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WEEK 8: ROBOTICS

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Topic 9: Intelligent Robot

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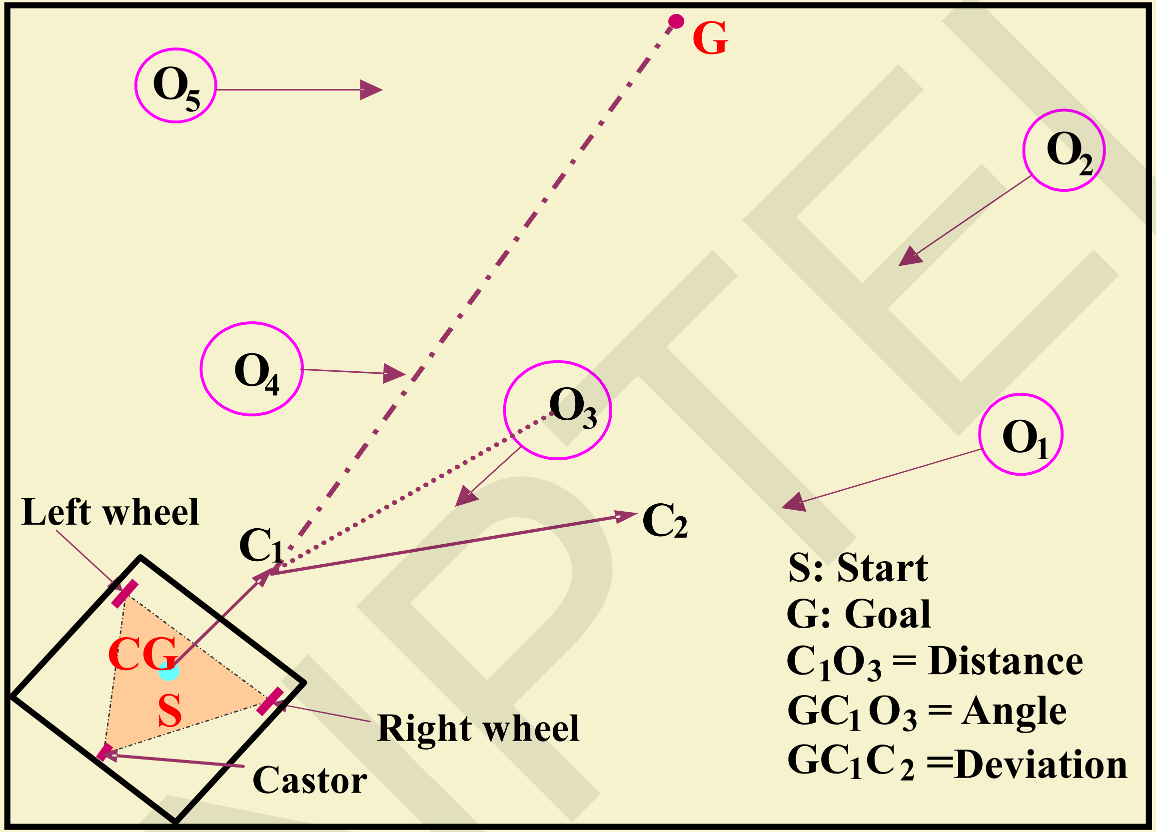
Introduction

- **Intelligent Robot** – Adaptive Motion Planner & Controller (AI to be merged with Robotics); Ex. Robot Soccer

- **Ultimate Goal of the RoboCup**: "By the mid-21st century, a team of autonomous humanoid robots shall beat the human World Cup champion team under the official regulations of FIFA"


G
O5
O2
O4
O3
O1
Left wheel
C1
C2
CG
S
Right wheel
Castor
S: Start
G: Goal
C1O3 = Distance
GC1 O3 = Angle
GC1C2 =Deviation

