RoboJackets

CAT®

THE ARTHUR M. BLANK FAMILY FOUNDATION

2007 TE Sessions – Manipulators II

Nov. 12, 2007

www.robojackets.org

End Effector

- Essential to every robotics application
- Connects your manipulator to the environment
- Needs to be custom made for the application

End Effector

- Pneumatics work best for “gripping” applications
- Actuators can be dead-headed at limits without damage
- Motorized grippers require limit switches and controls
- Motorized grippers also need gear reduction
  - Angle of attack important to consider, too

End Effector

- Magnetic grippers are useful for applications involving steel
- Hooks and straight members can be implemented to interact with targets
- Other means of actuation?

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Sensors

- You may need to know feedback from your manipulator
- Sensors can be placed on joints to feedback the exact positions
  - Potentiometers, encoders, etc

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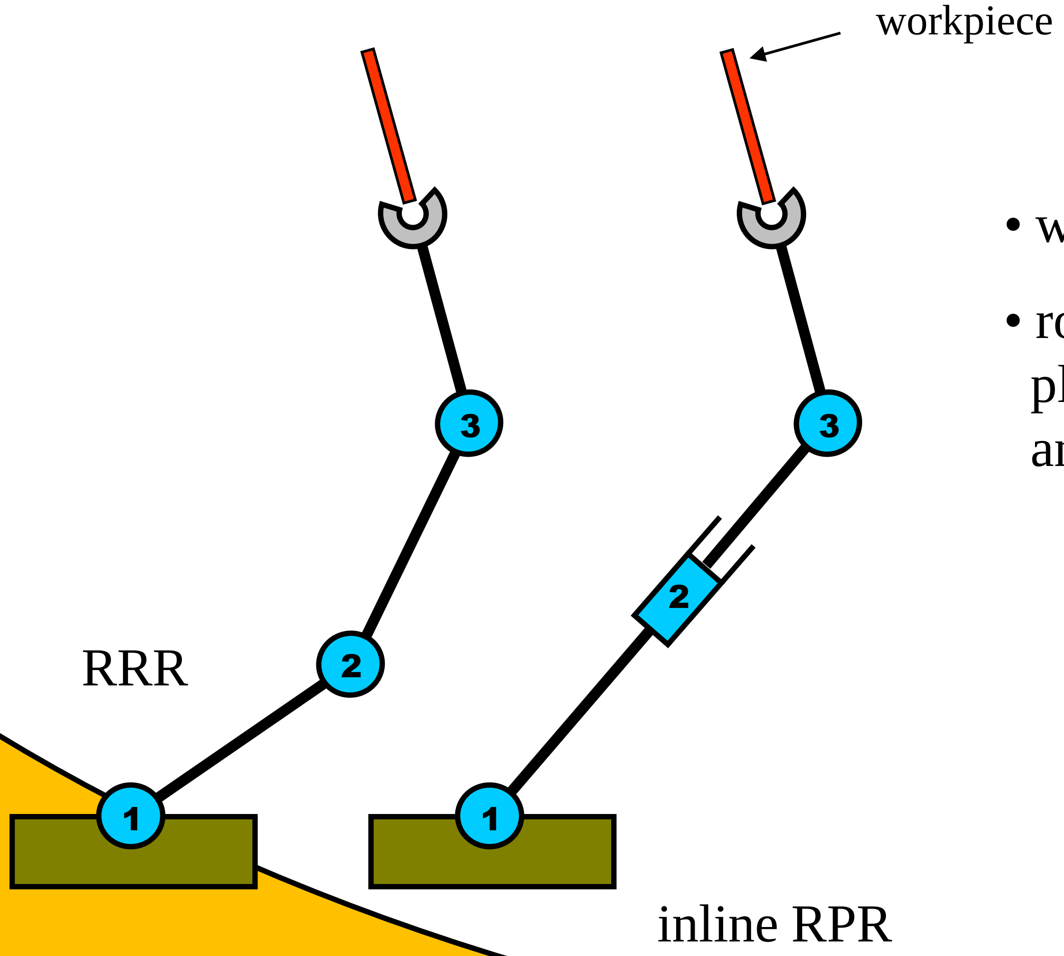
Displacement analysis – serial robots

