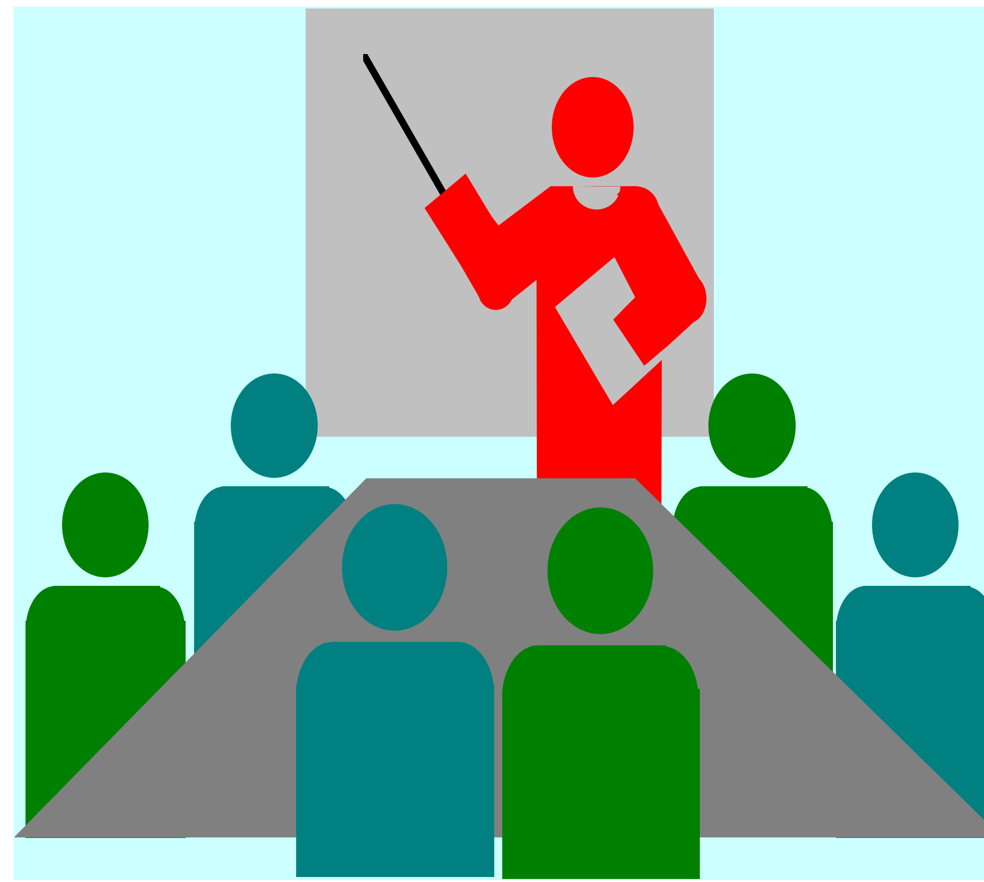
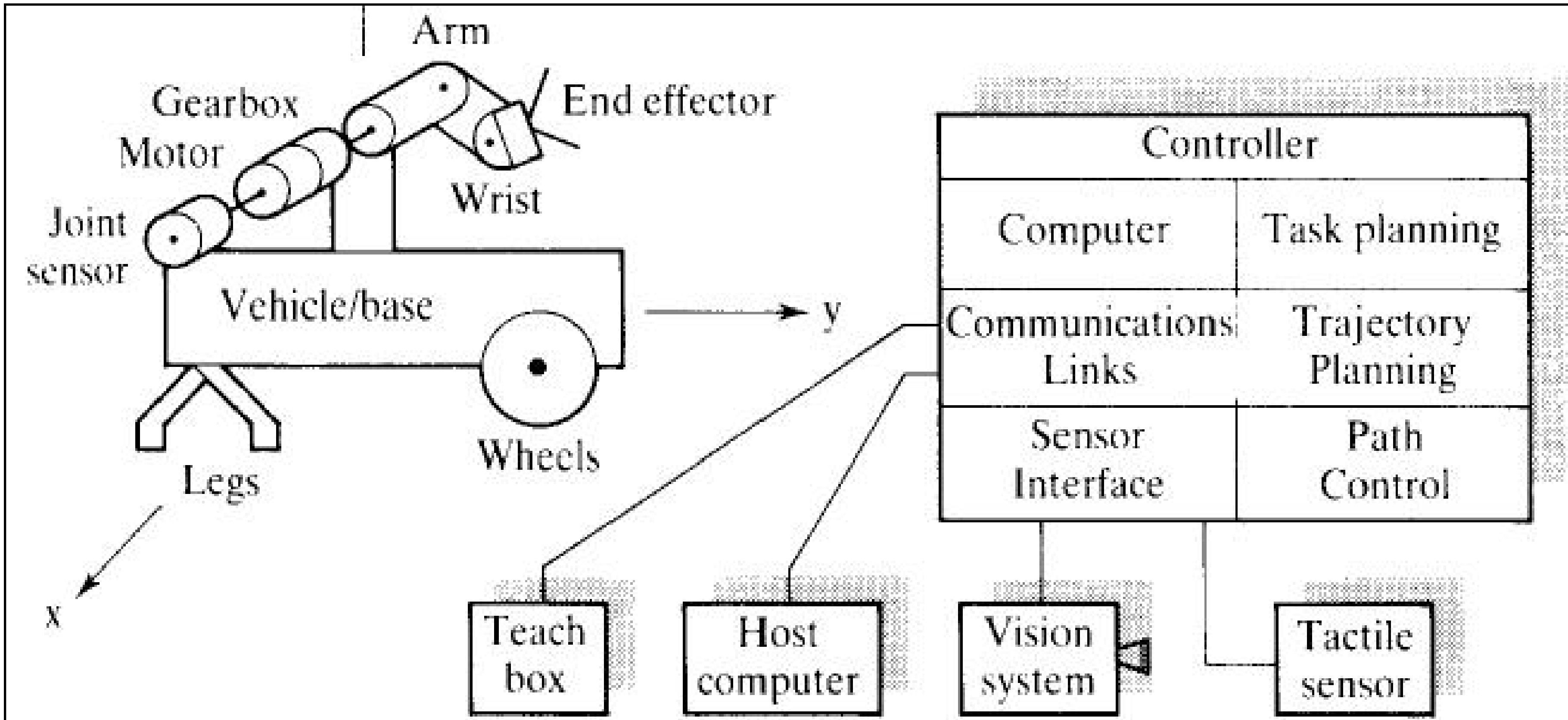
Topic 3: Robot Platforms and Mobility



3.1 Introduction

Physical parts of a mobile robot



3.1 Introduction – Typical Robot Platform

- ***<u>Landed mobile robots</u>***

  <u>Wheeled/tracked mobile robots:</u>

  - They are common robotic systems in the real-world applications today.
  - They are used both indoor and outdoor- simple to control, faster than legs.

  <u>Legged mobile robots:</u>

  - able to walk around rough ground, up-down stairs, over obstacles , etc.
  - However, they are more difficult to control.

- ***<u>Flying mobile robots</u>***

  - Flying mobile robots have many DOFs and are difficult to control in comparison with the wheeled or tracked robots.

- ***<u>Underwater mobile robots</u>**:*

  - Underwater is an extremely difficult environments for robots.
  - More difficult to control comparing with the wheeled or tracked robots.

3.1 Introduction

Some basic terminologies:

- Locomotion – the process of causing an autonomous robot to move.
  – Forces must be applied to the robot in order to produce motion.

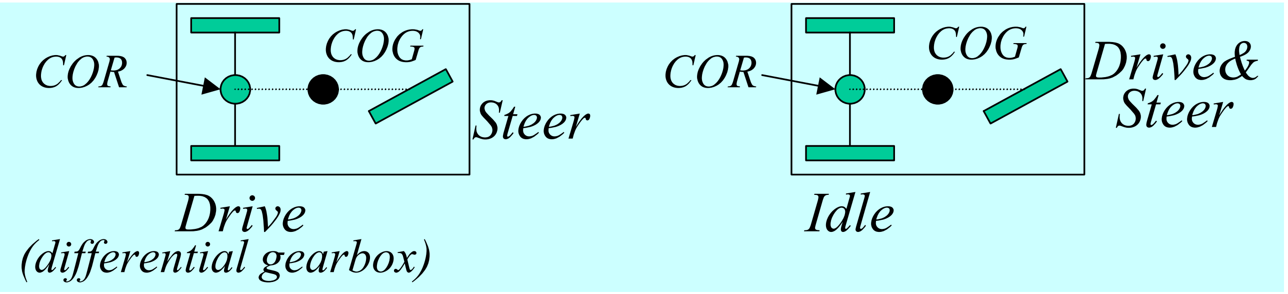
- Dynamics – the study of motion in which forces are modelled.
  – Includes the energies & speeds associated with these motions.

- Kinematics – the study of the mathematics of motion without considering the forces that affect the motion
  – To deal with the geometric relationships that govern the system
  – To deal with the relationship between control parameters and behaviour of a system in state space.

3.2 Wheeled Mobile Robots

3.2.1 Tricycle Drive Mobile Robots

- Achieve wheel-to-ground contact without a suspension system.
- The Centre-of-Rotation (***COR***) is located at the midpoint of rear axle.
- Able to turn at the centre of rotation without moving forward.
- Two rear wheels must rotate at different speed during turning.
- The robots are 2-degree-of-freedom platform (2 control valuables).