Optimization

Minimize

Traveling time

subject to

Path is collision-free

Kinematic and Dynamic constraints

are satisfied

Potential Field Method

Attractive potential generated by the target/goal

$$U_{att}(X) = \frac{1}{2}\xi_{att} d^2_{goal}(X)$$

where ξ_{att} is a scaling factor and

$d_{goal}(X)$ is Euclidean distance between the goal and CG of the robot

Repulsive potential provided by obstacles

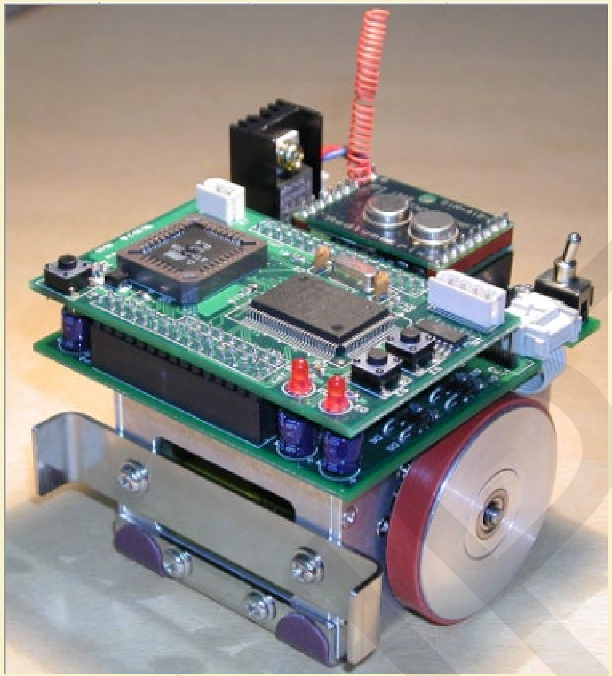
$$U_{rep}(X) = \frac{1}{2}\xi_{rep}\left[\frac{1}{d_{obs}(X)} - \frac{1}{d_{obs}(0)}\right]^2$$

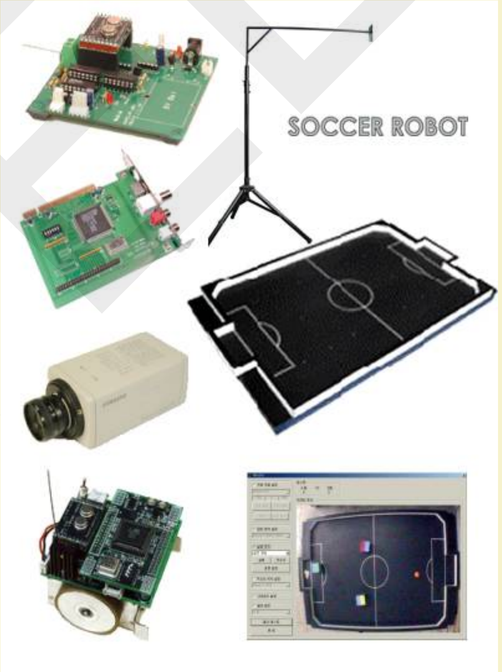
where ξ_{rep} - scaling factor

$d_{obs}(X)$ -distance of the obstacle from the robot

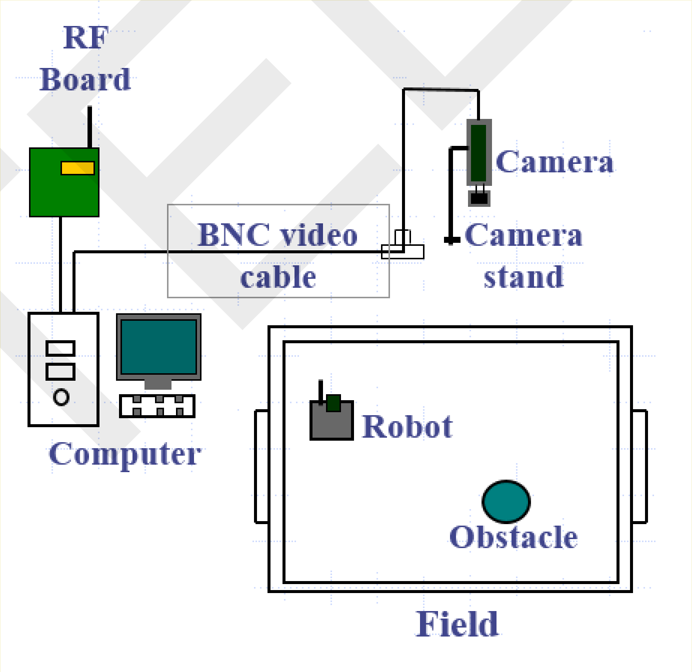
$d_{obs}(0)$ -distance of influence of the obstacle

