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# Research on Hexapod Walking Bio-robot's Workspace and Flexibility

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## 1. Introduction

Because of the natural selection and the long period evolution of various animals in the nature, the animals generates the strong adaptability to the surroundings on energy conversion, locomotion control, gesture adjustment, information processing and discerning direction. The animals' structure and function is better than the man-made mechanical equipment's. Therefore animals are becoming references of human's advanced technology equipment .AT the 2004 IEEE Robotics and Bionics International Academic Conference, the experts pointed out :"The bio-robots imitating the animal body structure and function, will take the place of the traditional industry robots and become the trend in robot study field."

The definition of the bio-walking robot is a foot framework moving device which imitates the body structure and walking styles of multi-leg animals in the nature controlled by the computer [1]. According to the investigation, nearly half of the ground on the earth can not be reached by traditional wheel or pedrail vehicles, while many multi-leg animals can walk on it freely. Inspired by this phenomenon, many experts from different countries begin to study the technologies concerning to the walking bio-robots.

Compared to others, the locomotion of the walking bio-robot has some unique capabilities which are not owned by other driving styles. For example, the walking bio-robot has many DOFs(degree of freedom), walking deftly like animals, therefore they have stronger adaptability to the complex changeable ground. Compared to the pedrail robot, the falling feet spots are discrete, so their feet tips can adjust the walking gesture within the reachable areas and choose the proper supporting pots, which makes the robot has the ability to avoid and overcome the obstacles[2]. Furthermore, the vibration can be isolated by the walking bio-robot's locomotion system independently, that is to say, it allows body moving track and feet moving track relieve coupling. Although the ground is uneven, the robot can walk smoothly.

Among all kinds of the walking bio-robots, because of the hexapod walking bio- robot's advantages on structure and locomotion, people pay more attention on the hexapod walking bio-robot, which is becoming the key and hot point in robot study field. Figure 1 shows the new style hexapod walking bio-robot designed by the authors using the software UG. Due to its large number joints and the complex structure, how to make its body structure and legs ,realize the optimum design to extend its feet reachable area, improve its body agility, and fulfil the whole body's optimum design becomes the key point. Because



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the scientific optimum design of the hexapod walking bio-robot can provide the exact and firm basis on robot's whole body design, gait programming, driving and control.

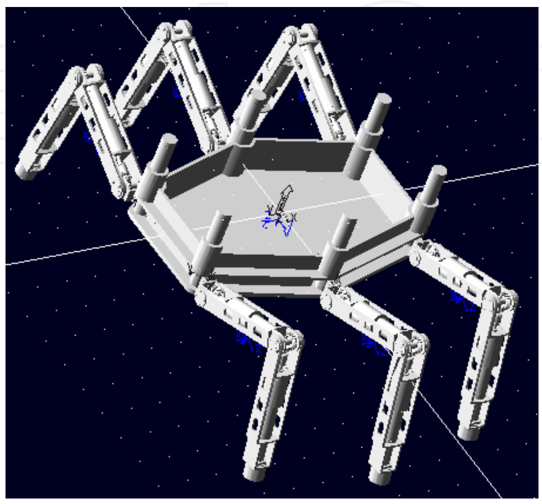

Figure 1. The substantiality sculpt of hexapod walking robot

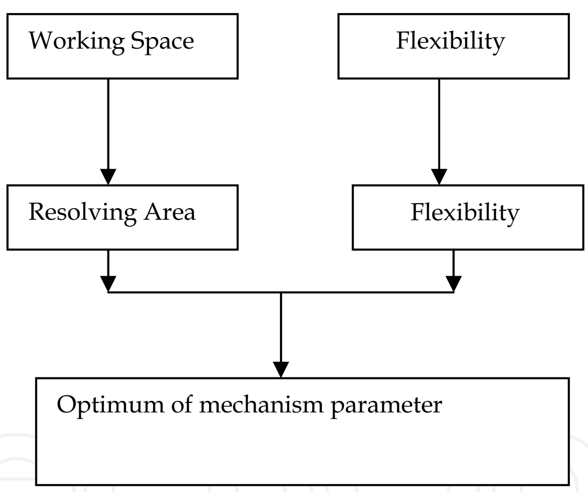


Figure 2. The flow chart of mechanism optimum

From what we discussed above, according to the hexapod walking bio-robot's characteristic of structure and locomotion, utilizing virtual prototyping technique and the numerical analysis method, aiming at the robot's feet walking space and body flexibility this chapter proposes the approach on hexapod walking bio-robot's optimum design of mechanism to reach the valuable and analyzable conclusion. The optimizing process can be seen from Figure 2.