There are two main configurations of tricycle mobile robots:

- Rear-wheel driven and front wheel steering
- Single front wheel driven and steering

3.2.1 Tricycle Drive Mobile Robots

- Let V be the robot velocity, the robot heading, the steering angle, R the wheel radius, and B the wheelbase (.
- Assume that the robot has the front driven speed (radian/s) and the steer angle (radian).

<u>kinematics equations</u>

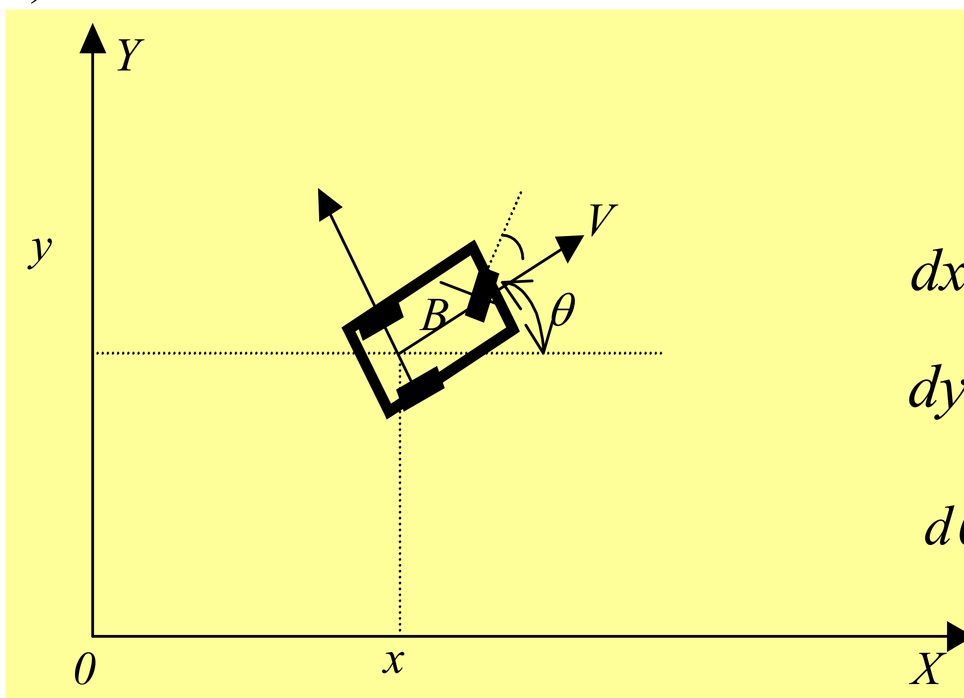
$$V = R\omega \cos\alpha$$

$$V_b = R\omega \sin\alpha$$

$$\dot{x} = V \cos\theta$$

$$\dot{y} = V \sin\theta$$

$$\dot{\theta} = V_b / B$$



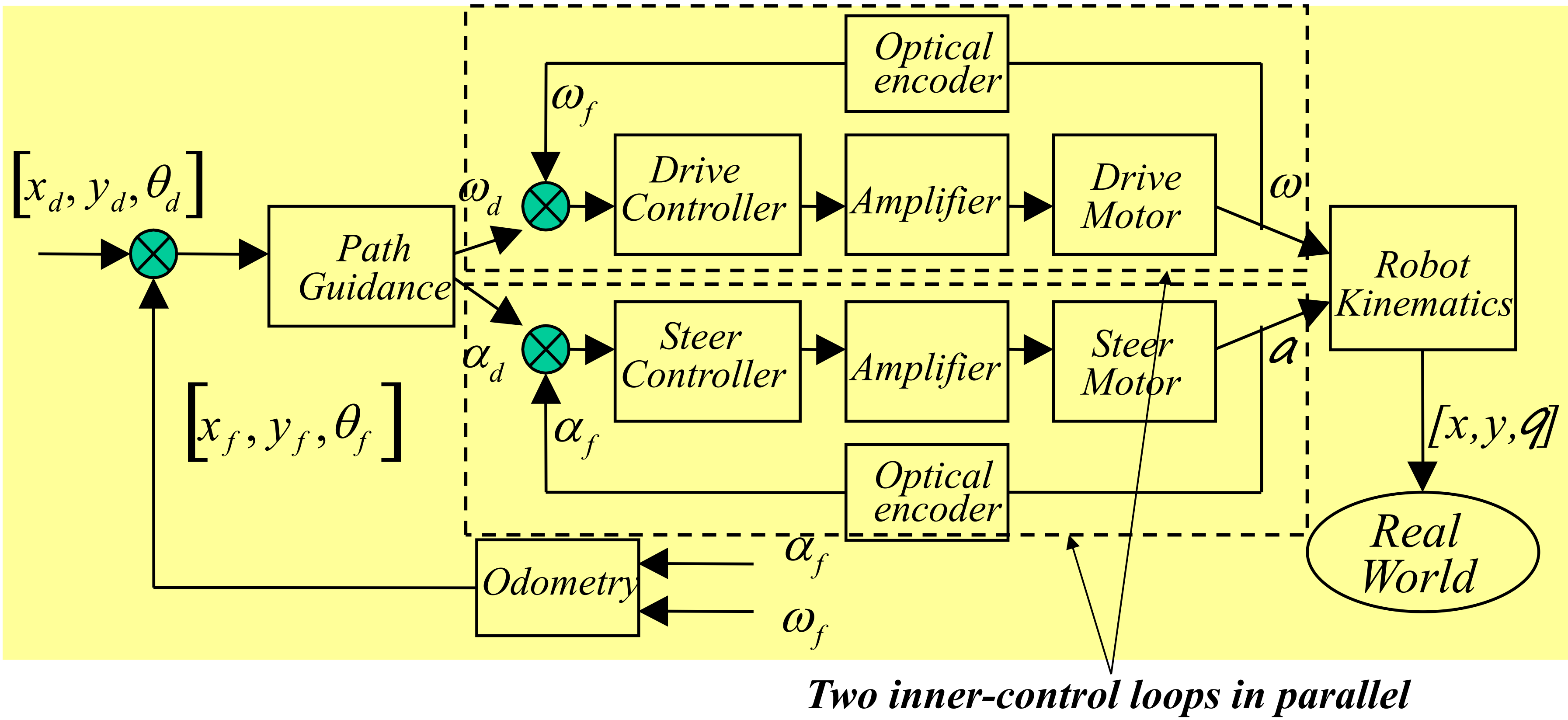
$$dx = V \cos\theta \bullet dt$$

$$dy = V \sin\theta \bullet dt$$

$$d\theta = (V_b / B) \bullet dt$$

3.2.1 Tricycle Drive Mobile Robots

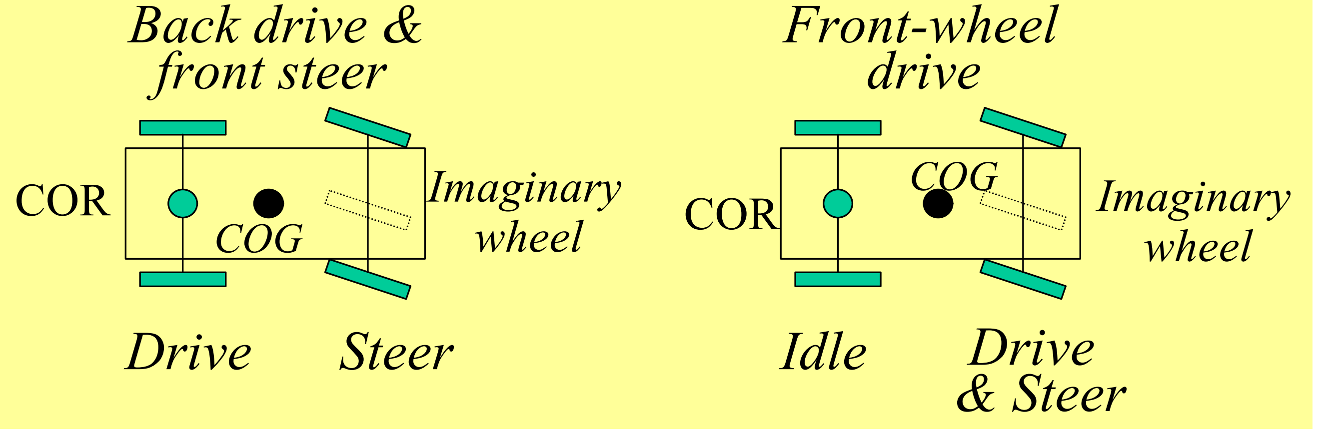
A simple block diagram of the motion control for both tricycle and car-like mobile robots



3.2.2 Car-like Mobile Robots

Main features:

- Limited manoeuvrability -- move forward/backwards to turn (nonholonomic).
- Inside wheels rotate slower than outside when turning corners.
- Needs a suspension system to keep 4 wheels to ground contact.
- They are 2-degree-of-freedom vehicles (2 control valuables).