ROBOT AND ITS ACCESSORIES





EXPERIMENT ON REAL ROBOT



Experimental setup

Methods of Conducting Experiment

- Camera calibration
- On-line image processing
- Activation of the motion planning approach
- Wireless communication through RF board
- Actuation of the robots through motors

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Topic 10: Biped Walking

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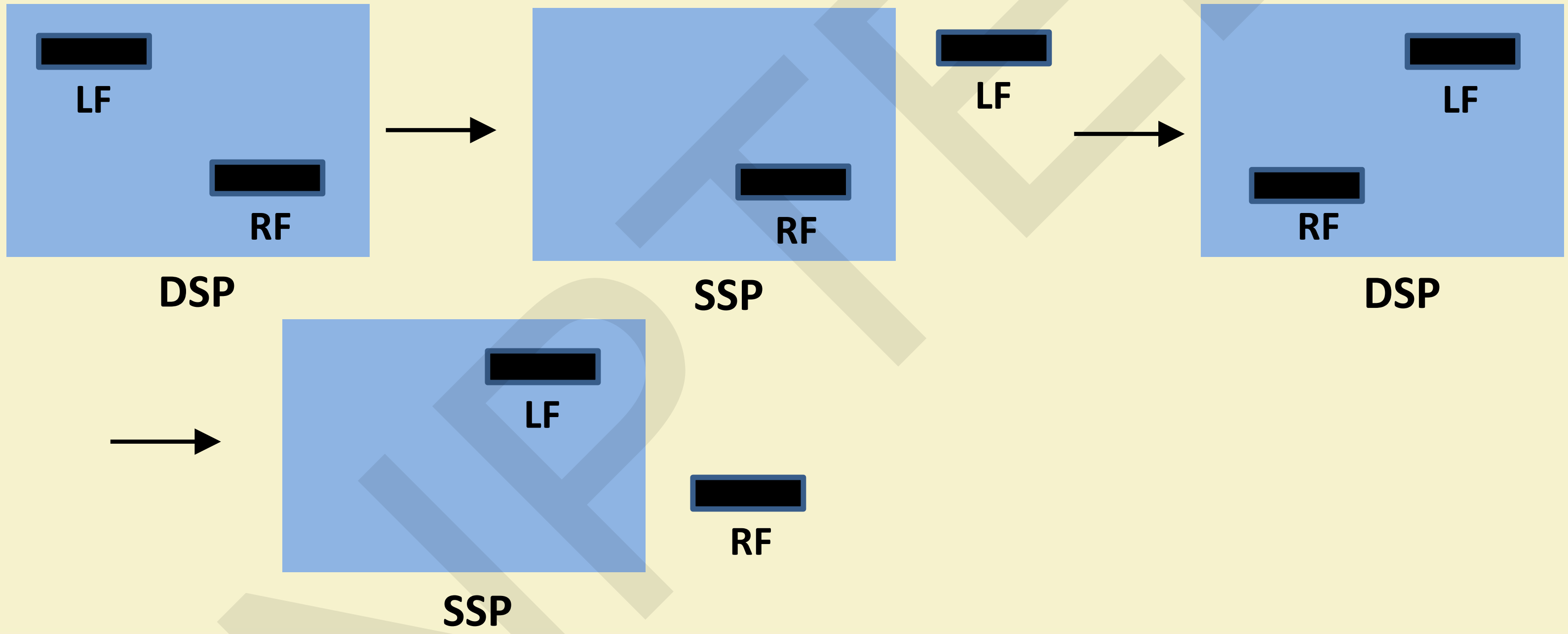
Introduction