## 1. Analysis of the hexapod walking bio-robot's single leg's workspace

When we analyze the robot's parameters and optimize the design, we can view the robot's uplift leg as a series mechanical arm, therefore the uplift leg's reachable area can be equalled as the mechanical arm's working space, which is the important standard to measure the robot's locomotion ability. Because the robot's walking foot is equalled as a series mechanical arm, working out the series mechanical arm means working out the reachable space reference spots setting of foot tip. This set represents the moving range of the robot's walking feet, which is a important factor for optimum design of robot and driving control.

### 1.1 Resolve the feet tip workspace of the hexapod walking bio-robot

Nowadays, Analytic Method, Diagrammatizing Method and Numerical Method are the main methods used to work out the robot's working space. Diagrammatizing Method ensures the edge of the working space through a lot of surrounding meshwork. Although this method can express the edge of the robot's working space through equation, it is not intuitionistic and its process is complex. The Numerical Method can work out the edge of the robot's working space, but usually what we get is the cut section or cut section line. This method is intuitionistic enough, but it is restricted by the DOF. When the robot has many joint, we must divide them into different group to deal with. The Numerical Method is based on the extremum theory and the optimizing method. First it calculates the eigenvalues on the robot's workspace edge curving plane, the lines composed by these spots represents the robot working space edge curving lines, then it uses the planes composed by these lines to represent the robot working space edge curving plane. As the software and hardware are developing so fast, the Numerical Method is widely used to analyze the robot workspace. Actually when this method is used by the computer to analyze the robot workspace, the computer chooses the compounding of different joints' variable randomly and independently, the more the better. Then it makes use of the positive locomotion equation to calculate the robot feet tip's coordinate value, which makes up robot working space. The more coordinates, the more vividly can it reflect the robot working space. Compared to other method, The Numerical Method has many advantages such as fast speed, high precision, easy to operate, large application range, and it can be used to all the robot structures. Therefore it is widely used [4-6].

The specific process of using the Numerical Method to work out the equivalent arm's working space is following:

1. Work out the positive solution of robot kinematics; ensure the coordinate equation of the foot tip in the reference frame.
2. Within the each joints' variety range, make the joints circumgyrate according to some pace angle in turn, get the compounding of different joints' variable.
3. Put the compounding of the joints' variable into the locomotion equation, get the coordinate value of the foot tip, save the corresponding $x$ , $y$ 's coordinate into matrix $X$ and $Y$ .
4. Display these values, we can get the "cloudy graph" of the robot equivalent arm's working space.

### 1.2 Resolving the area of the hexapod walking robot's food tip working space

In order to make the resolving process simple and fast, first we divide the robot equivalent arm's working space into many strip parts, then equal every strip part as a rectangle, last add up all the rectangles' areas to get the total area. The specific process is as follows:

Find out the max. $y_{max}$ and the min. $y_{min}$ of the matrix, ascertain the number of dividing $n$ based on the precision, and the width of each row is

$$\xi = \frac{y_{max} - y_{min}}{n} \quad (1)$$

1. Divide the corresponding $x_s$ into $n$ groups, find out the extremum of each group. We should pay attention that if there are hollows in the region, code the edge spot and resolve them one by one.
2. Calculate every rectangle's area and add them up, we can get the working space:

$$S = \sum_{i=1}^{i=n} S_i = \xi \sum_{i=1}^{i=n} \left( x_{i\max} - x_{i\min} \right) \quad (2)$$