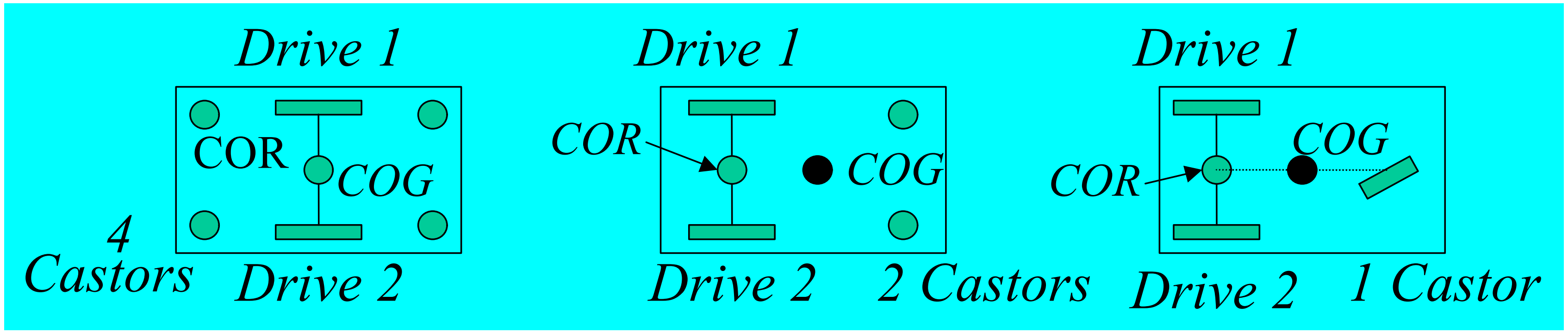


Note: *Car-like mobile robots have similar kinematics equations and control system to tricycle mobile robots, which are given in the previous three slides.*

3.2.3 Differential Drive Mobile Robots

Main features:

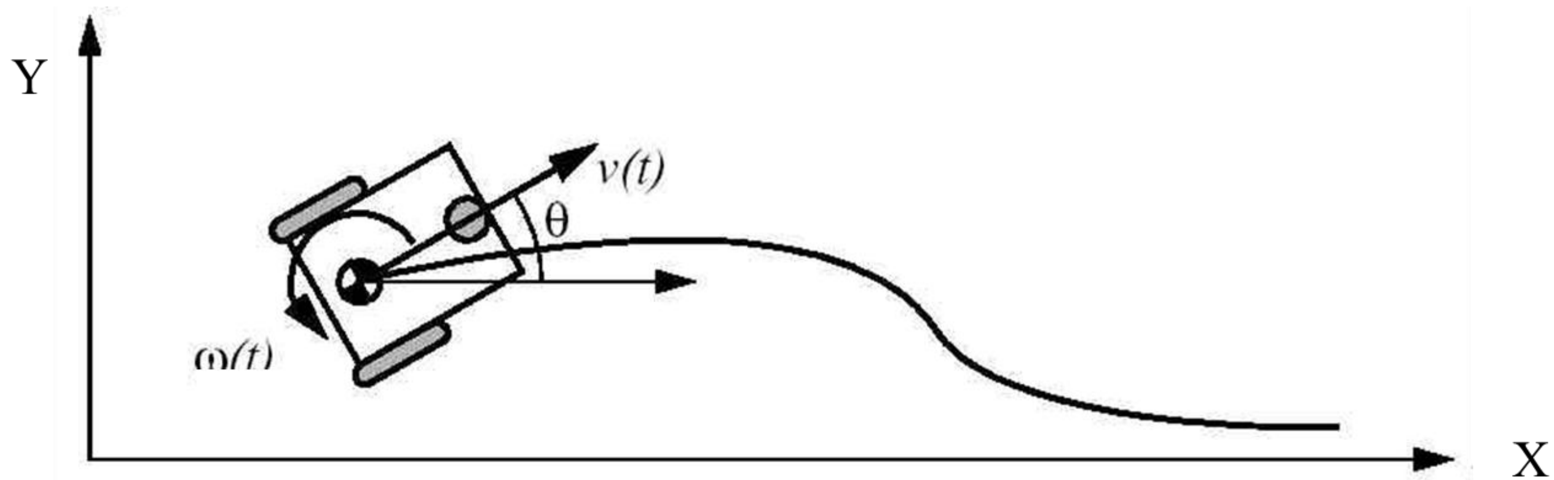
- Two wheels are driven independently & other wheels are castors.
- Steering is accomplished by driving the wheels at different speeds.
- The robot can turn around the centre of rotation (ROF).
- The robots are 2-degree-of-freedom platforms(2 control valuables).
- Castors are used to achieve stability.



3.2.3 Differential Drive Mobile Robots

Kinematics equations:

$$\dot{x} = \frac{V_l + V_r}{2}\cos\theta, \quad \dot{y} = \frac{V_l + V_r}{2}\sin\theta, \quad \dot{\theta} = \frac{V_r - V_l}{W}$$



Discrete form

$$dx = \frac{V_l + V_r}{2}\cos\theta * dt, \quad dy = \frac{V_l + V_r}{2}\sin\theta * dt, \quad d\theta = \frac{V_r - V_l}{W}dt$$

3.2.3 Differential Drive Mobile Robots

3.2.3 Differential Drive Mobile Robots

Odometry calculation:

$$x(k+1) = x(k) + \Delta x$$
$$y(k+1) = y(k) + \Delta y$$
$$\theta(k+1) = \theta(k) + \Delta\theta$$

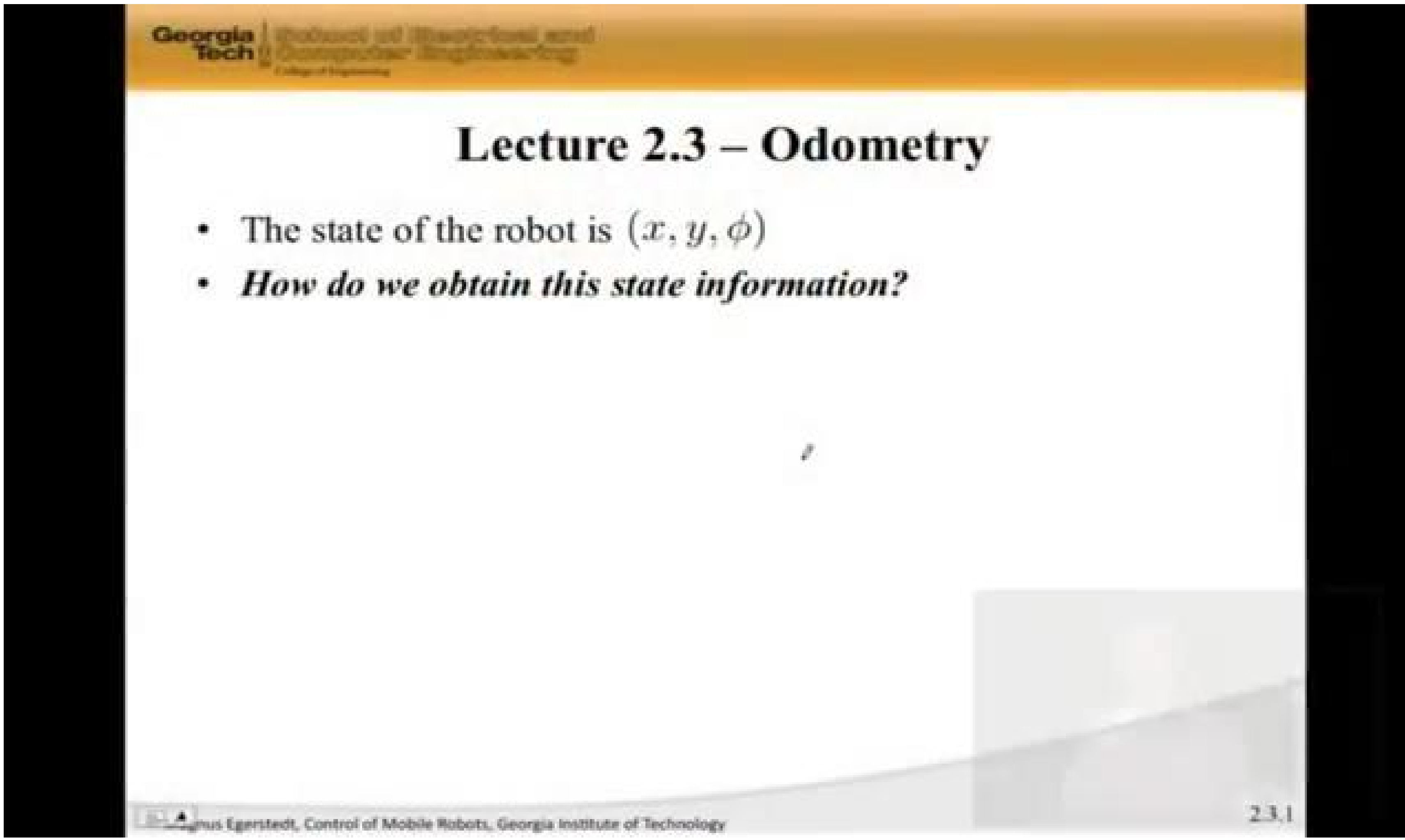
$$x(k+1) = x(k) + \frac{V_r + V_l}{2} \cos\theta * \Delta t$$
$$y(k+1) = y(k) + \frac{V_r + V_l}{2} \sin\theta * \Delta t$$
$$\theta(k+1) = \theta(k) + \frac{V_r - V_l}{W} * \Delta t$$