- A biped robot should be able to walk on plane surface, negotiate staircases, cross ditches, take turn, as the situation demands

- **Walking cycle** consists of two single-support phases (SSPs) and two double-support phases (DSPs)

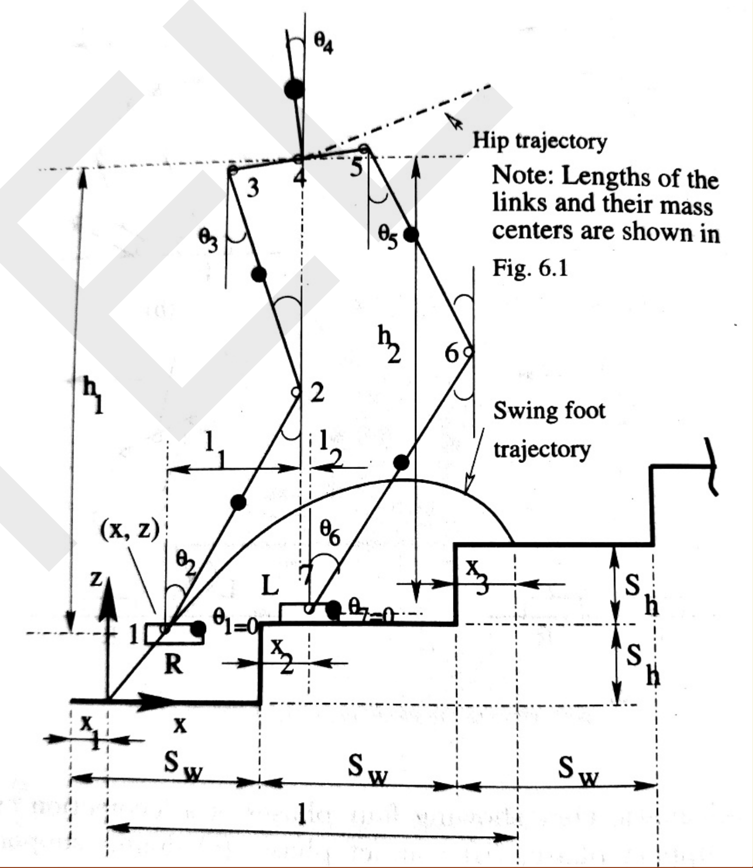


- **Gait**: sequence of legs' movement synchronized with its body movement during walking
- **Power consumption** during walking is to be optimized
- **Balance** is to be maintained during walking

Staircase Ascending (SSP)

➢ In the present study, movement has been considered in the saggital plane only.

$$\text{step length } l = (2s_w + x_3) - x_1$$
$$\text{hip height } h = L_2\cos\theta_2 + L_3\cos\theta_3$$