### 1.3 The influence of the mechanism parameter on robot's walking foot tip space

The hexapod walking bio-robot has many leg joints (including coxal joint, femur and tibia, shown as Figure 3).Therefore it is very important to realize the optimum proportion of the leg length when we design the hexapod walking bio-robot's structure. Each joint of the robot is connected by the revolution, under the precondition that it will not influence of the correctness of the kinematics analysis, we can ignore the rotation of the coxal joint, only calculate the 2-Dimension workspace. At this time, the coordinate equation of the foot tip reference spot in the basement frame is as follows:

$$p\left(x,y\right) = \begin{bmatrix} l_1 \cdot \sin\theta_1 + l_2 \cdot \sin(\theta_1 + \theta_2) + l_3 \cdot \sin(\theta_1 + \theta_2 - \theta_3) \\ -l_1 \cos\theta_1 - l_2 \cdot \cos(\theta_1 + \theta_2) - l_3 \cdot \cos(\theta_1 + \theta_2 - \theta_3) \end{bmatrix} \quad (3)$$

Where, $\theta_1 = 45^0, -45^0 \le \theta_2 \le 135^0, 0^0 \le \theta_3 \le \theta_1 + \theta_2, l_1, l_2$ and $l_3$ is the length of coxal joint, femur and tibia respectively, and suppose all the gait length is $l = l_1 + l_2 + l_3 = 400$mm. With this method, we can get the hexapod walking robot's 2-Dimension working space, as can be seen from Figure 5.From the figure, we can see that the smaller proportion the coxal joint has, the larger working space it has. When the proportion of the femur reaches 0.45, the working space curving line has the largest area.