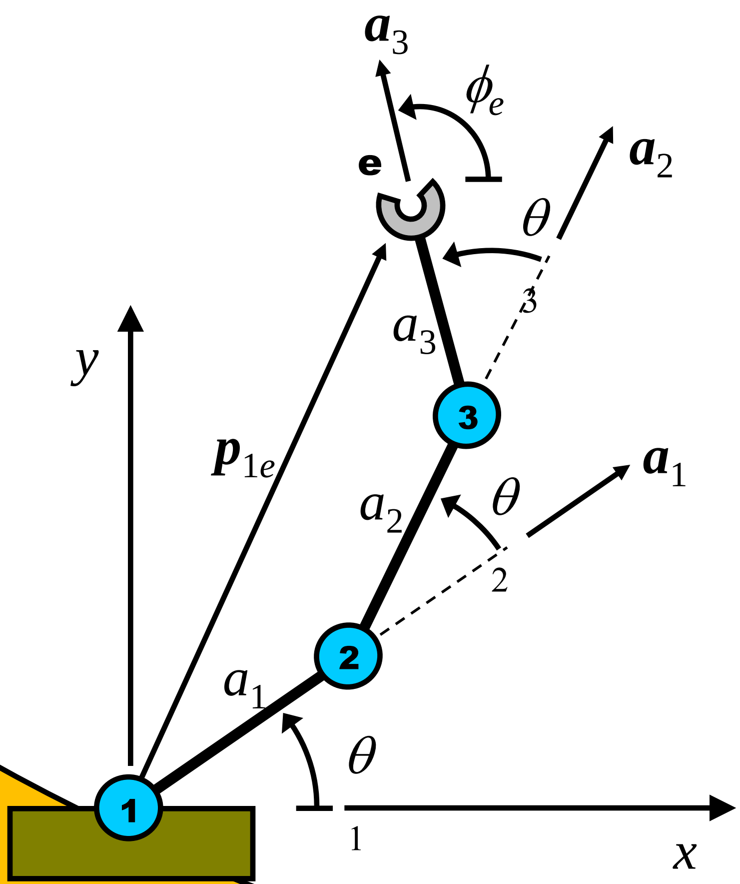
RRR and inline RPR robots



- workpiece has 3 dof
- robots also require 3 dof to place workpiece with position and orientation.

Displacement analysis – serial robots

RRR robot - notation



Joints and links

θ_i – i^{th} joint angle

a_i – i^{th} link length (fixed)

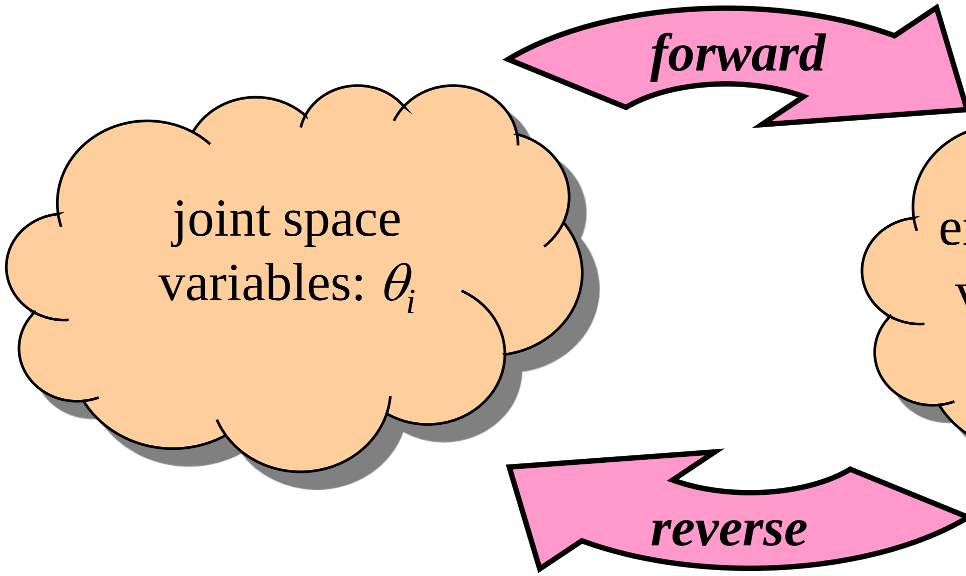
$\boldsymbol{a}_i$ – i^{th} link direction (unit vector)