Swing foot trajectory generation

$$z = c_o + c_1 x + c_2 x^2 + c_3 x^3$$

Subject to the conditions

$$at\ x = 0, z = 0,$$

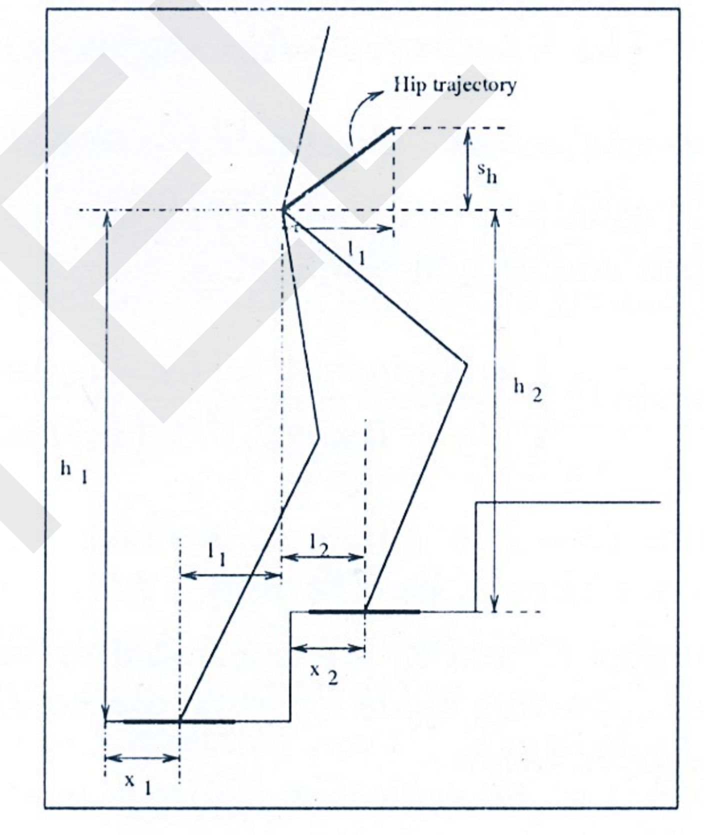
$$at\ x = s_w - x_1 - \frac{f_s}{2}, z = s_h + \frac{f_s}{2},$$

$$at\ x = 2s_w - x_1 - \frac{f_s}{2}, z = 2s_h + \frac{f_s}{2},$$

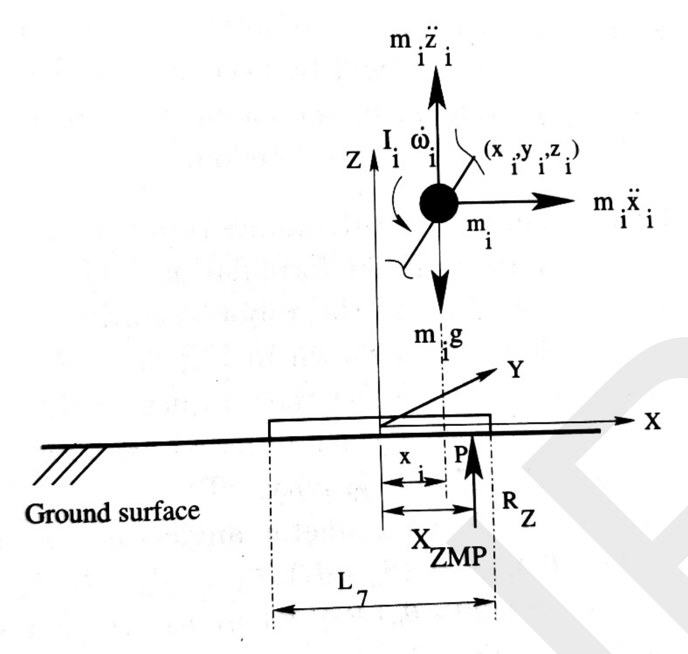
$$at\ x = 2s_w - x_1 + x_3, z = 2s_h.$$

Hip joint trajectory generation

h_1 : hip height
l_1 : distance of the ankle of swing foot from the projection of hip