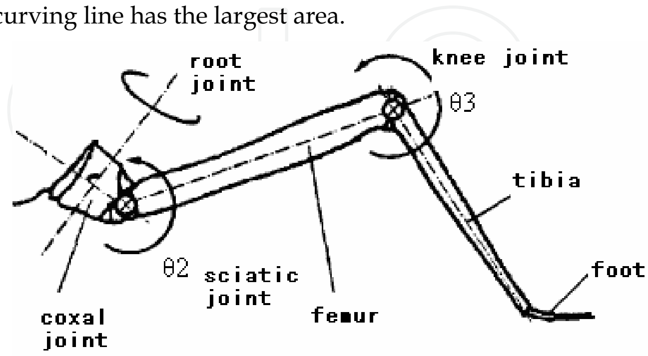


Figure 3. The sketch map of leg joints

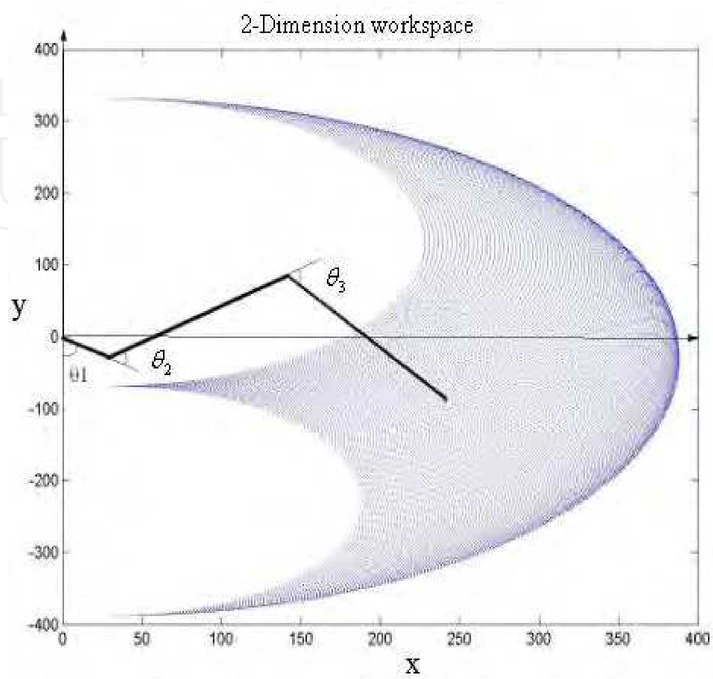


Figure 4. The "Cloudy graph" of foot tip working space

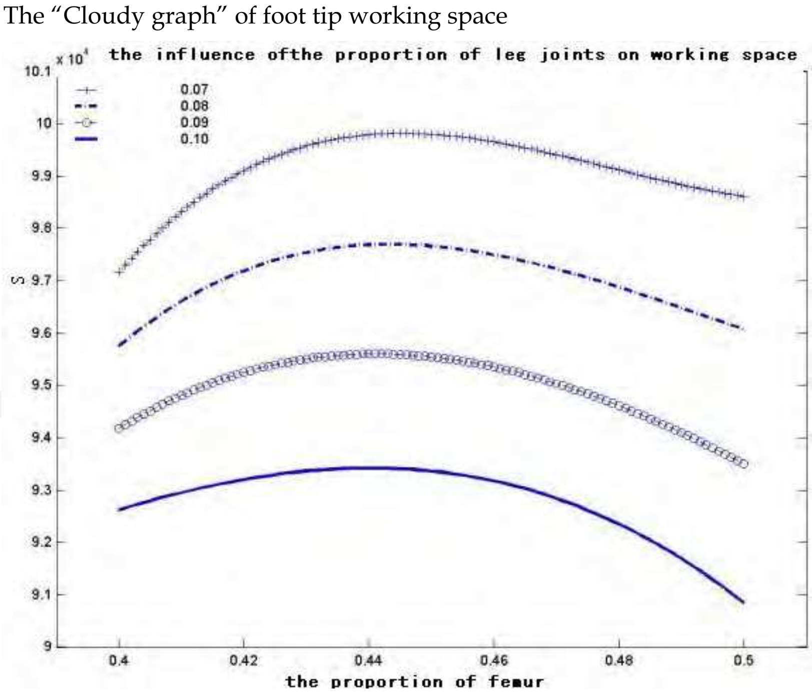


Figure 5. The influence of the proportion of leg joints on working space

## 2. The agility analysis of the hexapod walking robot

The agility of the hexapod walking robot ensures when the robot walks steadily on the located spots with still gait, it can change the gesture freely in large scale of the series mechanism composed by the body and supporting legs. Literature [8] gives us a standard of measuring of the agility, that is to say, using the robot's agility as the object function, analyze the body agility and assess the structure optimum.

### 2.1 The definition of the hexapod walking robot's agility[8]

The robot's body structure can be expressed by $\{X, Y, Z, \alpha, \beta, \gamma\}$, which are the body frame's displacements and angle displacements compared to the ground frame. Due to the restriction given by the multi-loop series mechanism, the parameter of the body location gesture varies among some range, from which the agility $FB$ comes.

$$FB = \frac{1}{6}\left\{\frac{1}{2L}\left(S_x + S_y + S_z\right) + \frac{1}{180}\left(\phi_x + \phi_y + \phi_z\right)\right\} \tag{4}$$

In which, L represents the length of the leg, $S_x$, $S_y$, $S_z$, $\phi_x$, $\phi_y$ and $\phi_z$ represent the displacements and angle displacements along the $X$ , $Y$ ,and $Z$ axes.

$$S_x = X_{\max} - X_{\min}, S_y = Y_{\max} - Y_{\min}, S_z = Z_{\max} - Z_{\min}$$

$$\phi_x = \alpha_{man} - \alpha_{\min}, \phi_y = \beta_{man} - \beta_{\min}, \phi_z = \gamma_{man} - \gamma_{\min}$$

The agility FB is a parameter which has no dimension among [0,1], showing the robot's structure and location. It represents the whole body's agility.

### 2.2 The method of robot optimum design based on the prototyping technique

The prototyping technique concerns multi-system's kinematics and dynamics modeling theory and their realization. It is an integrated applying technique based on the advanced modeling technique, multi-field simulation technique, information management technique, alternant UI technique and virtual realization technique. ADMAS software developed by MSC company is the famous and widely used mechanism system simulation software set up based on the multi-rigid body theory. It can establish three-dimensional model conveniently, add the acting force and restriction to the model, and has strong simulation and disposal ability.

