

## ◆ Vehicles

Most mobile robots use either wheels, tracks or legs to move around. The most versatile robots are serpentine (snake-like) robots. These may be used in confined spaces where people cannot fit and where the environment is often unhealthy, such as in mines, tunnels, sewers, and cable ducts.

A major problem faced by all mobile robot designers is the generation and storage of power: umbilical cords restrict motion while providing unlimited power. In contrast free roaming robots are restricted by the amount of energy they can carry and require wireless communication links.



*Mars rover, a wheeled vehicle for rough terrain.*

**Most mobile robots roll on wheels**, which are simpler to control, pose fewer stability problems, use less energy per unit distance of motion, and can go faster than legs. Stability is maintained by ensuring that the centre of gravity of the vehicle is always within a triangle formed by three points touching the ground. Wheeled vehicles are reasonably manoeuvrable, some are able to turn in their own length, and some can move sideways. However, wheels are only usable on relatively smooth, solid terrain; on soft

ground they can slip and get bogged down. In order to scale rough terrain, wheels have to be larger than the obstacles they encounter.

The most familiar wheel layout for a vehicle uses four wheels placed at the corners of a rectangle. Most four-wheeled vehicles have limited manoeuvrability because they have to move in a forward direction in order to turn. Also, a wheel suspension system is required to ensure that the wheels are in contact with the ground at all times.

Three-wheeled vehicles have the advantage that wheel-to-ground contact can be maintained on all wheels without a suspension system. The centre of a three-wheeled vehicle is the centre of the circle defined by the ground contact points of the three wheels. Other variants of the three-wheeled vehicle configuration are found in practice. In one, the single wheel is the drive wheel as well as the steering wheel, enabling the other wheels to idle. Combining drive and steering mechanisms in one wheel results in a more complex mechanical design, and small tolerances can result in noticeable steering errors over a distance of a few meters.

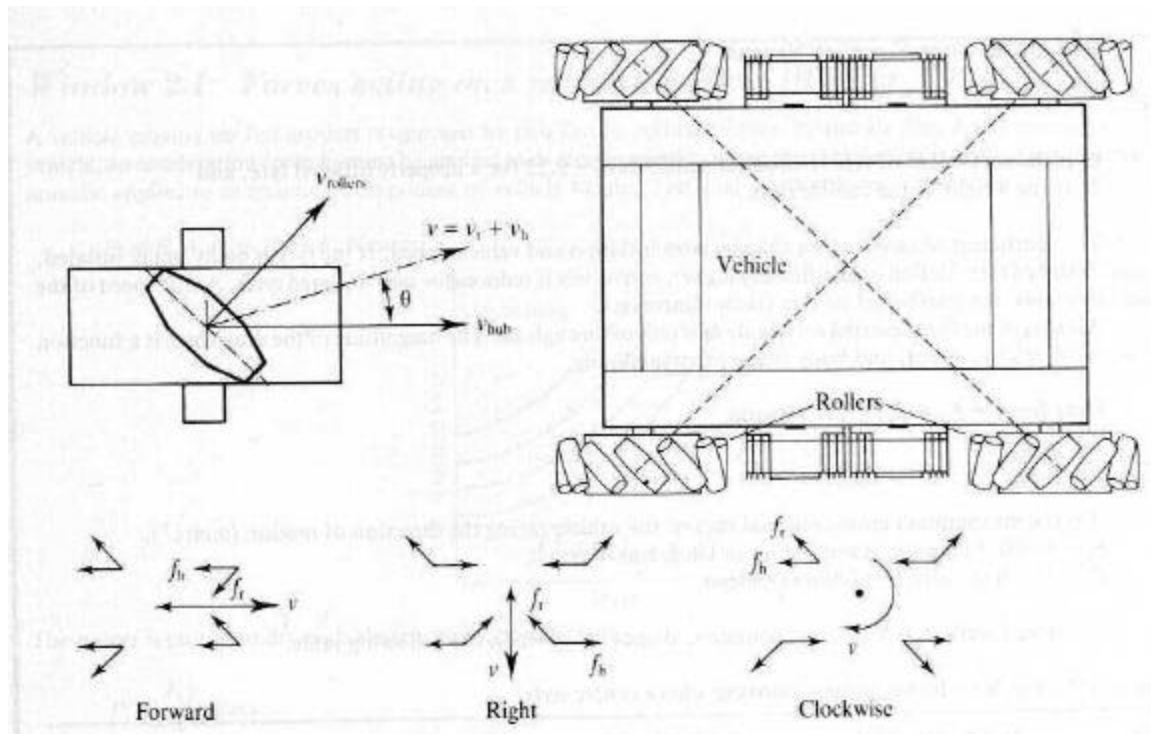
Some wheeled vehicles are capable of sideways motion. They use wheels which consist of a circular hub surrounded by rollers. On the Stanford wheel, the rollers are perpendicular to the axis of the hub and on the *Illanator* wheel, the rollers are at 45 degrees to the axis of the hub. In both cases, the hub is driven, and the rollers idle.