End-effector

$\boldsymbol{p}_{1e}$ – end-effector position (vector)

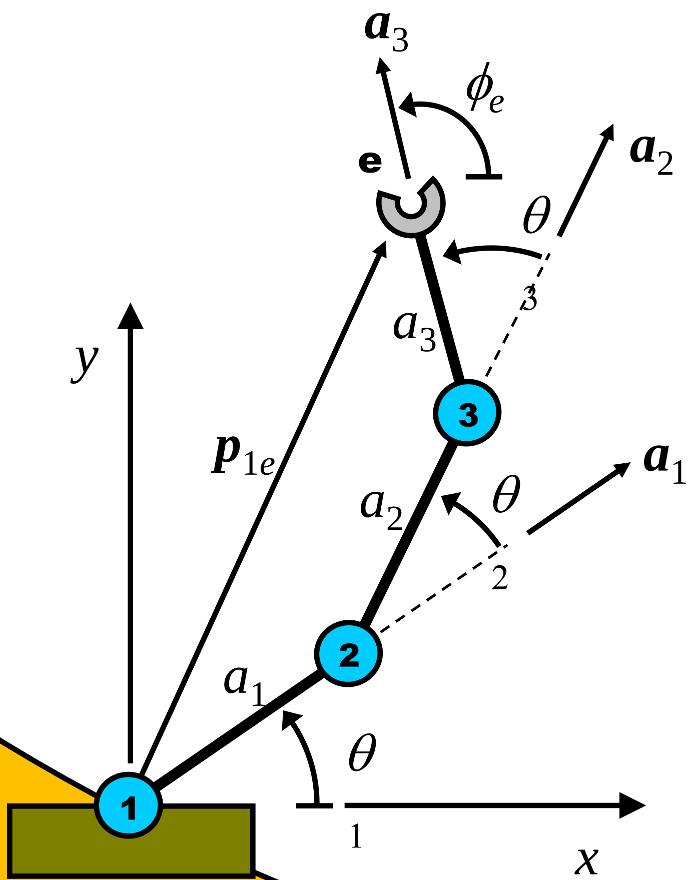
ϕ_e – end-effector angle with x axis

Displacement analysis – serial robots
RRR forward and reverse displacement analysis



all a_i (fixed lengths) assumed known

Displacement analysis – serial robots
RRR robot – forward displacement analysis



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

Find : $\mathbf{p}_{1e}, \phi_e$

Solution :

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

position: $\boldsymbol{p}_{1e} = a_1 \boldsymbol{a}_1 + a_2 \boldsymbol{a}_2 + a_3 \boldsymbol{a}_3$ (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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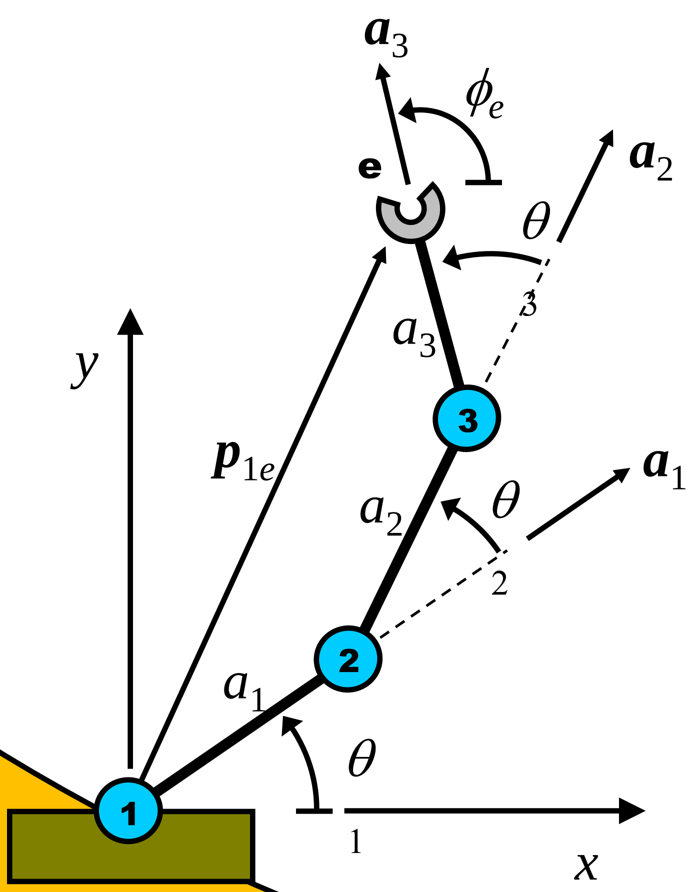
Displacement analysis – serial robots
RRR robot – reverse displacement analysis