Question: We assume $v_l = 10cm/s$; $v_r = 8cm/s$; $W = 40cm$; $\Delta t = 1$

$x(0) = 100cm$; $y(0) = 50cm$; $\theta(0) = \pi/4$

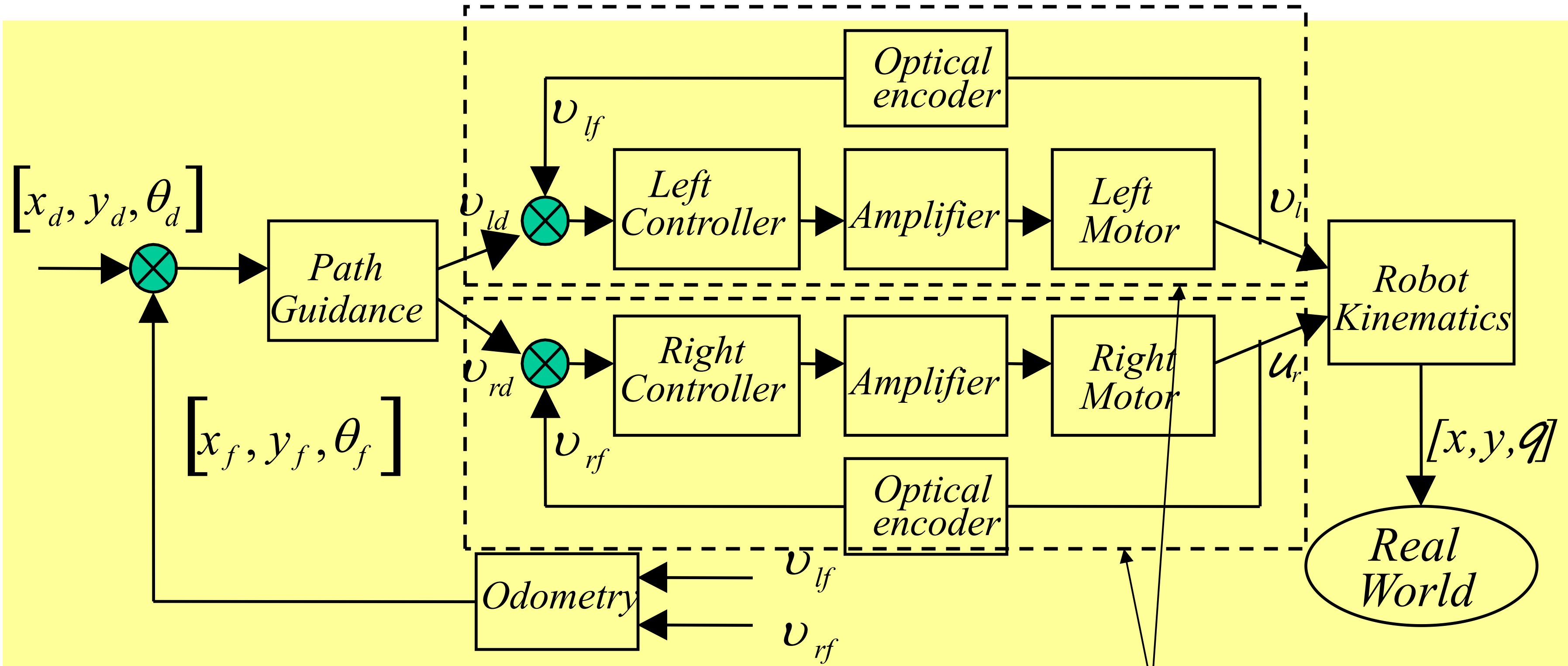
Write C code to calculate the robot trajectory (*k=0,1,2,3,4,5,6,7,8,9,10*) using the odometry equations above.

3.2.3 Differential Drive Mobile Robots



3.2.3 Differential Drive Mobile Robots

A simple block diagram of the motion control system for differential drive mobile robots

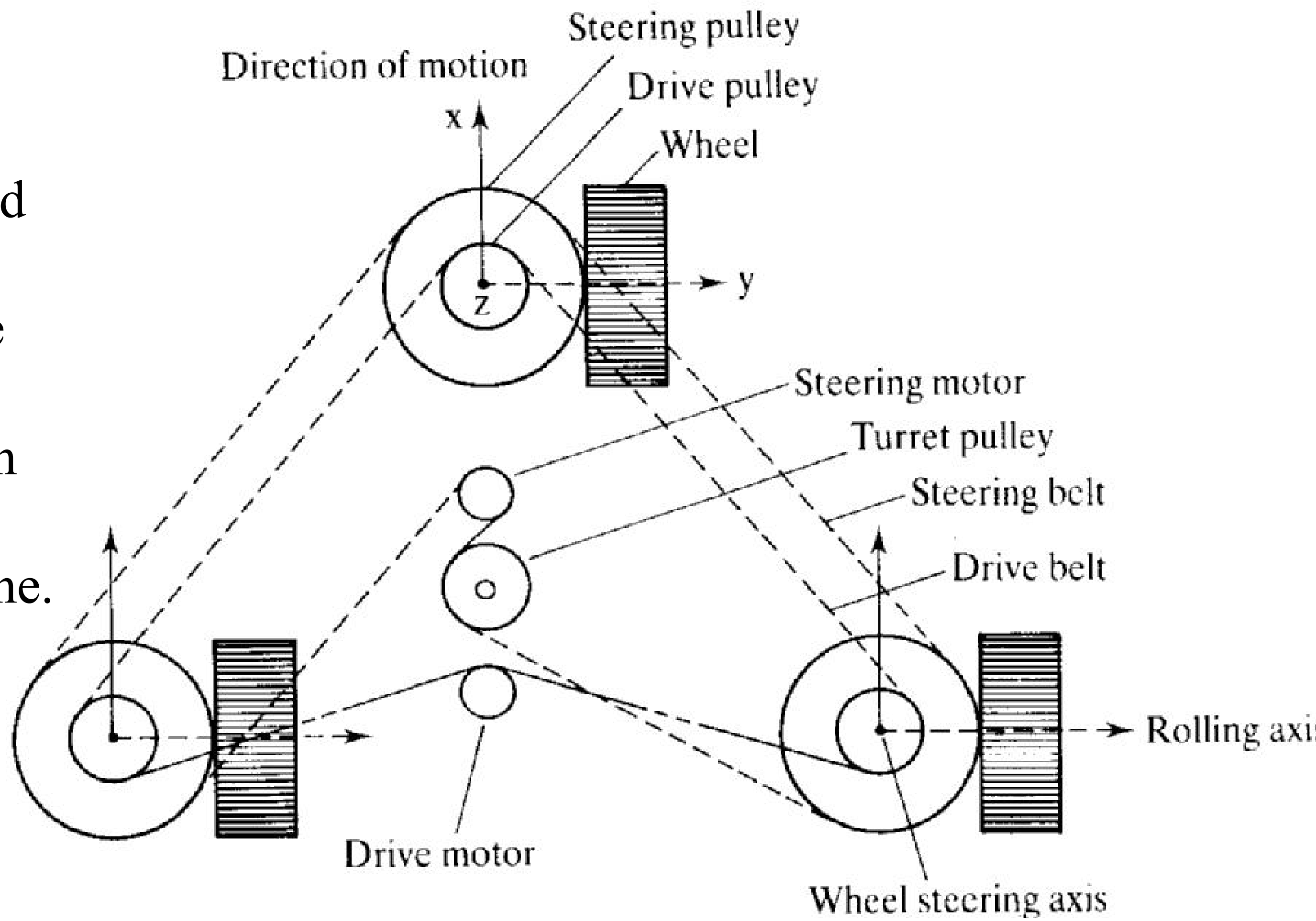


Two speed-control loops in parallel

3.2.4 Synchros Drive Mobile Robots

Main features:

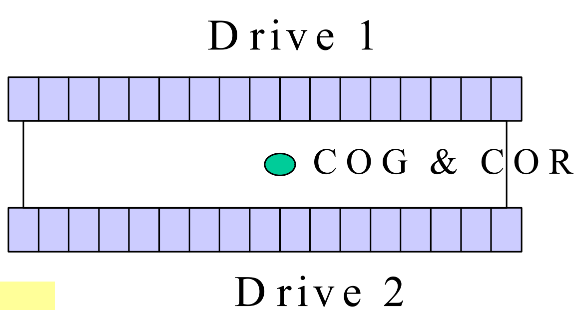
- All wheels (three or more) are mechanically coupled by a chain, belt, or gear drive to achieve synchronisation.
- All wheels are driven by one motor and steered by another one.
- The robot's body keeps a fixed orientation to the external world.



3.2.5 Tracked Drive Mobile Robots

Main features:

- They are able to traverse rough terrain and smooth ground.
- They are 2-degree-of-freedom vehicles and are differentially driven.
- Their skid-steering operation provides rather poor odometry.



