A Roller Skating Robot

Nantha K. Kanesen, John Billingsley

Mechatronic Research Group
Faculty of Engineering and Surveying
University of Southern Queensland
Toowoomba, Australia, 4350

kanesenn@usq.edu.au, johnbill@usq.edu.au

Abstract

By including wheels on the legs of a mobile robot, it can gain the benefit of wheels where the terrain is smooth and the versatility of legs when climbing is necessary. This paper discuss the design and possible gaits of such a robot.

Keywords:
Mobile Robot, Skating, Legged, Wheel, VGTM

1 Introduction

Wheeled mobile robots can travel with good speed on a surface which is nearly flat. However when the terrain has large variation, a wheel cannot sustain traction when it meets an obstacle that is taller than its radius. Even a large crack in the ground can trap the wheeled mobile.

Legged mobile robots, on the other hand, have an excellent potential to adapt to terrain changes but the maximum speed is very low when compared with a wheeled robot. The need is to build an ideal mobile robot with good top speed and good capability to manage rough terrain.

This paper presents a mobile robot in which wheels are mounted on the legs to give an extremely resilient suspension when rolling and the versatility of a leg when climbing or walking should become necessary. The robot is controlled by an 80486 computer, using five microcontrollers to achieve a hierarchical control system.

2 Structural design

The body of the robot is designed using the Variable Geometry Thrust Method (VGTM)[1]. The body of the robot is assembled from several components, which

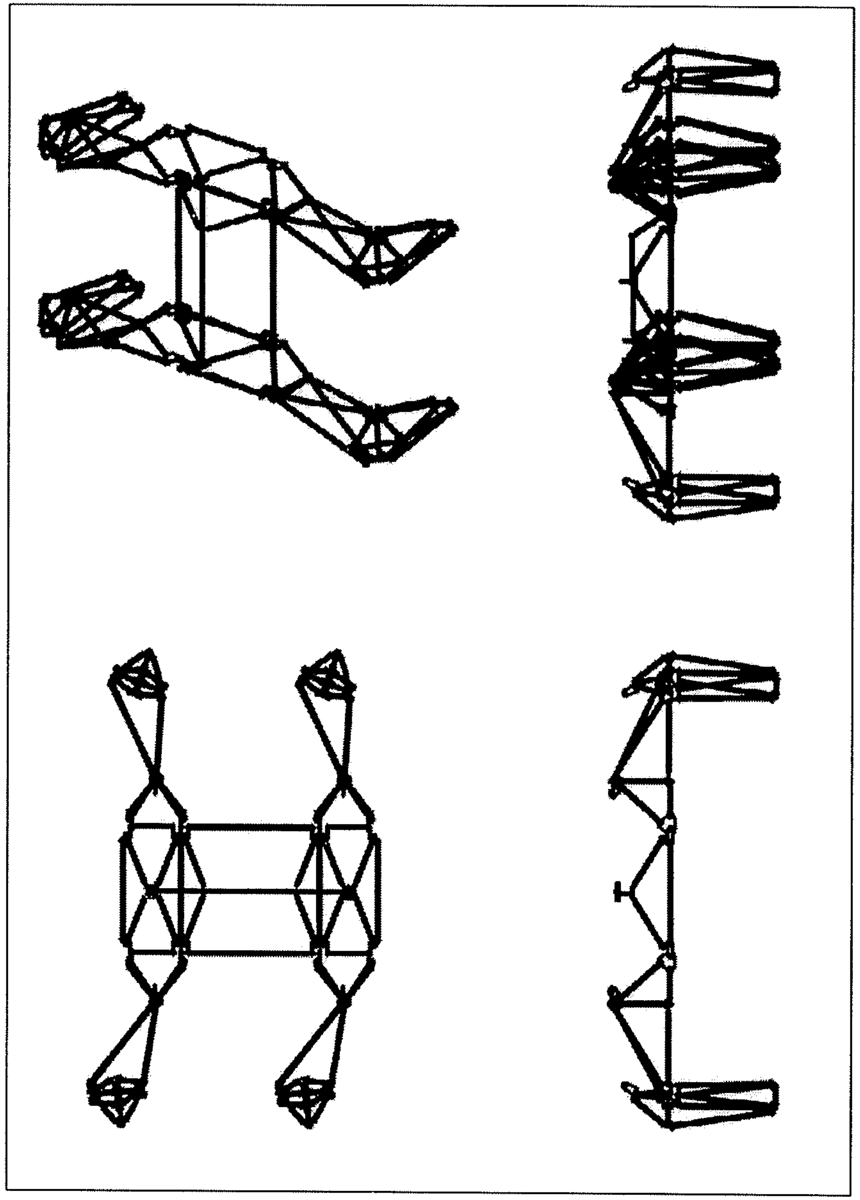


Fig 1. Structural modal of Roller Skating robot (pneumatics cylinders and wheels are ignored in this drawing)

consist in turn of assemblies of sub-components made up of aluminium tubes as connection members and aluminium brackets as connecting nodes.

