

Selected planar robots

- In this class robots restricted to planar motion:
 - translations parallel to a plane and rotations normal to same plane
 - much simpler to analyze than spatial robots
 - planar subchains often part of spatial robots
 - well illustrate range of robotic mechanisms
- Two basic topological structures:
 - serial (no structural loops, e.g. arm-like)
 - parallel (structural loops, usually with ground, e.g. table)

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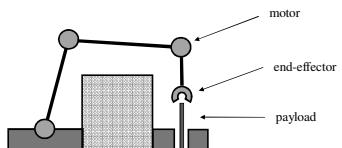
Selected planar robots Serial manipulators (arm)

The slide shows two types of serial manipulators. On the left is the 'ABB 6 DOF robot' with '6 revolute joints (spatial)'. On the right are two models of the 'Denso 4 DOF SCARA robot': the 'Cleanroom model' and the 'Basic model'.

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 Selected planar robots
Serial manipulator (arm)





Advantages

- large workspace (long reach)
- dexterous (avoids obstacles)
- lightweight

Disadvantages

- low power-to-weight ratio
- low accuracy
- low loads
- low stiffness

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 Selected Planar Robots
Parallel platforms





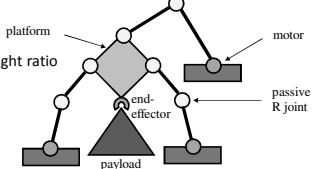
Fanuc F-200iB 6 DOF robot
(spatial)

ABB 6 DOF FlexPicker robot
(spatial)

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 Selected Planar Robots
Parallel platform





Advantages

- moderate power-to-weight ratio
- high accuracy
- high loads
- high stiffness

Disadvantages

- small workspace
- low dexterity
- heavy

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Selected Planar Robots

Cable-driven parallel platforms

SkyCam robot
4 cables + 2 camera tilts
(spatial)

Prototype ship loader
3 or 4 cables
(spatial)

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Selected Planar Robots

Cable-driven parallel platform

Advantages

- high power-to-weight ratio
- high loads
- lightweight
- large workspace

Disadvantages

- low dexterity
- cables only pull
- may rely on gravity
- low to moderate stiffness
- low accuracy

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Selected Planar Robots

Dexterous hands

Anthropomorphic hand
(spatial)

Anthropomorphic hand
(spatial)

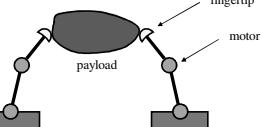
Two-fingered gripper
(planar)

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 Selected Planar Robots
Dexterous hand



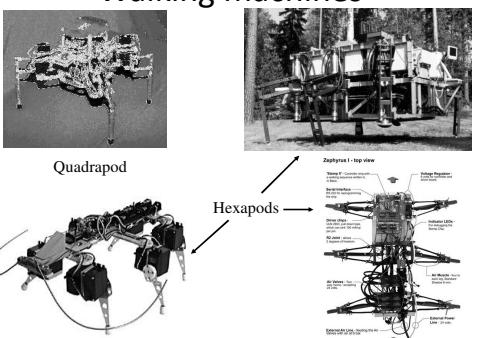
Advantages	Disadvantages
<ul style="list-style-type: none"> - reconfigurable contacts - moderate accuracy - adjustable squeezing forces - moderate stiffness 	<ul style="list-style-type: none"> - contacts may slip - contacts only push, not pull - low payloads - small workspace



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 Selected Planar Robots
Walking machines





Quadrupod

Hexapods

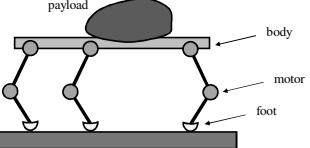
Zephyrus I - top view

R

 Selected Planar Robots
Walking machine

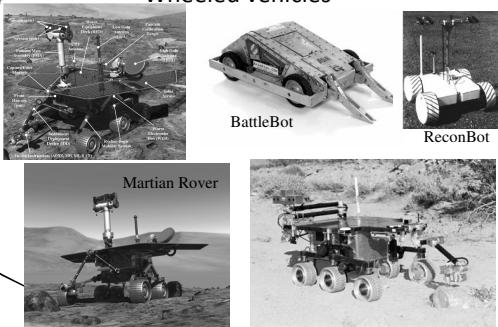


Advantages	Disadvantages
<ul style="list-style-type: none"> - all-terrain - adjustable gaits - redundant static support - body can be raised/lowered 	<ul style="list-style-type: none"> - contacts may slip - contacts only push, not pull - slow