Given : $\mathbf{p}_{1e}, \phi_e$

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

Solution :

$$\phi_e = \theta_1 + \theta_2 + \theta_3 \text{ (FDA)}$$

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

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

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

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

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

$$\theta_2^{(\pm)} = \text{ATAN}\,2(s_2^{(\pm)}, c_2) \Leftarrow \text{answer}$$

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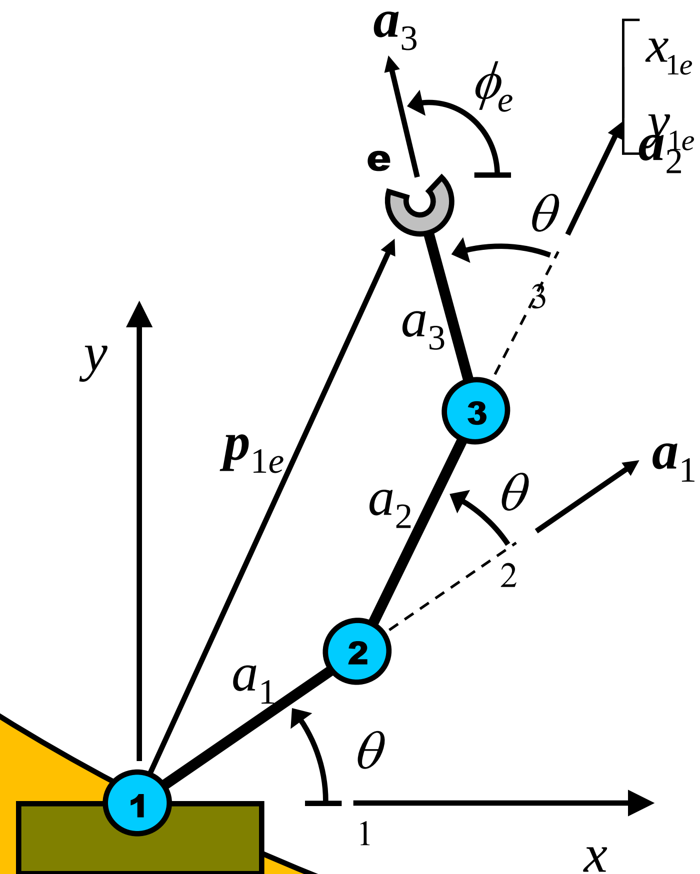
Displacement analysis – serial robots
RRR robot – reverse displacement analysis