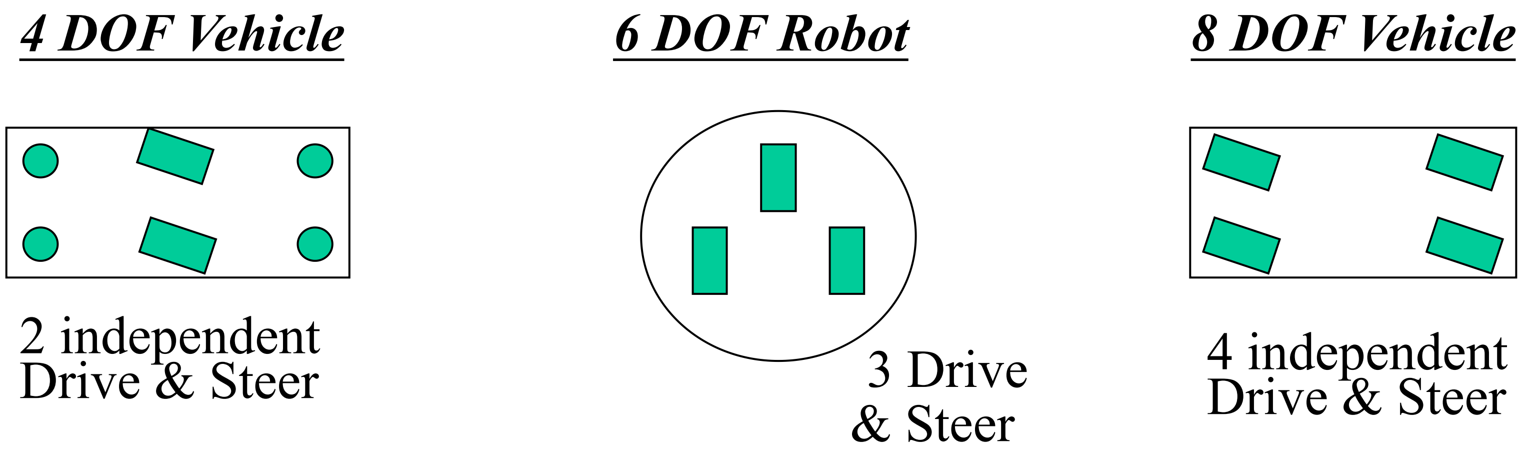
Kinematics equations:

$$V_0 = \frac{V_l + V_r}{2}, \quad \dot{x} = V_0 \cos\theta, \quad \dot{y} = V_0 \sin\theta, \quad \dot{\theta} = \frac{V_r - V_l}{W}$$

3.2.6 Multi-Degree-of-Freedom Vehicles

Main features:

- Multiple drive and steer motors (multiple-degree-of-freedom)
- Exceptional maneuverability in tight quarters.
- Difficult to control and coordinate multiple motors.



3.3 Legged Walking Robots

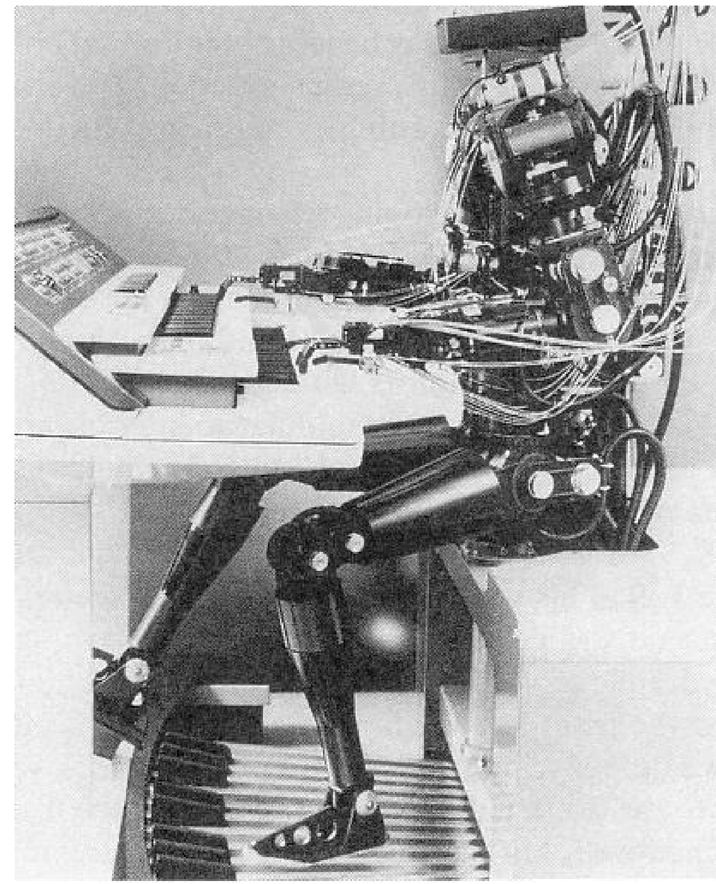
3.3.1 One-legged robot:

- It was built at CMU, consisting of a circular body with a cylindrical leg.
- The leg and body are connected by a gimbal joint that forms a hip.
- A pair of linear hydraulic actuators control the angles between the body & leg.

3.3.2 Two-legged Walking Robots

Main features:

- Two-legged walking robots can step over obstacles.
- They can walk up and down stairs like human.
- They can step over trenches and uneven ground.
- They can give a smooth ride over rough ground by varying the effective leg length to match the surface undulations.
- They are coupled with scientific curiosity.



3.3.2 Two-legged Walking Robots

However- Legged walking robots are more difficult to construct and control than wheeled mobile robots.

Hitec Robonova I

HRP-2 HRP(Kawada)

RoboSapien is a toy-like robot

Honda Asimo

Sony Qiao robot

3.3.2 Two-legged Walking Robots

Boston Atlas

3.3.3 Multi-legged Walking Robots

Remotely controlled Robot Crab made in Japan

The EH2 Walker Kit is a twelve servo hexapod featuring two degrees of freedom (DOF) per leg.

3.3.3 Multi-legged Walking Robots

In summary, Legged walking robots are grouped into two classes:

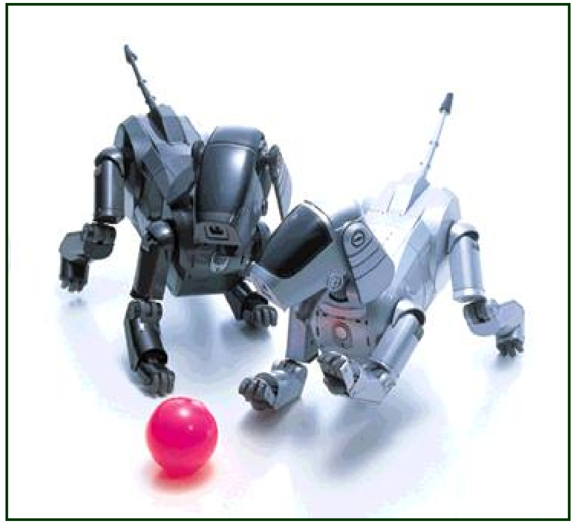
- *Static stable systems -- three or more legs*

  This requires at least three feet must be firmly placed on the ground and the center of gravity of the robot must be within the triangle formed by the feet contact points.

- *Dynamic stable systems – one or two legs*

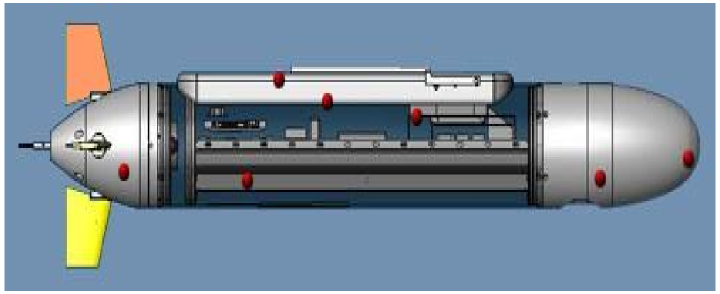
  ➢ Since robots have only one or two legs, they need balance themselves before walking around.

  ➢ Dynamic stability is achieved by moving either the body or the feet to maintain the center of gravity within stable area.



3.4 Underwater Robots

- Military interest in the undersea activities.
- Underwater environments are not human-friendly.



Autonomous Underwater Vehicle

A solar-powered underwater robot

The "Fetch2" AUV can discriminate between different types of fish.

3.4 Underwater Robots

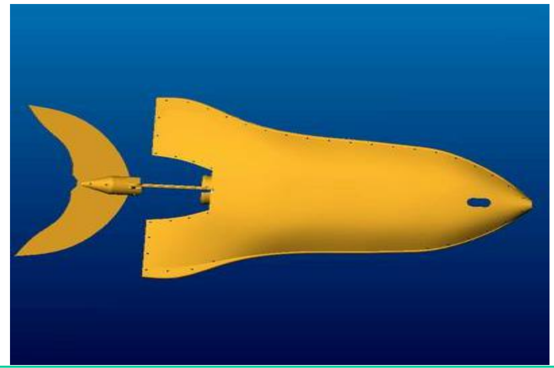
Inspired by the coordination of bird flocks and fish schools, oceanographers will launch this month an entire fleet of undersea robots in Monterey Bay, California.

The goal of this program is to make detailed and efficient observations of the ocean

3.4 Underwater Robots

Biomimetic Robots

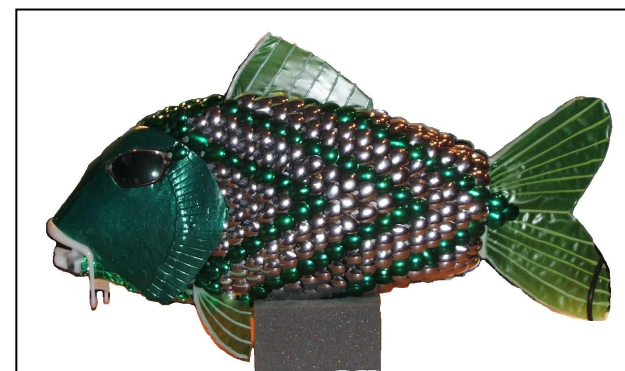
- Civilian activities driven by profound economic implications, including the exploring deep-sea life and mineral resources.
- Military interest in the undersea activities.
- Monitor underwater environments.