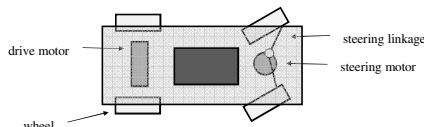
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 Selected Planar Robots
Wheeled vehicles 



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 Selected Planar Robots
Wheeled vehicle 



Advantages

- fast
- maneuverable
- redundant static support
- well-established technology

Disadvantages

- wheels may slip
- requires relatively flat surface
- nonholonomic (must control velocity, not position directly)

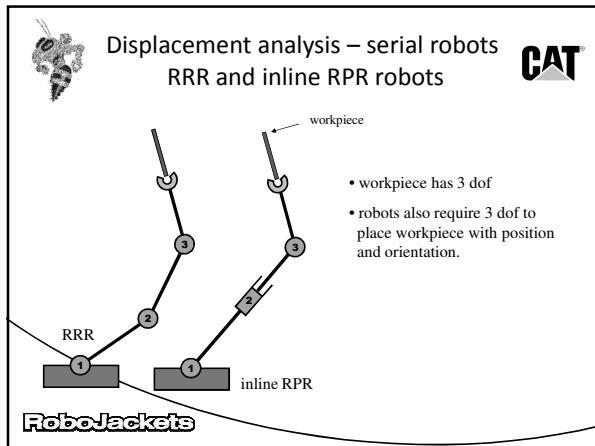
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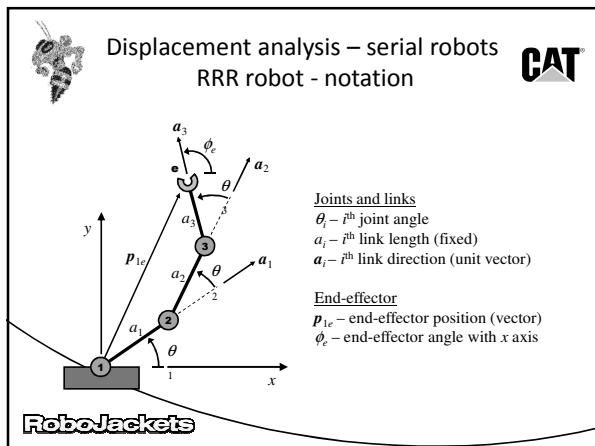
 Displacement analysis – serial robots 

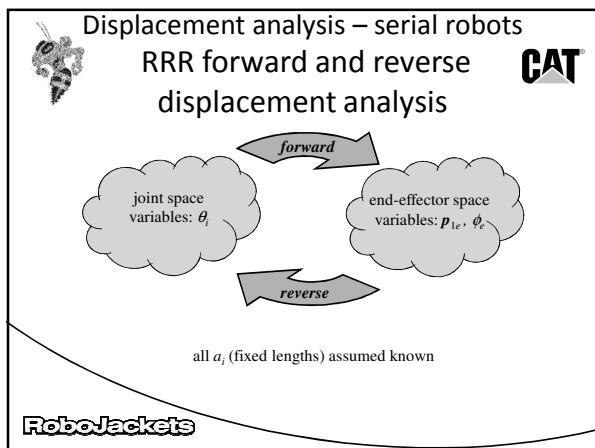
Forward and reverse displacement analysis

- The RRR and the inline RPR are two representative serial manipulators
- Forward displacement analysis (FDA)
 - joint displacements \longrightarrow end-effector displacement
 - used for simulation
- Reverse displacement analysis (RDA)
 - joint displacements \longleftarrow end-effector displacement
 - used for control

