

MiniQuad-I is a reconfigurable robot walking in variety environment. The reconfigurability means that the number of legs, the layout of joints and the body shapes are all adaptable and functional devices can be plugged into our robot without major change of other parts.

Firstly, the number of legs can be changed according to the demand of locomotion. A hexapod configuration as shown in Fig. 11(a) with a set of modules can be assembled for carrying loads, and a quadruped robot shown in Fig. 11(b) can be built with the same set of modules for tasks need agile walking. The width of the MiniQuad I body is 300 [mm], while the height is 200 [mm] and the length is 600 [mm] in quadruped configuration or 1000 [mm] in hexapod configuration. It should be noticed that those dimensions can be adapted by rescaling the body module. Weights of the joint module and the leg module are 1.4[Kg] and 7.7[kg] respectively. Weights of the body in quadruped and hexapod

<table>
<thead>
<tr>
<th>Robots</th>
<th>Modularity</th>
<th>1st Joint $\phi$</th>
<th>2nd Joint $\phi$</th>
<th>3rd Joint $\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITAN-VIII</td>
<td>Non-modular</td>
<td>$-60^\circ \sim 110^\circ$</td>
<td>$-65^\circ \sim 65^\circ$</td>
<td>0$^\circ \sim 145^\circ$</td>
</tr>
<tr>
<td>TITAN-IX</td>
<td>Modular Feet-End-Tools</td>
<td>$-120^\circ \sim 60^\circ$</td>
<td>$-90^\circ \sim 180^\circ$</td>
<td>$-180^\circ \sim 180^\circ$</td>
</tr>
<tr>
<td>SILO-04</td>
<td>Modular Legs</td>
<td>$-80^\circ \sim 80^\circ$</td>
<td>$-90^\circ \sim 45^\circ$</td>
<td>$-135^\circ \sim 10^\circ$</td>
</tr>
<tr>
<td>MoNOLeg</td>
<td>Modular Legs</td>
<td>$-90^\circ \sim 90^\circ$</td>
<td>$-90^\circ \sim 90^\circ$</td>
<td>$-120^\circ \sim 60^\circ$</td>
</tr>
<tr>
<td>MiniQuad-I</td>
<td>Modular Joints, Legs and Body</td>
<td>$-90^\circ \sim 90^\circ$</td>
<td>$-90^\circ \sim 125^\circ$</td>
<td>$-125^\circ \sim 160^\circ$</td>
</tr>
</tbody>
</table>

**Fig. 10** Coordinate frame of the leg

**Fig. 11** Hexapod, quadruped and mammal-like configurations of MiniQuad I
configurations are respectively 8.2 [kg] and 12.8 [kg]. The total weight of the MiniQuad-I in both configurations are estimated to be 39.0 [kg] and 59.0 [kg] in present state. In both above configurations, legs consist of two links and three joints and the robot has 6 DOFs. It means that the MiniQuad-I is a robot that can perform omni-directional walking gaits in both quadruped and hexapod configurations. When using the same gait strategy, the robot in quadruped configuration is lighter in weight, faster but less stably in locomotion than the hexapod one. Secondly, the layout of joints can be adapted. An insect-like walking robot as shown in Fig. 11(a) is different in the layout of joints with a mammal-like configuration shown in Fig. 11(c). With modular design method, we can build both insect-like and mammal-like robot with same modules. Thirdly, the architecture of control system is a layered open system adaptable for adding new device modules and software modules as described in the following section.

4. Architecture of Control System

Based on the mechanical structure of MiniQuad-I, we proposed the biomimetic control architecture of MiniQuad-I. The control architecture sources from multiped animals, which have millions of years of evolution history and can survive well under complex and varied environment. The aim of control is the independent motion and working of robot without either the interruption of the human kinds or any regulation and modification to environment.

4.1. Architecture Model

In the control architecture of MiniQuad I, the behavior control ways of multiped animals are introduced, the study and evolutionary thought of activities are borrowed, and biomimetic control architecture conceptual model of MiniQuad-I as in Fig. 12 is constructed.

In this architecture, the environment is classified into natural environment and social environment, in which natural environment is the outside physical environment of robots, and social environment is the environment where robots and other intelligent agents interacted and collaborated. For example, the control of robot group and the man-machine conversation are under the social environment. In Fig. 12, the information stream denoted by green comes from natural environment, the information stream denoted by blue comes from social environment, and the information stream denoted by red comes from the inside of an individual robot.

The whole biomimetic control architecture consists of 4 blocks, which are:

1. Information communication block, which function is communicating information in social environment. This information can be a simple signal or the complex semantics expressed by advanced languages, and can be loaded by several of communication ways. Therefore, the communication correspondence center in these blocks is responsible for the organization, coordination, and fundamental analysis of information between different communication ways.