SPC at BUAA, China

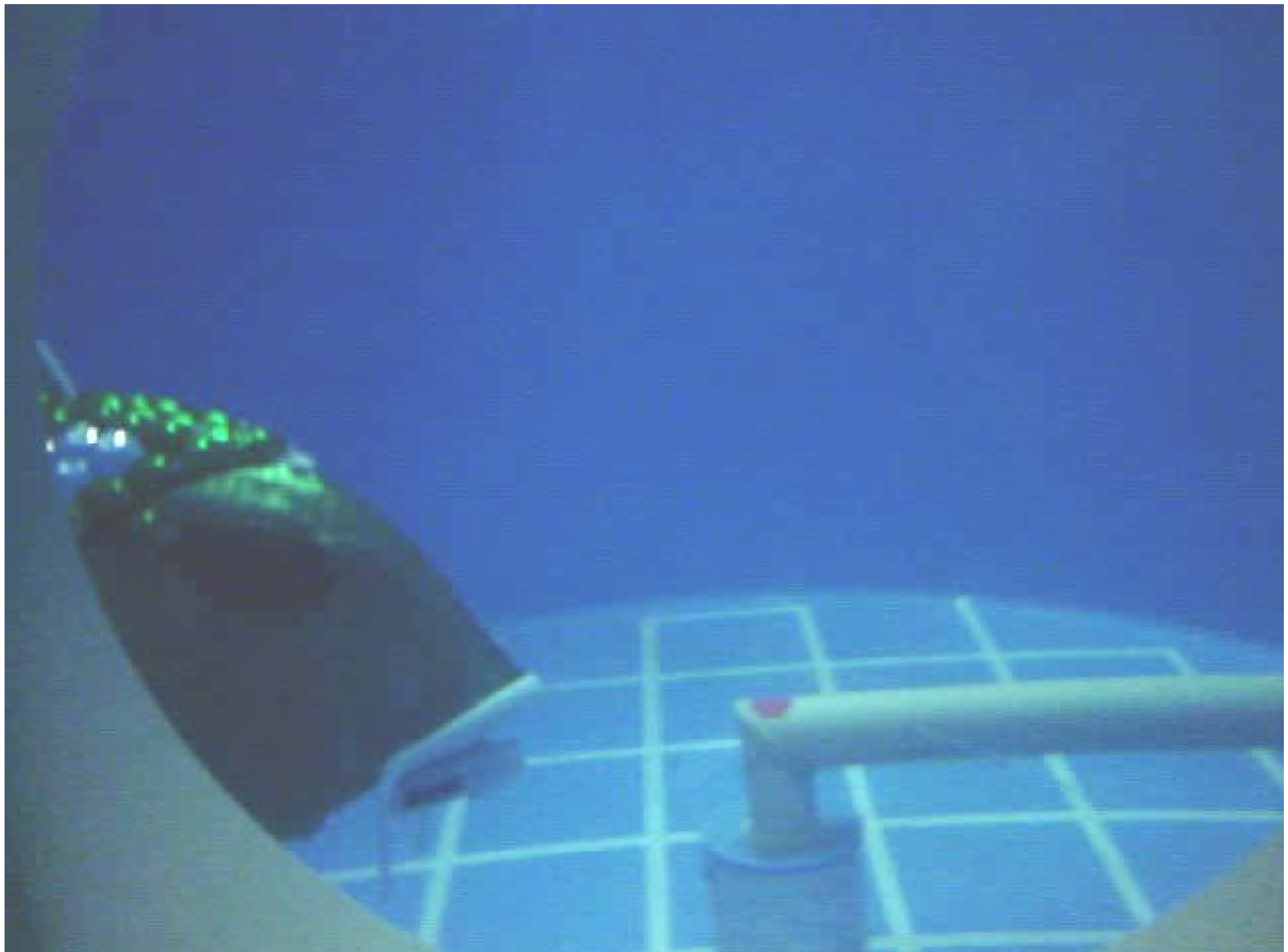
Robotuna built at MIT

ACM-R5, Japan



G9 robot fish built at Essex

3.4 Underwater Robots



Essex Robotic Fish

3.5 Flying Robots

Military needs such robotic systems, such as autonomous rapid refueling, weapon loading and decontamination.

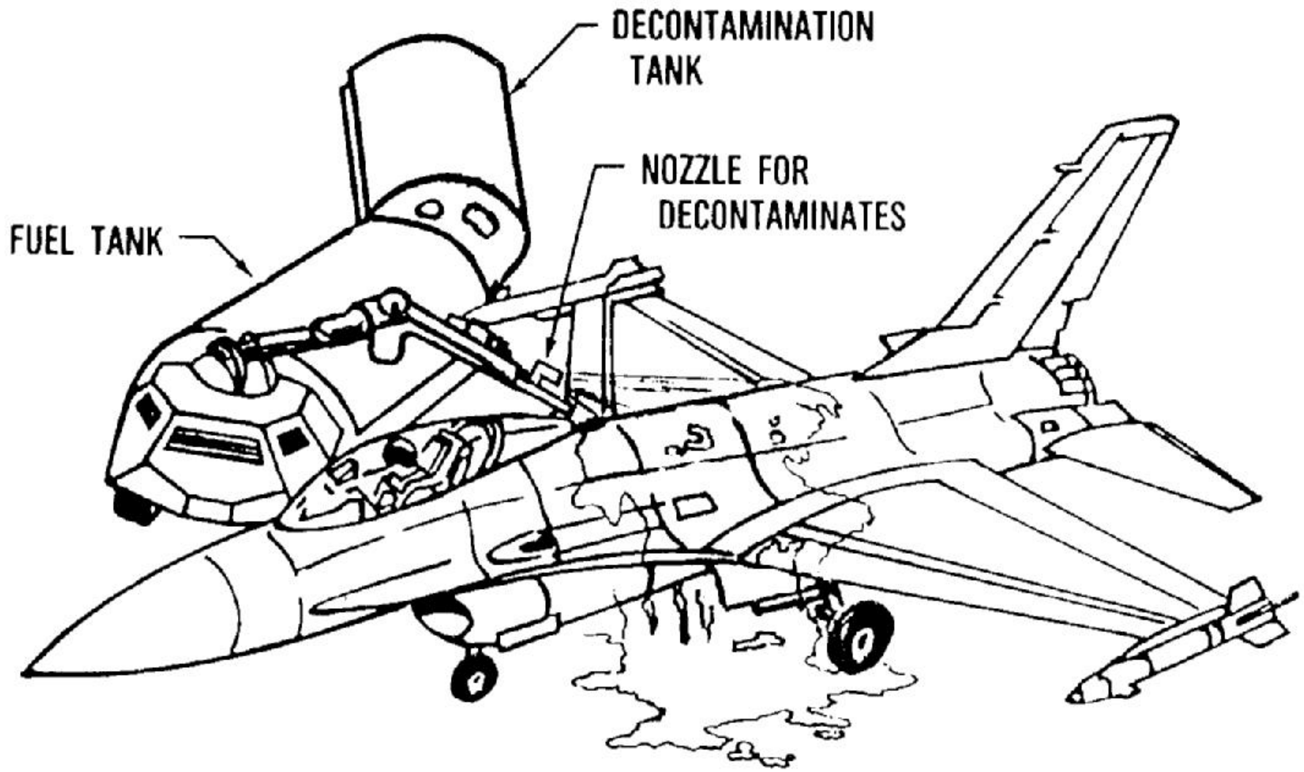
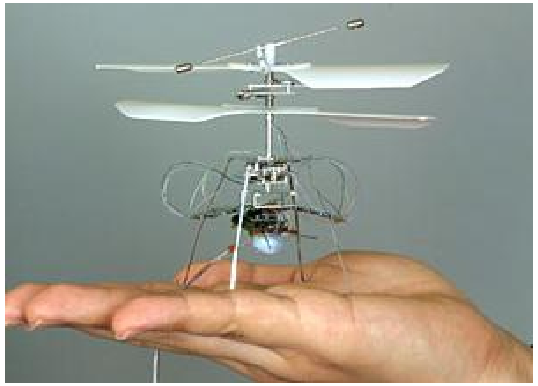


Figure 15.1.6 *Robotic decontamination (US Air Force)*

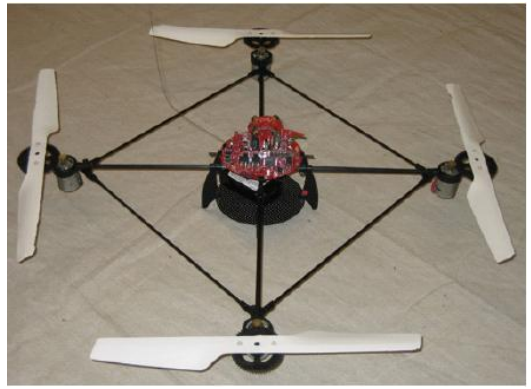
3.5 Flying Robots

Civilian aircraft

servicing will demand such robotic systems for cost effective solution, such as rescue flying robots.