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Displacement analysis – serial robots

RRR robot – forward displacement analysis

Given: $\theta_1, \theta_2, \theta_3$

Find: p_{1e}, ϕ_e

Solution:

angle: $\phi_e = \theta_1 + \theta_2 + \theta_3 \Leftarrow$ answer

position: $p_{1e} = a_1 a_1 + a_2 a_2 + a_3 a_3$ (vector add)

$$\begin{bmatrix} x_{1e} \\ y_{1e} \end{bmatrix} = \begin{bmatrix} a_1 c_1 + a_2 c_{1+2} + a_3 c_{1+2+3} \\ a_1 s_1 + a_2 s_{1+2} + a_3 s_{1+2+3} \end{bmatrix} \Leftarrow \text{answer}$$

where,

$$c_{i+j} \equiv \cos(\theta_i + \theta_j)$$

$$s_{i+j} \equiv \sin(\theta_i + \theta_j)$$

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Displacement analysis – serial robots

RRR robot – reverse displacement analysis

Given: p_{1e}, ϕ_e

Find: $\theta_1, \theta_2, \theta_3$

Solution:

$\phi_e = \theta_1 + \theta_2 + \theta_3$ (FDA)

$$\begin{bmatrix} x_{1e} \\ y_{1e} \end{bmatrix} = \begin{bmatrix} a_1 c_1 + a_2 c_{1+2} + a_3 c_{1+2+3} \\ a_1 s_1 + a_2 s_{1+2} + a_3 s_{1+2+3} \end{bmatrix} \quad (\text{FDA})$$

$$\begin{bmatrix} x_{1e} - a_3 c_e \\ y_{1e} - a_3 s_e \end{bmatrix} = \begin{bmatrix} a_1 c_1 + a_2 c_{1+2} \\ a_1 s_1 + a_2 s_{1+2} \end{bmatrix} \quad (\text{sub, move, then square})$$

$$(x_{1e} - a_3 c_e)^2 + (y_{1e} - a_3 s_e)^2 = a_1^2 + a_2^2 + 2a_1 a_2 c_2$$

$$c_2 = \frac{(x_{1e} - a_3 c_e)^2 + (y_{1e} - a_3 s_e)^2 - a_1^2 - a_2^2}{2a_1 a_2}$$

$$s_2^{(\pm)} = \pm \sqrt{1 - c_2^2}$$

$$\theta_2^{(\pm)} = \text{ATAN2}(s_2^{(\pm)}, c_2) \Leftarrow \text{answer}$$

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Displacement analysis – serial robots

RRR robot – reverse displacement analysis

Solution (continued):

$$c_1 = \frac{x_{1e} - a_3 c_e \quad - a_2 s_2}{a_1 + a_2 c_2 \quad \Delta}, \quad \Delta \neq 0 \quad (\text{Cramer's rule})$$

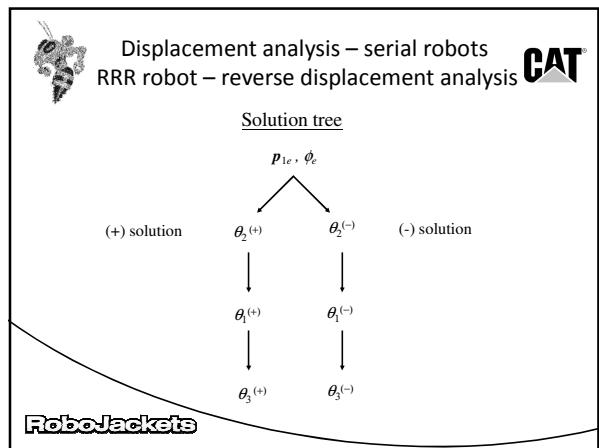
$$s_1 = \frac{y_{1e} - a_3 s_e \quad a_1 + a_2 c_2}{a_2 s_2 \quad \Delta}, \quad \Delta \neq 0 \quad (\text{Cramer's rule})$$