<u>Solution</u> (continued):

$$\begin{bmatrix} x_{1e} - a_3 c_e \\ y_{1e} - a_3 s_e \end{bmatrix} = \begin{bmatrix} a_1 c_1 + a_2 (c_1 c_2 - s_1 s_2) \\ a_1 s_1 + a_2 (s_1 c_2 + s_2 c_1) \end{bmatrix} \text{(expand, backsub)}$$

$$= \begin{bmatrix} a_1 + a_2 c_2 & -a_2 s_2 \\ a_2 s_2 & a_1 + a_2 c_2 \end{bmatrix} \begin{bmatrix} c_1 \\ s_1 \end{bmatrix}$$

$$c_1 = \frac{(x_{1e} - a_3 c_e)(a_1 + a_2 c_2) - (-a_2 s_2)(y_{1e} - a_3 s_e)}{a_1^2 + a_2^2 + 2 a_1 a_2 c_2}$$

$$s_1 = \frac{(a_1 + a_2 c_2)(y_{1e} - a_3 s_e) - (x_{1e} - a_3 c_e)(a_2 s_2)}{a_1^2 + a_2^2 + 2 a_1 a_2 c_2}$$

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

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

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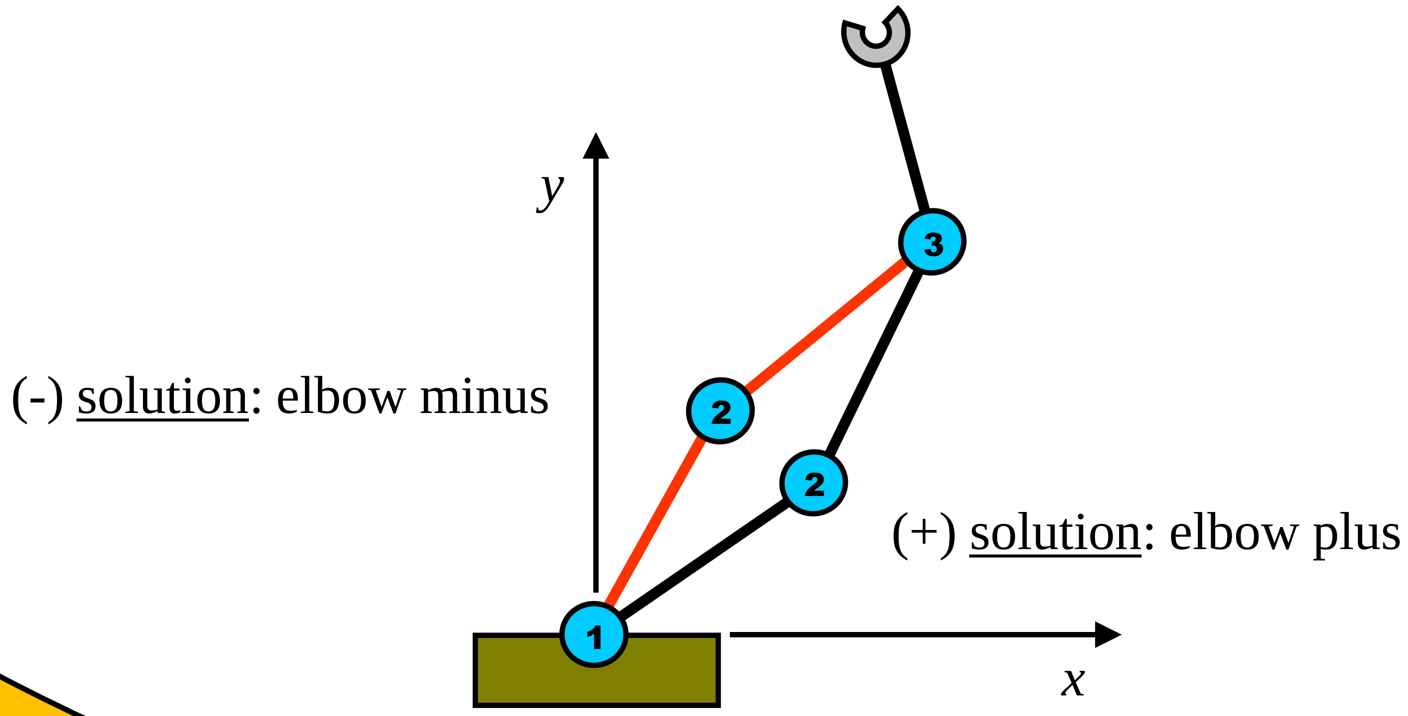
Displacement analysis – serial robots
RRR robot – reverse displacement analysis