A problem in designing and controlling the kinematics of a leg or manipulator is internal singularity, which can arise when two or more joint axes line up and lose a degree of freedom. Care has been taken to avoid this singularity problem in the leg of the Roller Skating robot, see figure 1.

An important factor that must be considered in designing the leg is the shock force acting on the leg when it collides with an obstacle. The impact force will give rise to a torque acting on the whole leg, which will be concentrated as shear force at the ends of the rod denoted as A in figure 2. Rod A will have to be designed to have a substantial length to limit these forces.

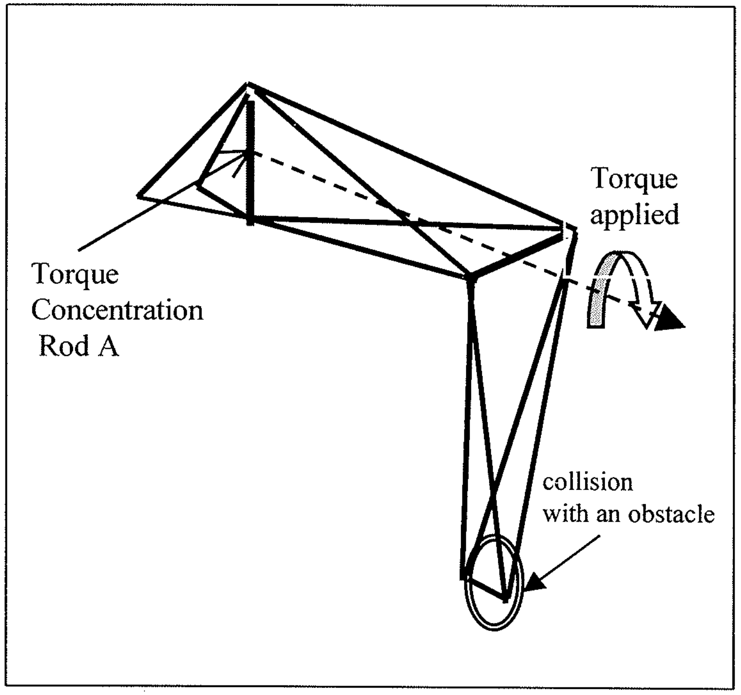


Fig 2. Applied torque to the leg when it collides with an obstacle

The great advantage of using a pin-jointed truss design for the leg is that it is lightweight, statically stable and highly resistant to deflections when heavily loaded at its nodes. Any applied force can be distributed throughout the entire structure. The experimental leg can be modified in size and scale by changing the length of the connection members but preserving the nodes [1].

3 Leg kinematics

3.1 Forward kinematics

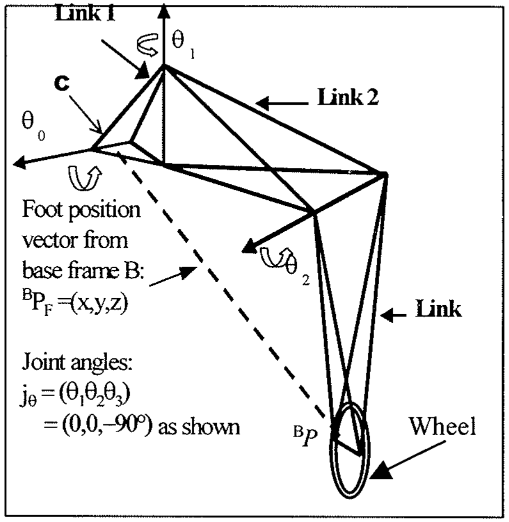


Fig 3. Leg design of Roller Skating Robot

The kinematics of the leg can be described using the following Denavit-Hartenberg table (D-H table). Through this table we can obtain the forward kinematics equations to find the position of the foot relative to the base frame coordinate for a given set of joint angles. Further analysis can be performed using the Differential Jacobian method to determine the joint angles relative to the foot position by the inverse kinematics method. In this analysis, variables with subscript F are used to indicate the cartesian coordinates of the foot whose origin is at the centre of the body-hip joint **C**, as shown in figure 2. The subscript $\upsilon_{\#}$ are the link angles in joint space.