Dynamic balance analysis



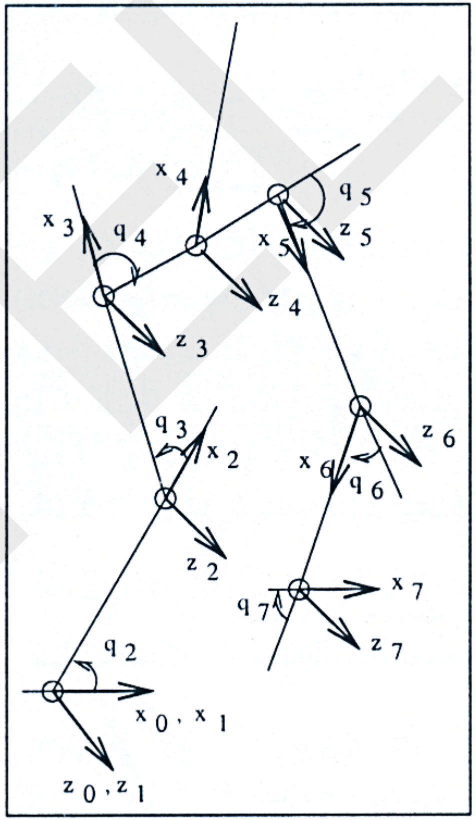
$$\sum_{i=1}^{7} m_i(\ddot{z}_i - g)(x_{ZMP} - x_i) + \sum_{i=1}^{7} m_i\ddot{x}_i z_i - \sum_{i=1}^{7} I_i\dot{\omega}_i = 0$$

$$x_{ZMP} = \frac{\sum_{i=1}^{7}\left(I_i\dot{\omega}_i + m_i x_i\left(\ddot{z}_i - g\right) - m_i\ddot{x}_i z_i\right)}{\sum_{i=1}^{7} m_i\left(\ddot{z}_i - g\right)},$$

$$x_{DBM} = \left(\frac{L_7}{2} - |x_{ZMP}|\right),$$

Torque calculation

D-H parameter setting



Trajectory for joint angle

$$q(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5,$$

Joint torques

$$\tau_i = \sum_{k=1}^{n} D_{ik}\ddot{q}_k + \sum_{k=1}^{n}\sum_{m=1}^{n} h_{ikm}\dot{q}_k\dot{q}_m + C_i, \qquad i = 1, 2, \cdots, n$$

$$where \qquad D_{ik} = \sum_{j=max(i,k)}^{n} Tr(U_{jk} J_j U_{ji}^T) \qquad i, k = 1, 2, \cdots, n,$$

$$h_{ikm} = \sum_{j=max(i,k,m)}^{n} Tr(U_{jkm} J_j U_{ji}^T) \qquad i, k, m = 1, 2, \cdots, n,$$

$$C_i = \sum_{j=i}^{n} (-m_j \bar{g} U_{ji} {}^j_j\bar{r}); i = 1, 2, \ldots, n$$

Average power consumption

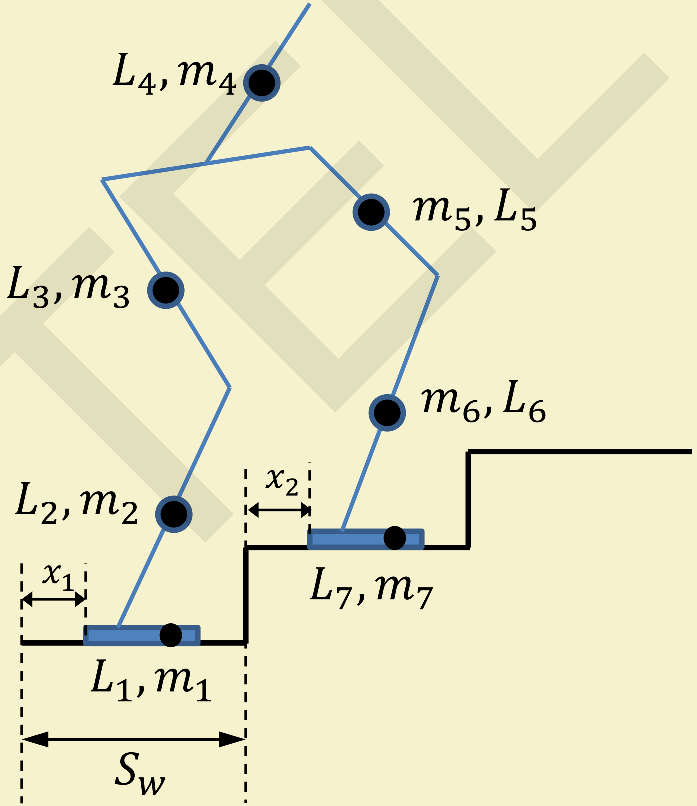
$$P_i = \frac{1}{T}\sum_{i=1}^{n}\int_0^T (|\tau_i \dot{q}_i| + k\tau_i^2)dt,$$