An *Illanator* wheel as used on the Carnegie-Mellon robot *Uranus*, can rotate about the hub with the rollers still, or move at 45 degree with the hub still and the roller in contact with the ground spinning. Left-handed and right-handed arrangements of the wheel are possible, where left or right is the direction the wheel will move with only the rollers spinning. Motion in other directions involves rotation of both the rollers and the hub. The velocity of the wheel can be resolved into two components one perpendicular to the axis of the wheel ( $\theta = 0$ ), and one perpendicular to the axis of the rollers ( $\theta = 45$ ). Similarly, the force applied to the ground by the wheels can also be resolved into components.

*Uranus* uses four wheels, two left-handed and two right-handed, and requires a suspension system. The wheels are arranged so that the diagonal lines through the wheel contact points intersect at the centre of the vehicle. Thus, the wheel contact points form a square. With these wheels, the vehicle can still move forwards or backwards if a roller jams. A disadvantage of *Illanator* wheels is that drive efficiency is poor when moving in a lateral direction, because vehicle movement is at 90 to the direction of rotation of the hubs.

*Uranus* moves forward and backward in the conventional manner, with the hubs rotating and the rollers still. To move laterally, diagonal pairs of wheels are driven in opposite directions. The robot can move at 45 to the forward direction, by driving one pair of diagonal wheels and holding the other pair still. The vehicle is omni-directional and can translate in any direction. If the magnitudes of the wheel velocities are equal and the pair of wheels on the right side of the robot rotate in the opposite direction to the pair on the

left side then the robot spins around its centre. Other combinations of wheel speeds result in circular trajectories – the natural trajectory for this platform. Many trajectories rely on friction to cause the rollers to rotate, otherwise the rollers would have to slide laterally on the ground. Again, the forces applied to the ground by the wheels sum to produce a force vector which determines the motion of the robot. As the platform has three degrees of freedom, only three of the four wheel velocities can be assigned independently.



*Uranus robot built at Carnegie-Mellon University using Illanator wheels*

Several designs are used for robots that traverse rough terrain. Tracked vehicles, like bulldozers, handle rough terrain very well, but can damage the environment, particularly when turning. There are many places on the surface of the earth where wheeled and tracked vehicles cannot go, but people and animals can. While more difficult to build and control than the wheeled vehicles, **legged robots** have a number of advantages :

- can step over obstacles
- can walk up and down stairs.
- can give a smooth ride over rough ground by varying the effective length of their legs to match the surface undulations.

Legged robots are grouped into two classes : dynamically and statically stable systems. For static stability, at least three feet must be firmly placed on the ground and the centre of gravity of the vehicle must be within the triangle formed by the feet contact points. Dynamic stability is essential for vehicles with less than three feet, and useful for multi-legged vehicles. It is achieved by moving either the body or the feet to maintain the

centre of gravity within the area described by the contact points between the feet and the ground.



*Hexaped legged robots*

In some industrial flexible manufacturing systems (FMSs) parts are carried from one work cell to another by conveyors or by **automated guided vehicles (AGVs)**.



*Automated Guided Vehicle (AGV) developed  
In the SMRLab at the University of Ottawa*