Denavit-Hartenberg Table for the leg:

Link I	Twist αi	Link length	Joint angles
0	0	0	0
1	0	0	θ_1
2	90°	L_1	θ_2
3	-90°	L_2	0
4	16°	L_3	θ_3

From the above table, the foot position (x,y,z) is calculated to be:

$$^BP_F = (x,y,z) \qquad (3.1.1)$$

Where

$$x = L_3(C_1C_2S_3) + C_1C_2L_2 + C_1L_1 \qquad (3.1.2)$$

$$y = L_3(S_1C_2S_3) + S_1C_2L_2 + S_1L_2 \qquad (3.1.3)$$

$$z = L_3(S_2S_3) + S_2L_2 \qquad (3.1.4)$$

∴ $C_1=\cos\theta_1$; $C_2=\cos\theta_2$; $C_3=\cos\theta_3$; $S_1=\sin\theta_1$; $S_2=\sin\theta_2$; $S_3=\sin\theta_3$

From McKerrow[2], the Jacobian matrix for the leg takes the form:

$$^BJ_\theta = \begin{bmatrix} \frac{\partial x_B}{\partial\theta_1} & \frac{\partial x_B}{\partial\theta_2} & \frac{\partial x_B}{\partial\theta_3} \\ \frac{\partial y_B}{\partial\theta_1} & \frac{\partial y_B}{\partial\theta_2} & \frac{\partial y_B}{\partial\theta_3} \\ \frac{\partial z_B}{\partial\theta_1} & \frac{\partial z_B}{\partial\theta_2} & \frac{\partial z_B}{\partial\theta_3} \end{bmatrix} \qquad (3.1.5)$$

where:

$$\frac{\partial x_B}{\partial\theta_1} = -L_3\left(S_1C_2S_3\right) - S_1C_2L_2 - S_1L_1 \qquad (3.1.6)$$

$$\frac{\partial x_B}{\partial\theta_2} = -L_3\left(C_1S_{23}\right) + C_1S_2L_2 \qquad (3.1.7)$$

$$\frac{\partial x_B}{\partial\theta_3} = L_3C_{123} \qquad (3.1.8)$$

and other equations take similar trigonometric forms.

3.2 Inverse kinematics

The joint angles of the leg j_θ (θ_1, θ_2, θ_3), can be found relative to the foot position in space f_P = (x, y, z) by using the inverse kinematics method [3]. Since the differential kinematics equation represents a linear mapping between the joint angle and foot position, it can be utilised to tackle the inverse kinematics problem.

The relationship between the differential foot position and differential joint angles is given by:

$$\delta x = {}^{B}J_{\theta}\,\delta\theta \qquad (3.2.1)$$

From equation 3.2.1, the inverse kinematics solution is

$$\delta\theta = {}^{B}J_{\theta}^{-1}\delta x \qquad (3.2.3)$$

4 Force calculation

The force is calculated by using the virtual work method. Since work has units of energy and it must be equal, measured in any set of generalised coordinates, we can equate the work done in cartesian coordinates with the work done in the joint space [4]. Because work is a dot product of the force vector and the displacement vector, we have:

$$F^{T}.\delta X = \tau^{T}.\delta\theta \qquad (4.1)$$

Where F is the cartesian force-moment vector acting on the foot, δX is the infinitesimal cartesian displacement of the foot, τ is the vector of torque at the joints and $\delta\theta$ is the vector of infinitesimal joint displacement.

Since the definition of Jacobian is

$$\delta X = J\delta\theta \qquad (4.2)$$

we can write

$$F^{T}.J\delta\theta = \tau^{T}.\delta\theta \qquad (4.3)$$

And by simplifying equation 4.3, we have

$$J^{T}F=\tau \qquad (4.4)$$

The equation above gives the absolute relationship between the force acting on the foot and the resultant torque generated at the joints.

5 Gait

Of the many gaits of the Roller Skating robot, seven may be singled out:- walking, skating, speed skating, plod-roll, free wheel, scooting and climbing.

There is no drive to the wheels, only to the articulation of the limbs. However, each wheel is fitted with a brake which can be operated independently.

In walking robots, a common problem is instability when a leg is lifted from the ground. In the skating robot, walking can take the form of 'shuffling' where the leg being advanced is not lifted. The brakes are applied on three of the wheels whilst the fourth is unlocked.