Mathematical formulation for Double support phase

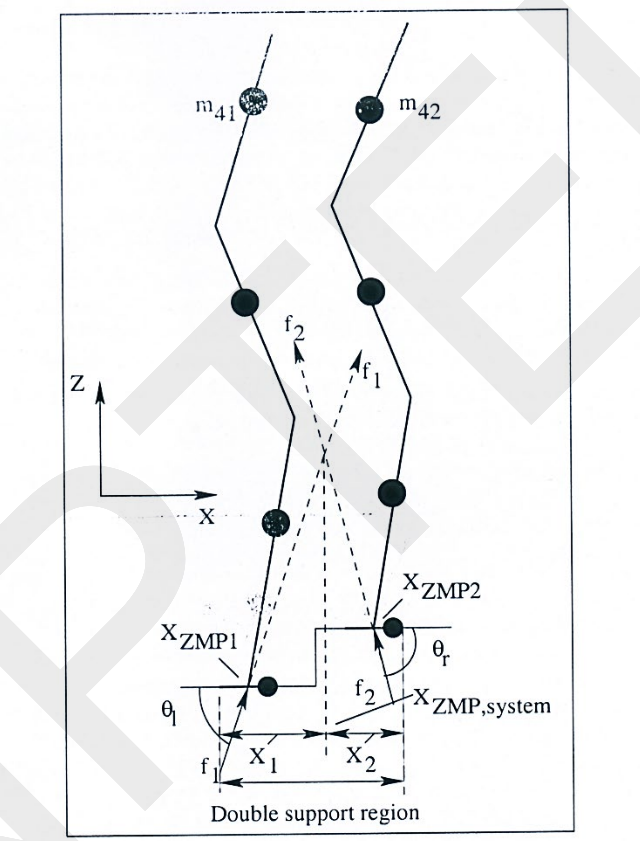
$$m_{41} = \frac{m_4 X_2}{X_1 + X_2}$$

$$m_{42} = \frac{m_4 X_1}{X_1 + X_2}$$

Double support phase



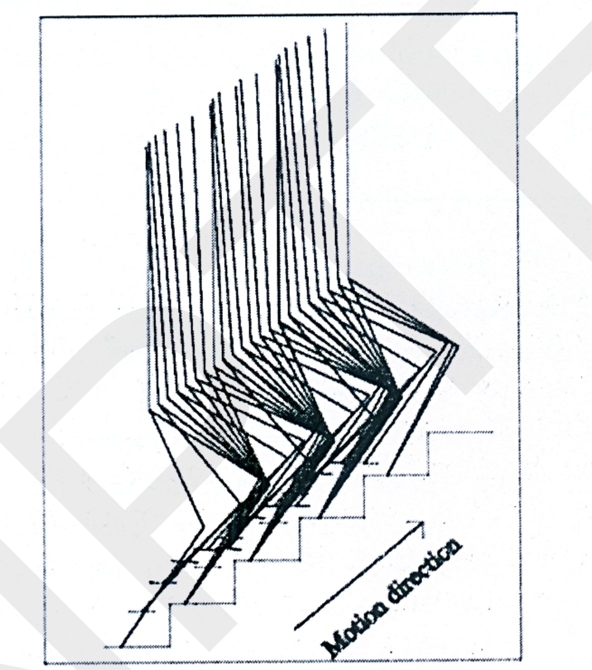
ZMP in double support phase



Dynamic balance margin

$$DBM_{system} = \frac{S_w - x_1 + x_2 + L_7}{2} - |X_{ZMP,system}|$$

Results of single support phase during ascending the staircases



Results of Double support phase during ascending the staircases

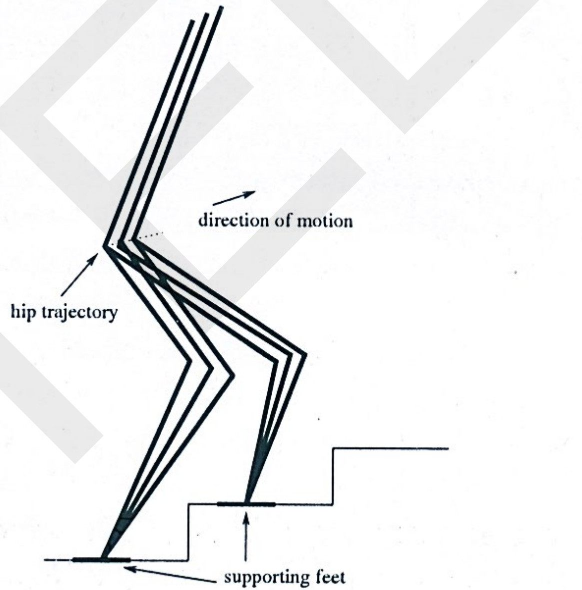


Fig Biped ascending staircase in double support phase posture

Real Experiments

- **Forward and Backward Movement**
- **Turning Motion**

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Topic 11: SUMMARY

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Topic 1: Introduction to Robots and Robotics

- Definitions of Robots and Robotics
- 3 Hs in Robotics
- Motivation behind robotics
- A brief history of Robotics
- Various components of a robot
- Different types of robotic joints

- **Degrees of freedom of a robotic system**
- **Classification of robots**
- **Workspace Analysis**
- **Resolution, Accuracy and Repeatability**
- **Applications of Robots**
- **End-effectors/gripper of robots**
- **Robot Teaching**
- **Specification of a robot**
- **Economic Analysis**

Topic 2: Robot Kinematics

- **Position and orientation of 3D objects**
- **Homogeneous Transformation Matrix**
- **Denavit-Hartenberg's Notations**
- **Forward Kinematics**
- **Inverse Kinematics**