Seiko Unveils Mini indoor Flying Machine



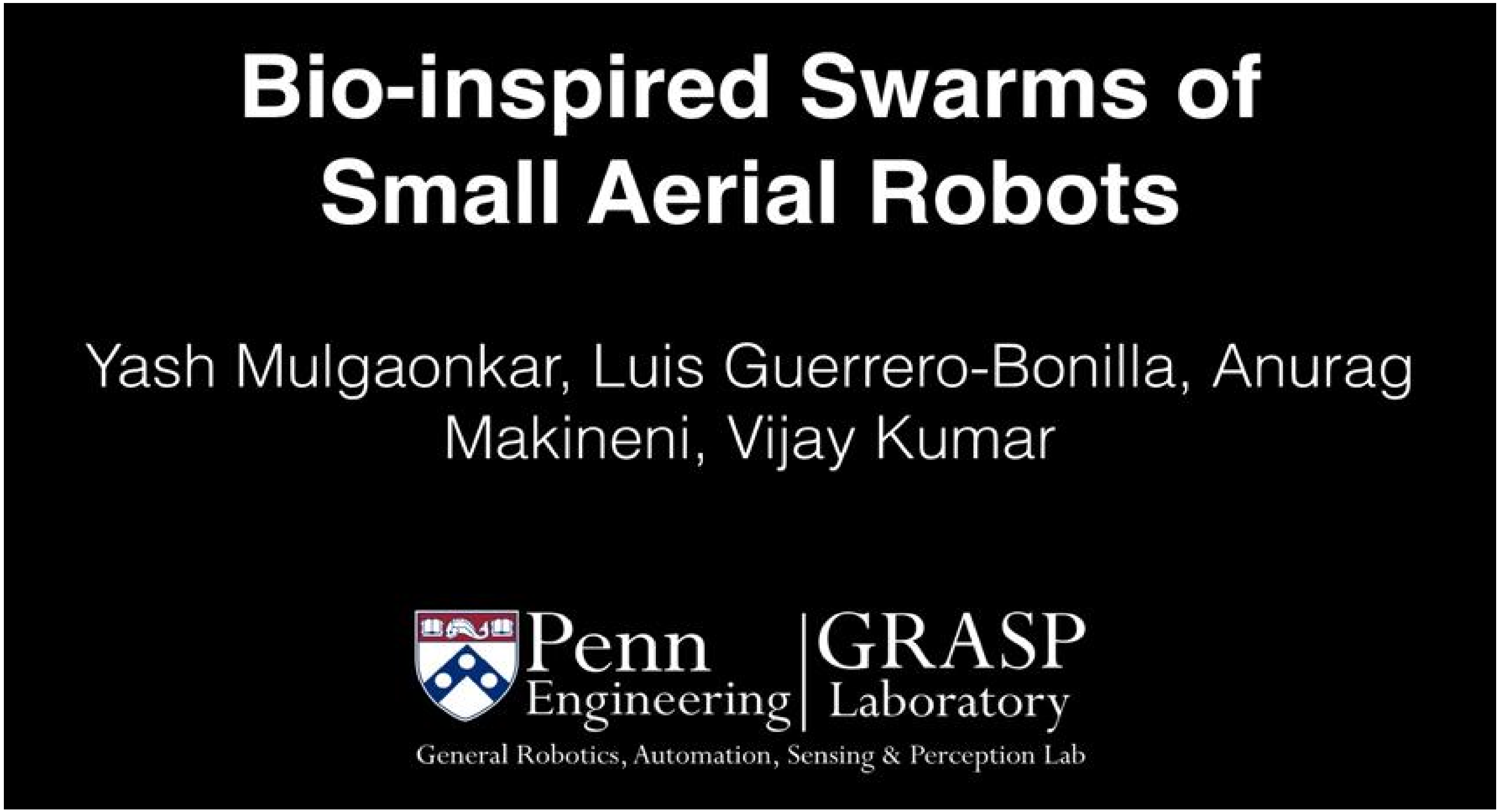
An indoor Autonomous Flying Robot - DraganFly