Human skating does not employ brakes at all. Instead, the 'pushing' foot is angled so that the blade lies across the direction of the force to be applied. Similarly the leg of the robot can be angled to turn a thrusting wheel across the direction of the required force. As speed builds up, this angle can be reduced to give a smooth motion, which becomes speed skating. See figure 5 and 5.1.

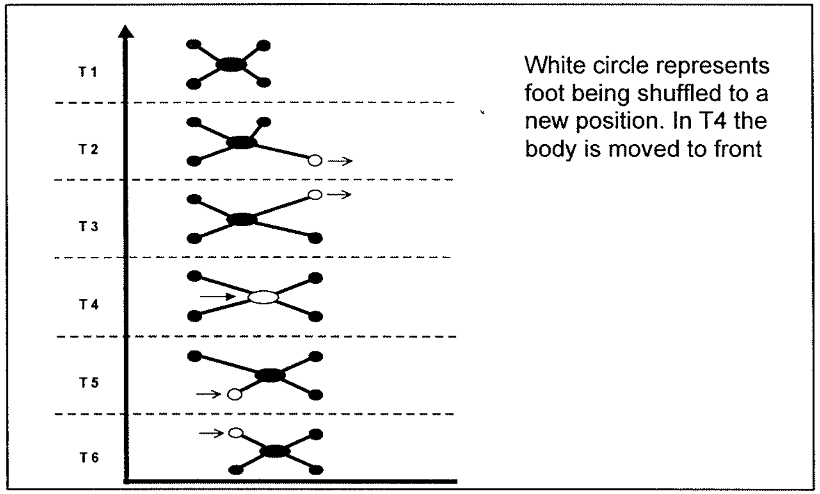
In one form, skating does involve remaining stable while a foot is lifted and replaced. A variation is possible, however, where the skater 'coasts' while drawing the feet together and then pushing them apart repeatedly, turning the feet appropriately.

Plod-roll is the counterpart of shuffling. Three wheels are freed to roll while the fourth one is locked and pushed to give a forward thrust to the body (figure 6). Trajectory planning and control is possible by changing the angles of the front wheels relative to the line of motion.

Free wheel motion is achieved by unlocking all the four wheels when coming down a smooth slope. Brakes can be applied to control the speed of the robot. No energy is required in this gait and the propulsion is initiated by gravity.

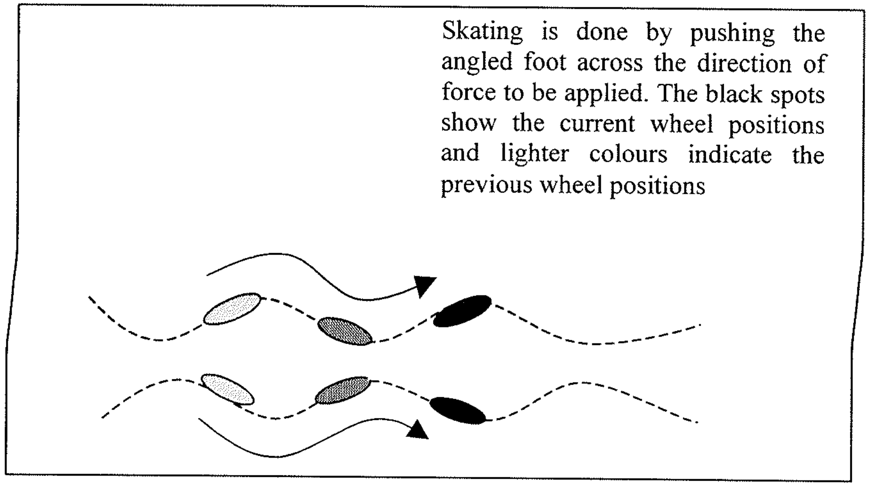
The scoot gait resembles the gait of a rabbit in motion. Initially the back wheels are unlocked, dragged inward and locked. Then the front two wheels will be freed while pushing the body forward. This gait will be excellent for the robot when climbing a hill since the stability is preserved by not lifting any leg (fig. 7).

There exist a possibility for the robot to be unstable when climbing over an obstacle. The reduction of legs attached to ground increases the instability where the robot might tip over (figure 8). But this problem converges with the stability problem of the conventional four-legged robot.