2. Information sensing block, whose functions are sensing, processing and managing the effective information sampling under natural environment and social environment. Sensors in the block are classified into several sensor groups according to the main information sources under natural environment. After the local information is processed by these sensor groups, the information inosculation center conducts the concentrated process. Furthermore, the inosculating information is processed with the relative stability and primitive accumulation of information as the feedback. Hence, it is proper to the real-time control of multi-legged walking robots.

3. Behavior generation block, which is the core of biomimetic control architecture and whose function is to realize algorithm according to the known information. This block proper control activities based on biomimetic control absorbs the control activities of
multiped animals in the form of behavior layers, and improves various control behaviors’ adaptability to the environment through study.

It is obvious that innate activities, such as taxis action, reflective action, and instinctive action, whose control behaviors are all generated in corresponding rule database. These kinds of behaviors can be generated in any local thought module in the architecture, but needn’t be in the control pivot. However, the acquired activities, such as social behavior, deliberate behavior, are generated in the nerve network. So it needs the supporting of the control pivot, and responses slower than innate control activities. If the connection strength of in-layer events satisfies the evolutionary threshold, the evolution between activities will be triggered. However, the study between activities brings the complex and sequential activities gradually to the instinct. and evolutionary mechanism, which aims to reach high independence and high agile control of multi-legged walking robots.

4. Joint driver blocks, which is generated according to activities and realizes the coordinated motion of multi-legged walking robots by controlling and driving mechanical executive machine. Obviously, the biomimetic control architecture is designed according to the ways and direction of information stream, which borrows the thought and behavior control characters of multiped animals. How to control and process information streams to realize the right and proper activities of multi-legged walking robots is realized by the biomimetic control algorithm.

The implementation of the algorithm in accordance with the information flow, which includes the natural environment information and social environmental information, is consistent with biomimetic architecture model. This improves the clarity and reliability of the algorithm. Furthermore, the structure of biomimetic generating algorithm is parallel, which pretend simple tasks such as collision avoidance going through the traditional map-based environmental planning algorithm. This enhances the response capacity of the robot. Motion control in the joint driver layer, which is intelligent with instinctive feature, is completely based on the basic research for kinematics and dynamics of multi-legged walking robot. From the perspective view of bionics, biomimetic control algorithm is the summarized and expansion of traditional foundational theoretical research on multi-legged walking robot. With this layered architecture, variety kinds of navigation and locomotion methods can be added. For example, navigation methods based on vision, auditory, and light e.g. can be added as rules used in reflection behaviors, and force control based locomotion can also be applied in instinctive behavior.

4.2. Biomimetic Control Algorithm

The procedure of biomimetic control algorithm works in the biomimetic control architecture, which includes the sensing and communication of information, the operation mechanism of every behavior control layer, the study and evolutionary methods of activities, and the formation of multiped motion gait, and so on. The biomimetic control mechanism due to the space limitation is implemented by the biomimetic control algorithm shown in Fig. 13. And the detailed processes are listed as follows:

1. Both social and nature environment information were gained via Information communication block and information sensing block respectively, fused by information inosculating process, and then saved to the database as known information.

2. Behaviors are generated by various behavior layers in behavior generation block with special rules and the known information stored in database. After a sorting process on all above behaviors, the best one is chosen.

3. Process task planning by using the chosen control behavior, including building motion command sequences and sending corresponding joints trajectory to joint driver blocks.

4. Add the chosen control behavior into behavior rules database and update both the learning and evolving databases.
4.3. Architecture Controller model

According to the software-hardware code sign, the physical model of controller in Fig. 14 is set up through setting up the mapping relationship between conceptual model and physical control model. The information transmits and process ways of such physical model are consistent with the conceptual model to guarantee the realization of biomimetic control from the hardware perspective. Based on such model, the biomimetic control system of multi-legged walking robots can be constructed very easily.

The control system of MiniQuad-I is composed of a biomimetic control CPU, information manage CPU and several joint control modules (the number is decided by the configuration of the robot). Modularized structure has been widely used in the hardware of MiniQuad-I’s control system to enhance the error tolerance.

5. Simulation and Experiment

To verify the validity of proposed modular multi-legged walking robot, simulation and
Experiments were carried out by the prototype of MiniQuad-I both in quadruped and hexapod configuration.