Solution tree

$\boldsymbol{p}_{1e}\,,\ \phi_e$

(+) solution		(-) solution
$\theta_2^{(+)}$		$\theta_2^{(-)}$
↓		↓
$\theta_1^{(+)}$		$\theta_1^{(-)}$
↓		↓
$\theta_3^{(+)}$		$\theta_3^{(-)}$

Displacement analysis – serial robots RRR robot – reverse displacement analysis



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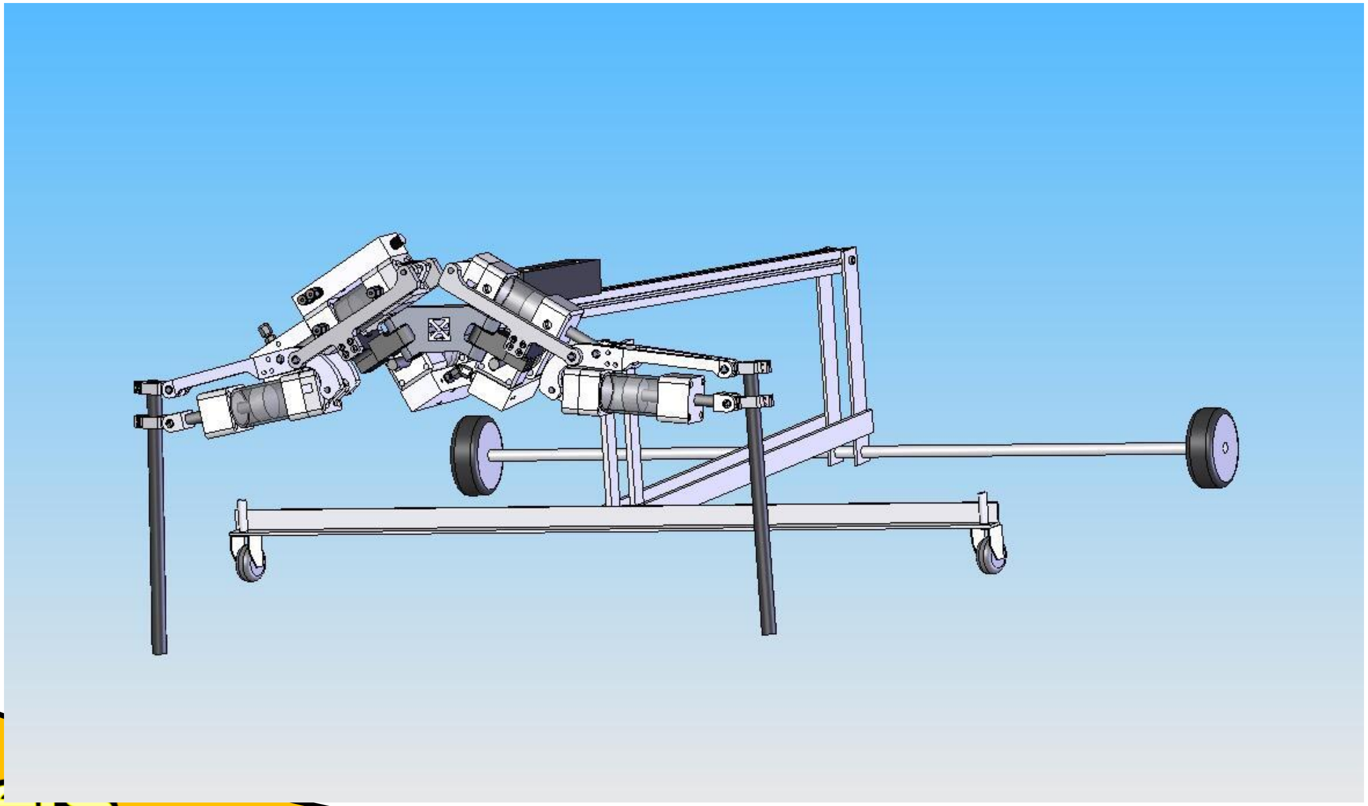
Check it out in real time