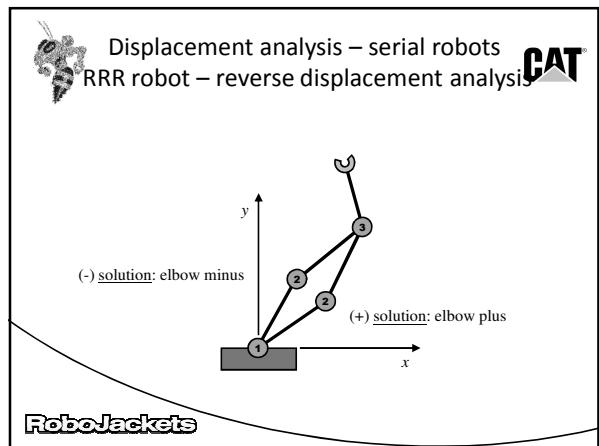
where, $\Delta = a_1^2 + a_2^2 + 2a_1 a_2 c_2$

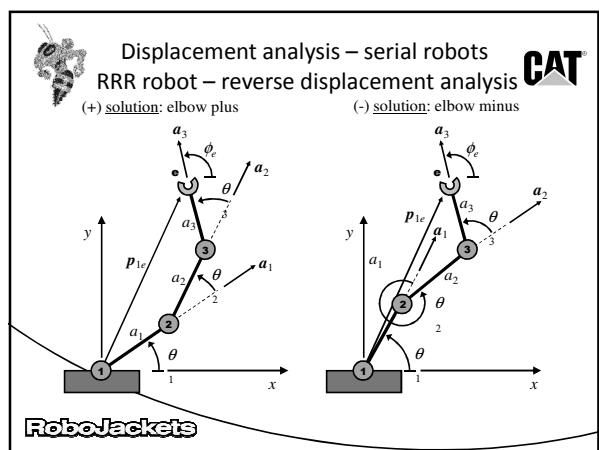
$$\theta_1 = \text{ATAN2}(s_1, c_1) \Leftarrow \text{answer}$$

$$\theta_3 = \phi_e - \theta_1 - \theta_2 \Leftarrow \text{answer}$$

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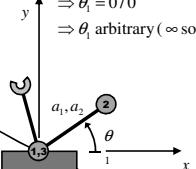
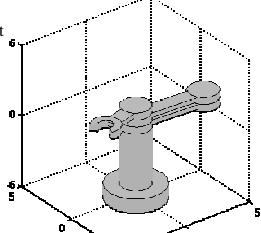
 Displacement analysis – serial robots
ATAN2 – unique trigonometric inverse for 360° 

Given	Solution	Graph
$x = \cos \theta$ $y = \sin \theta$	$\text{ATAN2}(y, x) = \theta$	
$x = \cos \theta$	$\arccos x = \theta, -\theta$	
$y = \sin \theta$	$\arcsin y = \theta, 180^\circ - \theta$	
$m = \frac{\sin \theta}{\cos \theta}$	$\arctan m = \theta, 180^\circ + \theta$	

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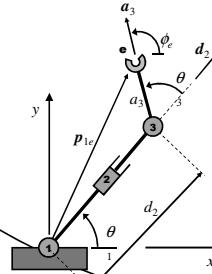
 Displacement analysis – serial robots
RRR robot – displacement singularity 

$\Delta = a_1^2 + a_2^2 + 2a_1a_2c_2 = 0$
 \Rightarrow joints 1 and 3 are coincident
 $\Rightarrow a_1 = a_2$ and $c_2 = -1$
 $\Rightarrow c_1 = s_1 = 0/0$
 $\Rightarrow \theta_1 = 0/0$
 $\Rightarrow \theta_3$ arbitrary (∞ solutions)

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 Displacement analysis – serial robots
Inline RPR robot - notation 



Joints and links
 θ_i – i^{th} joint angle
 a_i – i^{th} link length (fixed)
 a_i – i^{th} link direction (unit vector)
 d_i – i^{th} offset length (variable)
 d_i – i^{th} offset direction (unit vector)

End-effector
 p_{le} – end-effector position (vector)
 ϕ_e – end-effector angle with x axis

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