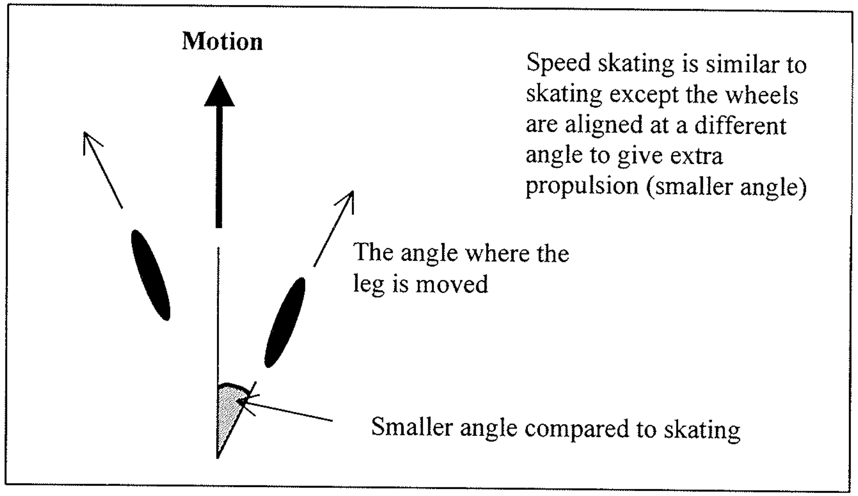
White circle represents foot being shuffled to a new position. In T4 the body is moved to front

Fig 4. Walking Gait



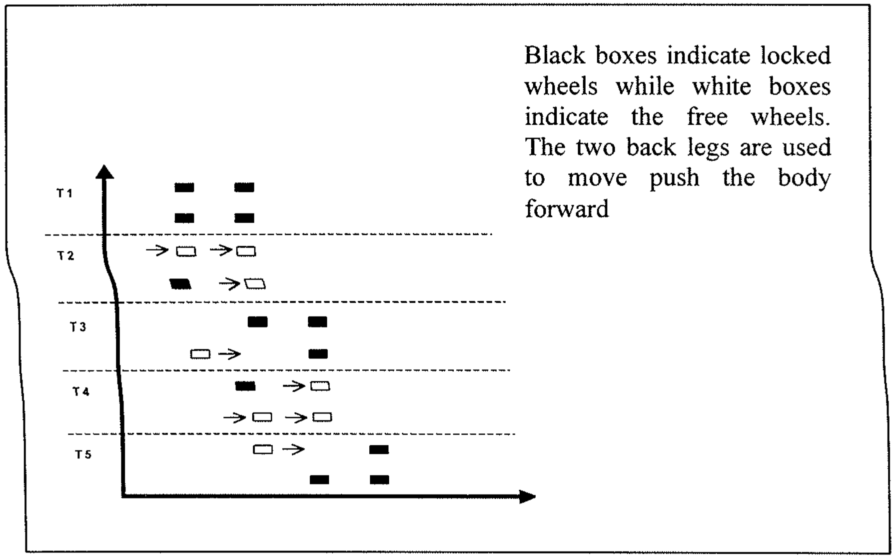
Skating is done by pushing the angled foot across the direction of force to be applied. The black spots show the current wheel positions and lighter colours indicate the previous wheel positions

Fig 5. Skating gait



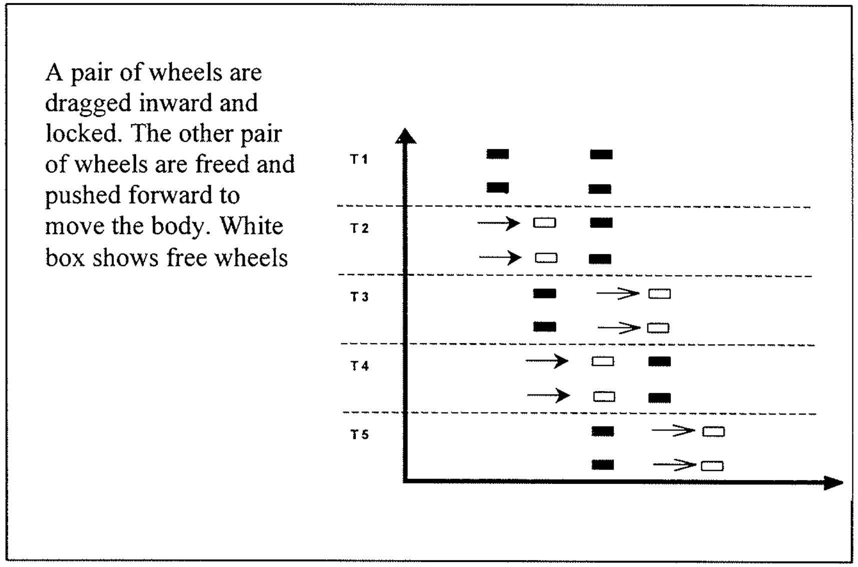
Speed skating is similar to skating except the wheels are aligned at a different angle to give extra propulsion (smaller angle)