We can now see this algorithm being solved in real time

Love Bldg. Rm 220; NSF Center for Compact and Efficient Fluid Power Lab

RRR



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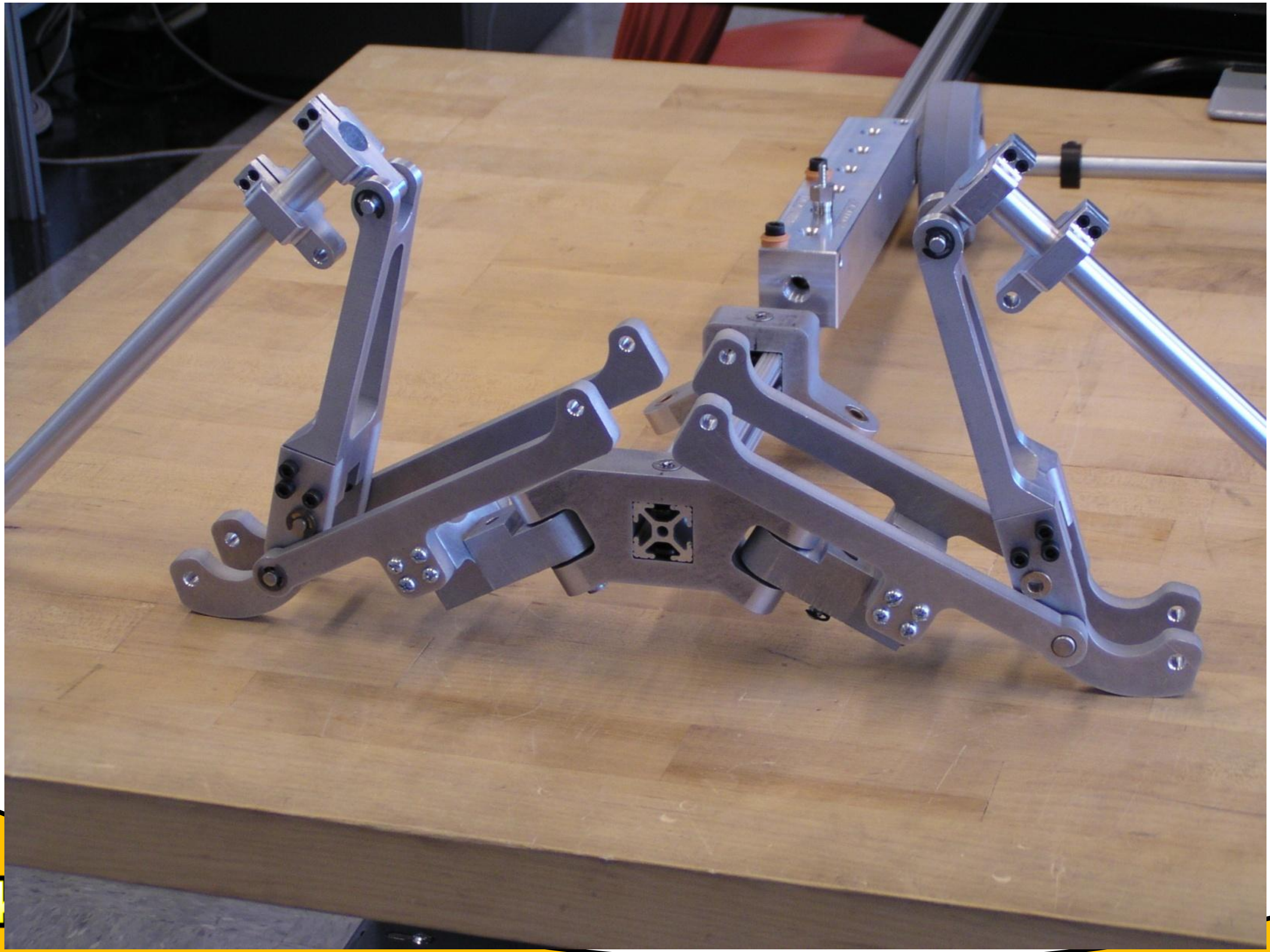
CRC: V2.0