Blimp - free-flying model airship

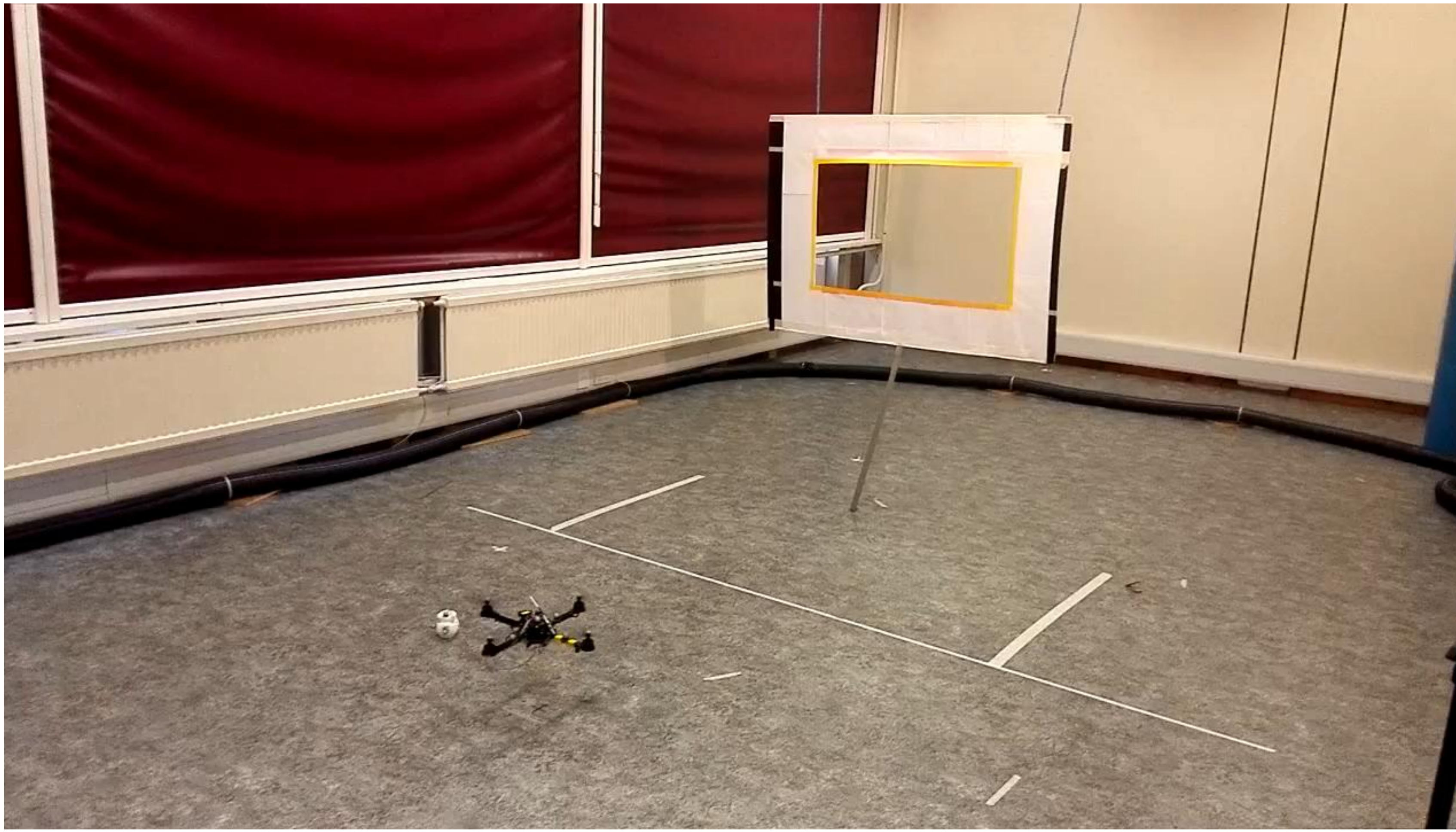
Blimp - free-flying model airship

A. Helios

3.5 Flying Robots



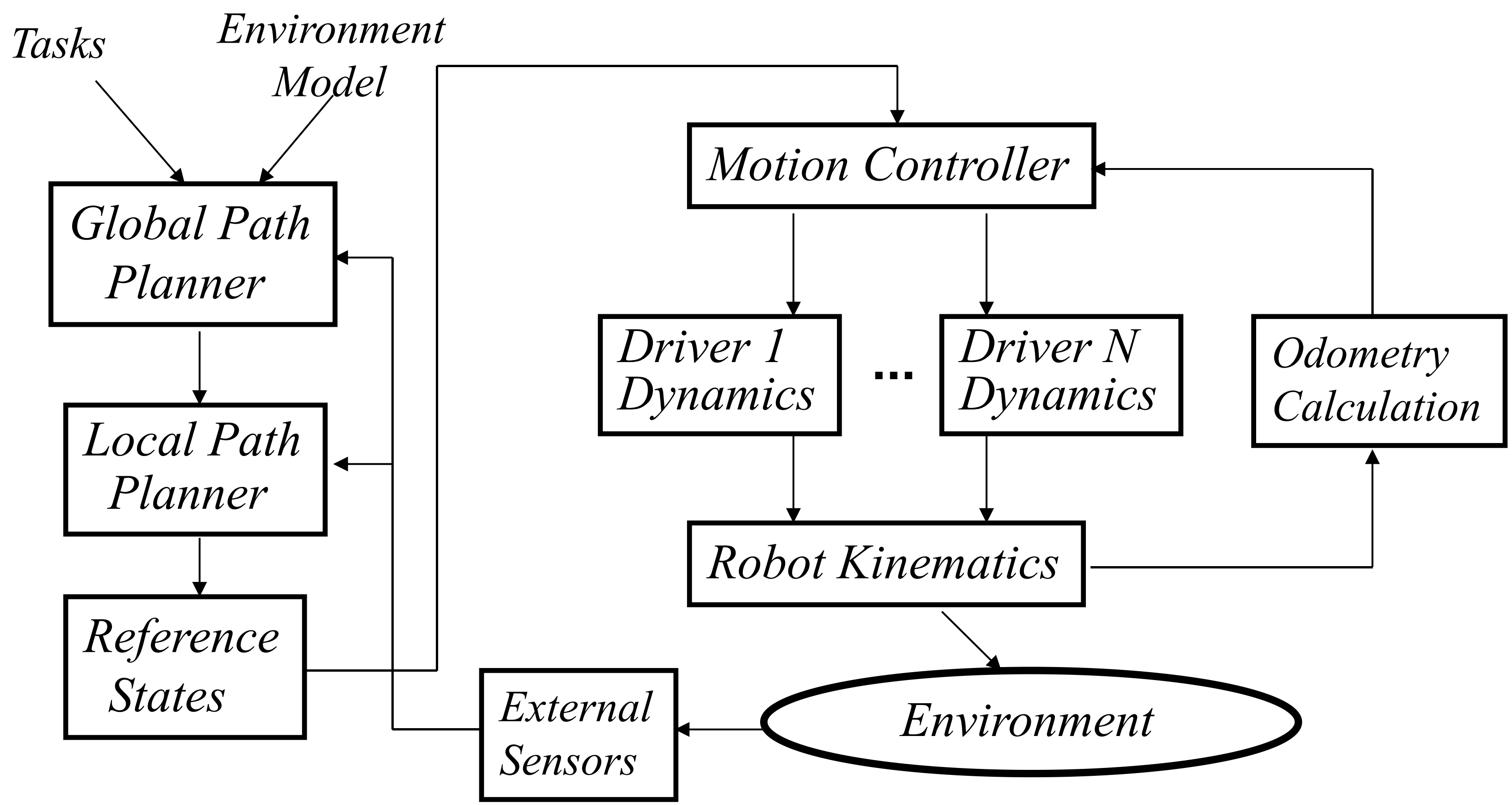
3.5 Flying Robots



Essex Drone

3.6 Robot Guidance and Control

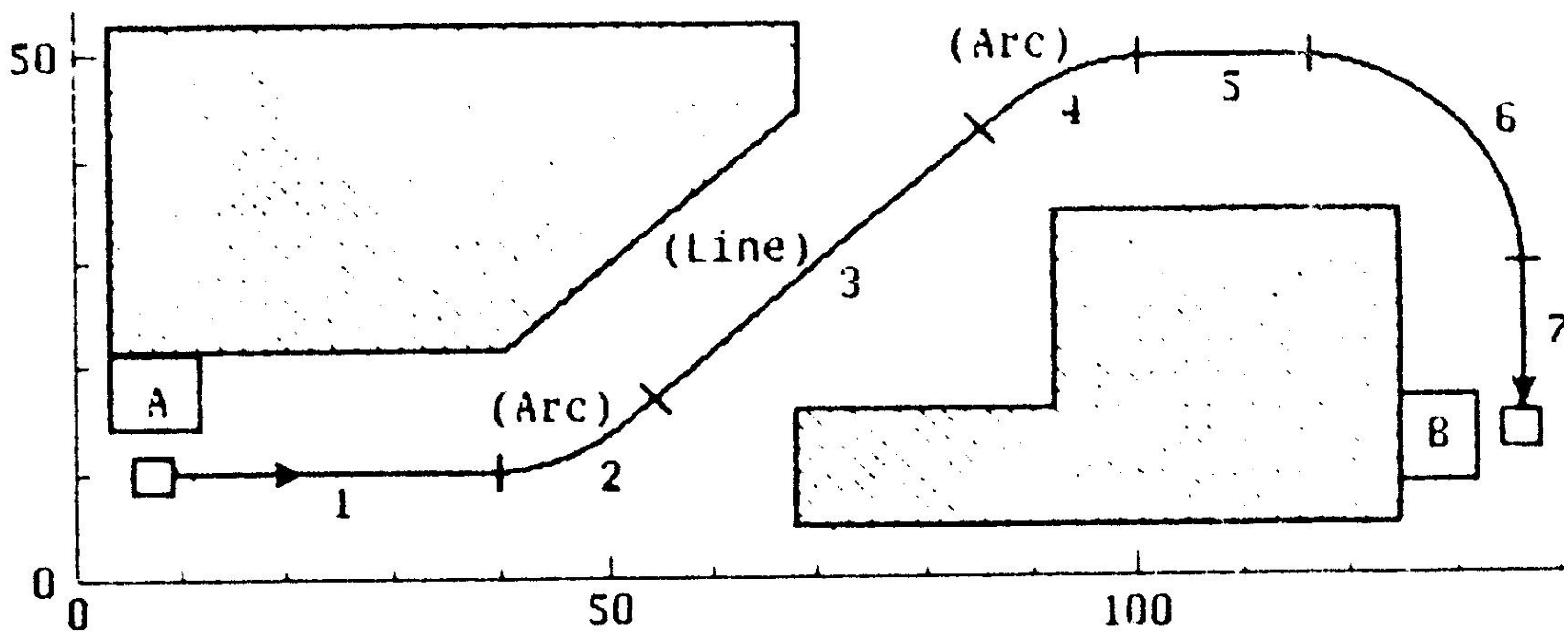
A typical guidance control system for mobile robots:



3.6 Robot Guidance and Control

Example:*Path guidance*

Suppose that the mobile robot is commanded to move from A to B. The path consists of 7 segments, including lines and arcs, as shown in the figure below.



3.6 Robot Guidance and Control

Example: Path guidance

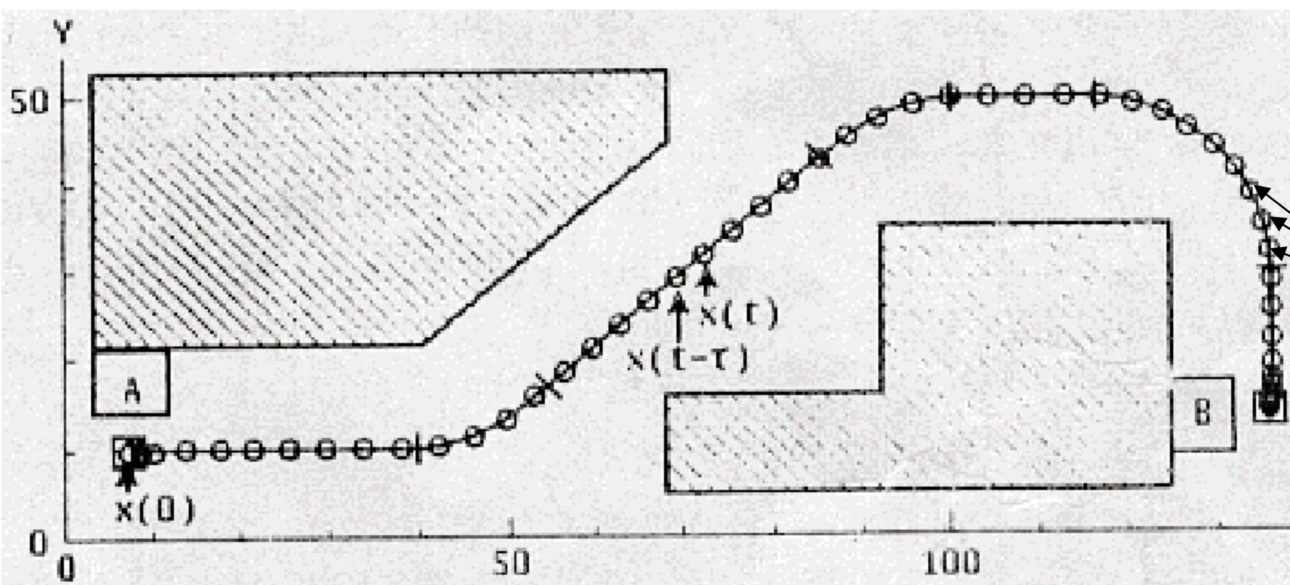
Robot state vector

$$\mathbf{X}_d(\mathbf{k}) = \begin{bmatrix} x_d(k) \\ y_d(k) \\ \theta_d(k) \\ v_d(k) \end{bmatrix}$$

Segment Number	Segment Type *	Desired End State x_d	y_d	θ_d	v_d
1	1	40.00	10.00	0.00	0.50
2	2	56.97	17.03	45.00	0.50
3	1	83.03	42.97	45.00	0.50
4	2	100.00	50.00	0.00	0.50
5	1	116.20	50.00	0.00	0.50
6	2	136.20	30.00	-90.00	0.40
7	1	136.20	14.22	-90.00	0.00

* 1 = line, 2 = arc

Path plan data produced by A Global path planner



A sequence of the reference states for the robot path guidance

3.7 Conclusions and Questions

Conclusions:

- The mobility of a mobile robot is depended on the configuration of its platform.
- A mobile robot is static stable when its centre of gravity (COG) lies within a polygon formed by the contact points between the robot and the ground.
- The centre of rotation (COR) is key for the motion guidance of the robot.
- Odometry calculation is based on the robot mobility configuration, i.e. the kinematics equations of the mobile robot.

Questions:

- Tabulate the advantages and disadvantages of different wheeled & legged robots.
- What is the basic computer feedback control system to integrate sensors and actuators for low-level motion control of a mobile robot with 6 DOFs?
- Using C/C++ to write a subroutine for odometry calculation of a differential drive mobile robot.