Fig 5.1. Speed skating



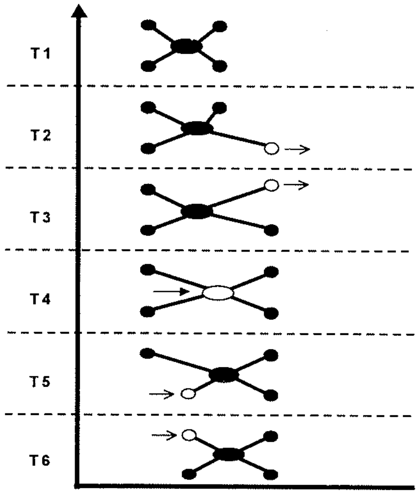
Black boxes indicate locked wheels while white boxes indicate the free wheels. The two back legs are used to move push the body forward

Fig 6. Plod–roll Gait



A pair of wheels are dragged inward and locked. The other pair of wheels are freed and pushed forward to move the body. White box shows free wheels

Fig 7. Scoot Gait



The white circles represent the foot being raised from the ground and placed in a new position. In T4 the body of the robot is moved to front

Fig 8. Climbing gait

6. Conclusion

This paper outlined the design of a leg, which can overcome the singularity problem by avoiding the rotation axis from falling in the same direction. The Jacobian discussed in this paper can be easily converted into software to be used in any applicable computer. The leg kinematics may seem tedious but it is simple enough for practical implementations to achieve a good kinematics control. The robot is being constructed while this paper is written.

Reference:

1. Samual N. Cubero, 1997, "Force Compliance And Position Control For Pneumatic Quadruped Robot", PhD Thesis, USQ, Australia.
2. McKerrow P.J., 1997, "Introduction to Robotics", Addison-Wesley.
3. Lorenzo Sciavicco, Bruno Siciliano, 1999, "Modelling and Control of Robot Manipulators", McGraw Hill.
4. Craig J., 1989, "Introduction to Robotics", second edition, Addison-Wesley

---

A Six-Legged Hybrid Walking And Wheeled Vehicle

Samuel N. Cubero
Lecturer in Mechatronics, School of Mechanical Engineering
Curtin University of Technology, Perth, Western Australia

Abstract

This paper discusses the mechanics and control specifications of a hybrid walking and wheeled robot currently being built at the Curtin University of Technology, Western Australia. The vehicle, called the "Hydrobug", is designed to transport three adult passengers over extremely rugged and broken terrain in "walking mode", and when commanded, it will be able to travel quickly over relatively smooth roads and surfaces in "wheeled" or 4-wheel-drive mode. The need for high speed, low cost and useful large scale walking vehicles is highlighted, followed by a brief discussion of the main mechanical design concepts, hydraulic circuit and control architecture for this new type of hybrid walking and wheeled vehicle.

Keywords:
Walking robot, adaptive suspension vehicle, hydraulic servo control, adaptive gait, 3D computer simulation, real-time rendering

1 Introduction

There is an enormous variety of walking robots in the world today. Most of them have six legs to maintain good static stability, many have 8 legs for greater speed and higher load capacity and there are some that implement clever balancing algorithms which allow them to walk on two legs to move over sloping ground and to climb up and down stairs, like humans do (eg. the HONDA robot). In general, the main motive behind the creation of most of these walking machines is to have fun learning about the physics of motion by applying "state of the art" technologies to control the movement of articulated limbs and joint actuators. After all, it is not an easy task to recreate the efficient yet very complex movements of biological insects and mammals which effortlessly execute various types of periodic gait patterns and adaptive gaits and very high speeds. (Visit the CLAWAR web site to view most of the modern walking robots that have been built in recent years).

Unfortunately, due to the very complex and multi-disciplinary nature of this field of research, very few walking robots and multi-legged vehicles have been proven to be the "best and most economical solution" for solving problems in domestic, industrial, construction, military or space applications. It seems as though most of today's small walking robots are only useful for modelling or entertainment value. Also, the majority of large scale 'high-powered' walking