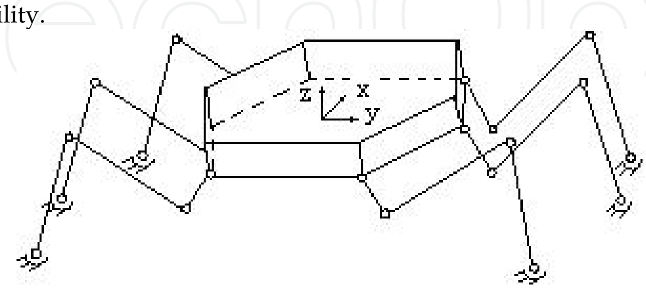


Figure 6. The simplified structure model of hexapod walking robot

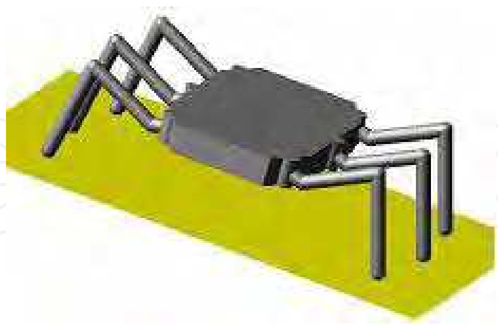

Figure 7a the crawl gesture

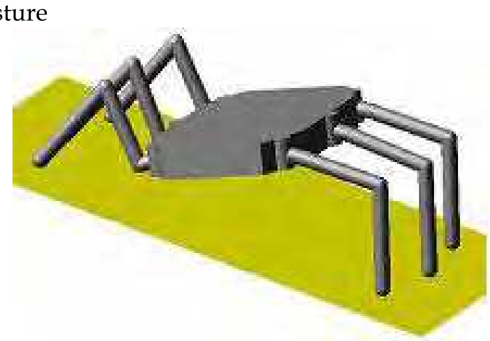

Figure 7b the sidle gesture

Figure 7c the turnaround gesture

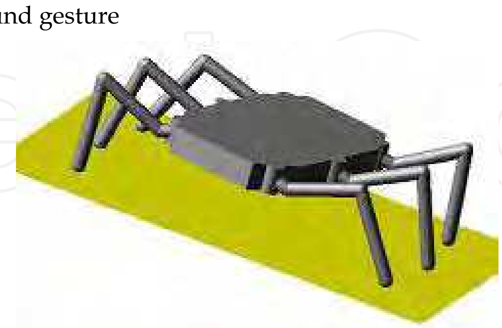

Figure7d the standing gesture

Figure 7. The gesture changing of the hexapod walking robot

In order to carry out the optimum design to the robot, first we use dynamics simulation software to set up the structure and parameter model. The parameters of the mechanism include: the body length along the X direction pa-1, the body length along the Y direction pa-2, the body length along the Z direction pa-3, the radius of the leg pa-4, the length of coxal joint pa-5, the length of femur pa-6, the length of tibia pa-7 etc. Based on the characters of the robot's structure and locomotion, we add restriction model newly established, add revolution to the three joints of the leg, add sphere between foot tip and ground, in order to meet the need of the gesture.( Shown as Figure 6). Meanwhile add the colliding force CONTACT and SENSOR between body, ground and leg. If the value of the colliding force is larger than set value, the robot stops, which can avoid the intervene of each part.

Further more, the location of movement is controlled by I marker and J marker. When we produce the preferences model, the preferences setting should be given to the location of the two marker spots concerning to movement, if not, during the process, the phenomenon of the movement stagger will emerge. Then use the order General_ motion to add the robot's locomotion, adding the movement and rotation along $X$ , $Y$ and $Z$ respectively. Figure 7 shows some typical moving gesture of the hexapod walking robot, in which Figure a is the crawl gesture, Figure b is the sidle gesture, Figure c is the turnaround gesture, while Figure d is the standing gesture. During the process of the locomotion, set Point Measure and Measure/ Orientation , record the moving and the rotating ultimate location of the walking robot body along $X$ , $Y$ and $Z$ .Last fill the object function, design variable and the number of simulation in the optimum design dialog box. The software will do some calculation automatically to get the max displacement and the max angle displacement, based on which it can work out the corresponding agility of the robot.

### 2.3 The influence of the mechanism parameters on agility

When we carry out the leg joint proportion optimum resolving, as we mentioned above, suppose the rotating angle range of the leg root joint, sciatic joint and knee joint is: $-45^0 \le \theta_1 \le 45^0$ , $-45^0 \le \theta_2 \le 135^0$ and $0^0 < \theta_3 \le 135^0$ respectively, the total length of the leg is 400mm. During the optimum design of mechanism, set the two variable parameters of the coxal joint proportion and femur proportion, aiming at the max displacement and the max angle displacement, then the software do some calculation automatically, according to which the relationship between the leg joint proportion and the agility, as can be seen from Figure 8.From the curving line, we can see that when the proportion of the coxal joint is too small, there is intervene between body and legs, which reduces the agility of the walking robot. When the proportion of the coxal joint increases over 0.08 and the proportion of femur is about 0.45, the amplitude of the robot's agility decreases and tends to stable.