Topic 3: Trajectory planning

- Polynomial Trajectory
- Linear Trajectory with parabolic blends
- Jacobian Matrix: Relationship between Cartesian velocity and Joint velocity and Singularity checking

Topic 4: Robot Dynamics

- Inverse Dynamics
- Lagrange Euler formulation – two approaches

Topic 5: Control scheme

- **Partitioned control scheme**

Topic 6: Sensors

- Characteristics of a sensor
- Classification of sensors
- Touch sensor; Position sensors – Potentiometer, LVDT, Optical Encoders
- Force/Moment sensors
- Range sensor; Proximity sensors – Inductive sensor; Capacitive sensor; Hall-Effect sensor
- Passive sensor : RCC

Topic 7: Robot Vision

- **Steps of vision**
  - ✓ Image capturing
  - ✓ Sampling – A/D conversion
  - ✓ Frame grabing
  - ✓ Pre-processing
  - ✓ Thresholding
  - ✓ Edge detection
  - ✓ Boundary descriptors
  - ✓ Identification of objects

Topic 8: Robot Motion Planning

- Gross/Free space motion planning

- Find path problems using
  - ✓ Visibility Graph
  - ✓ Voronoi diagram
  - ✓ Cell-Decomposition
  - ✓ Tangent-graph technique

- Dynamic Motion Planning Problems
  - ✓ Path–Velocity Decomposition
  - ✓ Accessibility Graph
  - ✓ Relative velocity scheme
  - ✓ Incremental planning
  - ✓ Artificial potential field approach
  - ✓ Reactive control scheme
    - Behavior-based Robotics

Topic 9: Intelligent Robot

- **Implement with the help of a wheeled robot**

Topic 10: Biped walking

- Power consumption
- Dynamic balance
- Demonstration of a real biped robot

Thank You