5.1. Simulation Tool

The simulation was conducted in the simulation platform of multi-legged walking robots shown in Fig. 15, which has the virtual sensing technology. Furthermore, it can transmit the physical information to the intelligent objects in the simulation environment, and can output the real-time authentic simulation scenes. The procedures are as follows:

Step 1) adds 3 objects in the scene, which are MinQuad-I in hexapod configuration, box model and ground model. It is supposed that the ground model has collide constrain to the z direction of other models, and its roughness is 40mm. MiniQuad-I is also supposed to be phototaxis, its evolutionary cycle is 300s, and the initial movement property is static.

Step 2) adds Light1 as illumination model, set its property to spotlight, and located behind the robot body. It is obvious that the robot turns around and moves forward to Light1, which proves the taxis reaction in the biomimetic control.

Step 3) change the location of box, and locate it in 500mm front of MiniQuad-I as shown in Fig. 16(a). The status shows the movement of the robot stops immediately, judges the physical properties of the box, and then turn around the box as shown in Fig. 16(b). This proves the instinctive reaction of the robot to avoid collision, and also proves the priority of instinctive reaction to taxis reaction.

Step 4) repeat step3 when the robot turns around the box and its body faces directly to Light1. After 6 minutes, when the box is put in front of the robot again, it can be observed that the robot no long stops to inspect, but turns around the box immediately. This proves the reaction of meeting barrier and turning around has changed form instinctive behavior to reflective behavior, and accordingly proves the evolutionary theory of biomimetic control.

Step 5) assign task 1, which is moving the box, to MiniQuad-I through man-machine virtual communication. It can be observed after the robot have received the task, it turns around immediately and begins to execute task 1, including walking toward to and picking
the box shown in Fig. 16(c) and Fig. 16(d) respectively. Because the man-machine command is social behavior, it proves the highest priority of social control behavior.

In the whole simulation process, not only the biomimetic control mechanism and method of multi-legged walking robots but also the correctness of kinematics and dynamics of multi-legged walking robots are validated.

5.2. Experiments

In locomotion experiments of quadruped and hexapod configurations, the crawl gait was tested. The realized photos are listed in Fig. 17.

![Fig. 17 The experiment results of walking](image)

In order to evaluate the object packing ability of MiniQuad-I, the integrated arm and leg movements are performed. If MiniQuad-I in hexapod, locomotion can be carried out by 4 legs, the rest of tow legs can work cooperatively as hands to pick, hold or move object. For example, in order to pick the object the robot firstly swings two fore legs to catch object shown in Fig. 18(a) to Fig. 18(b), and lifting the object by rotating the 3rd joint in both legs as show in Fig. 18(b) to Fig. 18(c).

To further verify the effectiveness of the proposed control architecture and algorithm, the experiment of avoiding obstacles is carried out. As shown in Fig. 19, under the rambling status of the robot, when tester command moving forward straight, the social control behavior of the robot surpasses its instinctive control behavior of avoiding obstacles and phototaxis behavior, and it completes the task successfully. Observing the experimental data, the 3 joints’ velocities of leg 1 in joint space during the experiment are smooth. It is indicated that the self-detect, which is the instinct behavior of the robot, limits the node and boundary in the gait navigation, to avoid damage to the robot body due to exceeding physical range. Hence, we obtain that the biomimetic control method makes more sense than conventional control methods in control mechanism.

![Fig. 18 The experiment result of object picking](image)

Experiments above are performed with several simplest behavior rules which are suitable in flat terrain. Results proved the correctness of the biomimetic architecture. Although the visual system has not been used, which is a part of biomimetic control architecture, the robot has been able to complete simple tasks using basal biomimetic control system. However, we will further study the biomimetic control system and more
complicated behavior rules to adapt to the real environment, as well as performing experiments in unknown and unstructured environment.

6. Conclusion

In this paper, we discussed about the modules and layered biomimetic control architecture design of a reconfigurable modular multi-legged walking robot, named MiniQuad-I.

By dividing the walking robot into several modules, MiniQuad-I is reconfigurable in both body and legs and has better adaptability, maintainability and extensibility simultaneously, which can be easily reconfigured into variety configurations by changing the layout of modules. And by proposing layered biomimetic control architecture and applying it with active study ability and self-adaptability, MiniQuad-I is able to achieve complex tasks in unstructured and unknown environment. Additional, by introducing the design principles of our robot considered of standing and hibernating, crawling and turning, stepping over obstacles, overturning, and picking and placing objects, we offered an effective developing technique for multi-legged walking robot. Finally, simulations and experiments on crawling, object picking and obstacle avoiding were performed to show the efficiency of the above design methods of the MiniQuad-I.

As future works, the mechanical structure of MiniQuad-I will be extended in by adding more functional modules. Similarly, the biomimetic controller applied in MiniQuad-I will be improved by developing advanced sensor blocks or integrating extra rules into behavior generation block.

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