## 3. Conclusions

Choosing the optimum design of hexapod walking robot's leg as the cut-in point, this chapter studies the working space, the flexibility of the robot and the calculation analysis process .In order to realize the optimum design of the robot mechanism; we review the robot's capability fully. Through analysis, we can get the different parameters from the different capability standard. For example, during the process of optimum design of leg design, the small proportion of coxal joint will do good to the robot's working space and while do harm to he robot agility. Therefore we should choose the small proportion of coxal joint under the precondition that the agility is not influenced. Through analysis, the proportion of coxal joint, femur and tibia is 0.08:0.45:047, which not only enables the foot tip to have large working space, but also makes the body has good locomotion agility. Therefore it provides the theory basis and technique support on the hexapod walking bio-robot's proper drive and exact control.

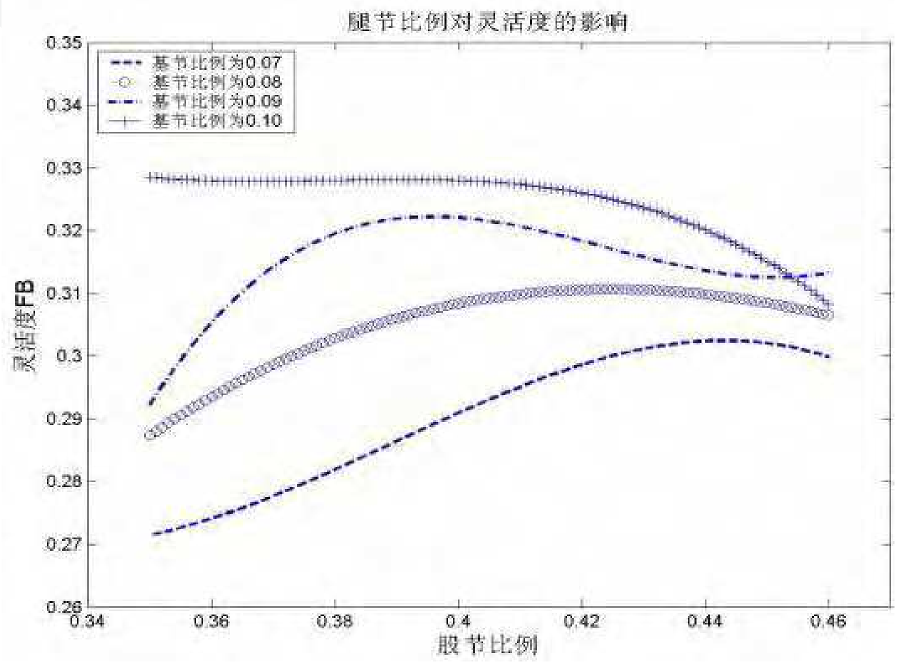


Figure 8. The influence of the proportion of leg joints on agility

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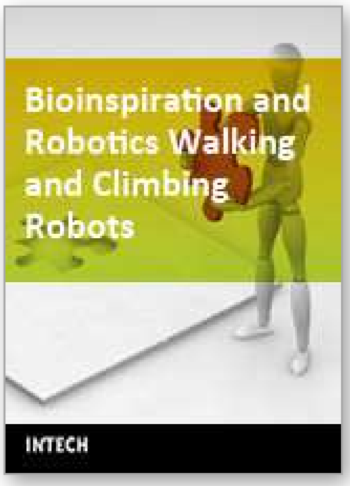
HAN Baoling, female, the Han nationality, from Anhui, Hefei Province, born in 1957, doctor, professor. Majoring in MEMS, Computer Graphics , Mechanical and Electronic Integration Design. Published more than 80 papers and three literatures

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Nature has always been a source of inspiration and ideas for the robotics community. New solutions and technologies are required and hence this book is coming out to address and deal with the main challenges facing walking and climbing robots, and contributes with innovative solutions, designs, technologies and techniques. This book reports on the state of the art research and development findings and results. The content of the book has been structured into 5 technical research sections with total of 30 chapters written by well recognized researchers worldwide.



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