Evolution



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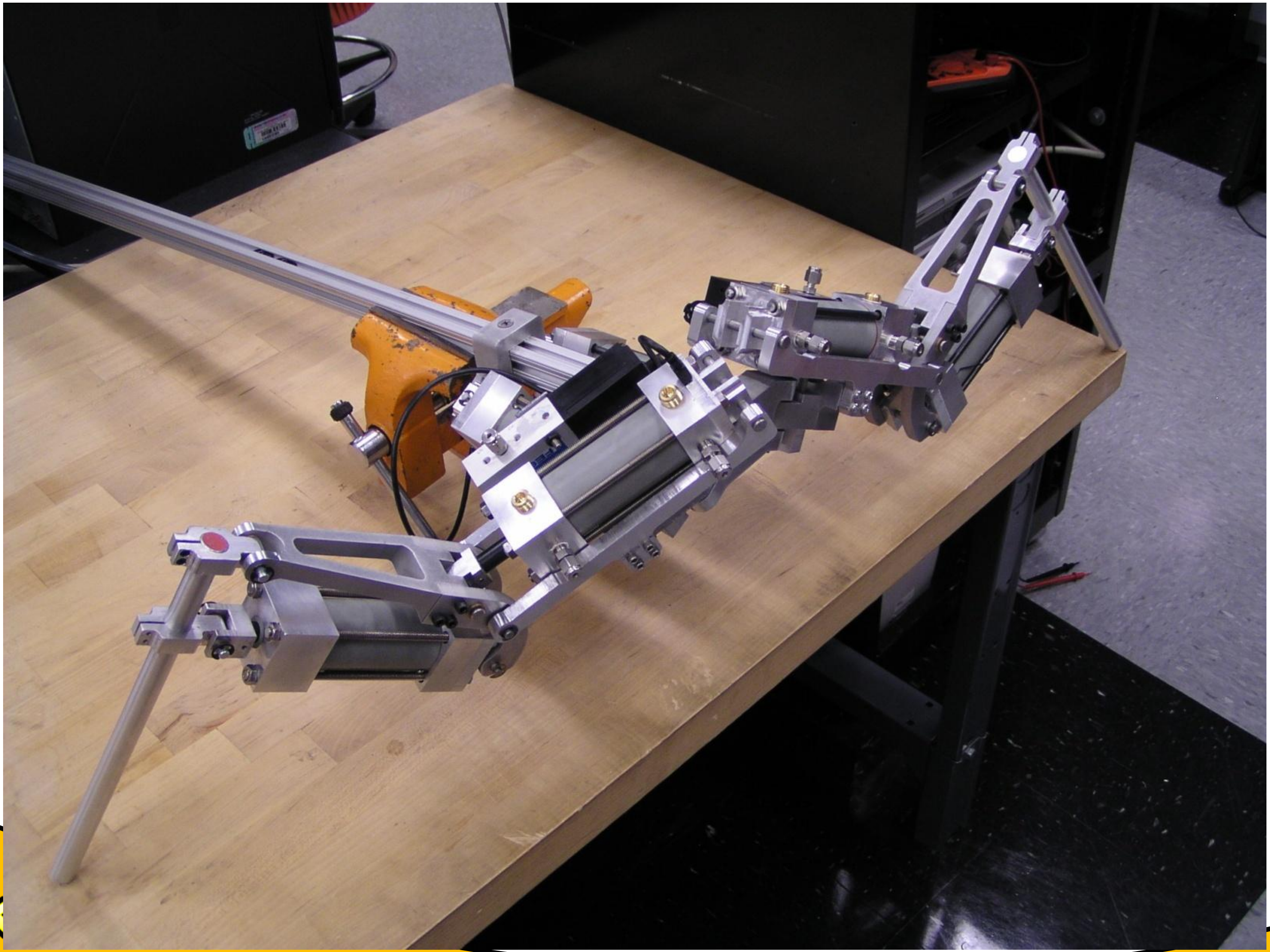
CRC: V2.0

Evolution



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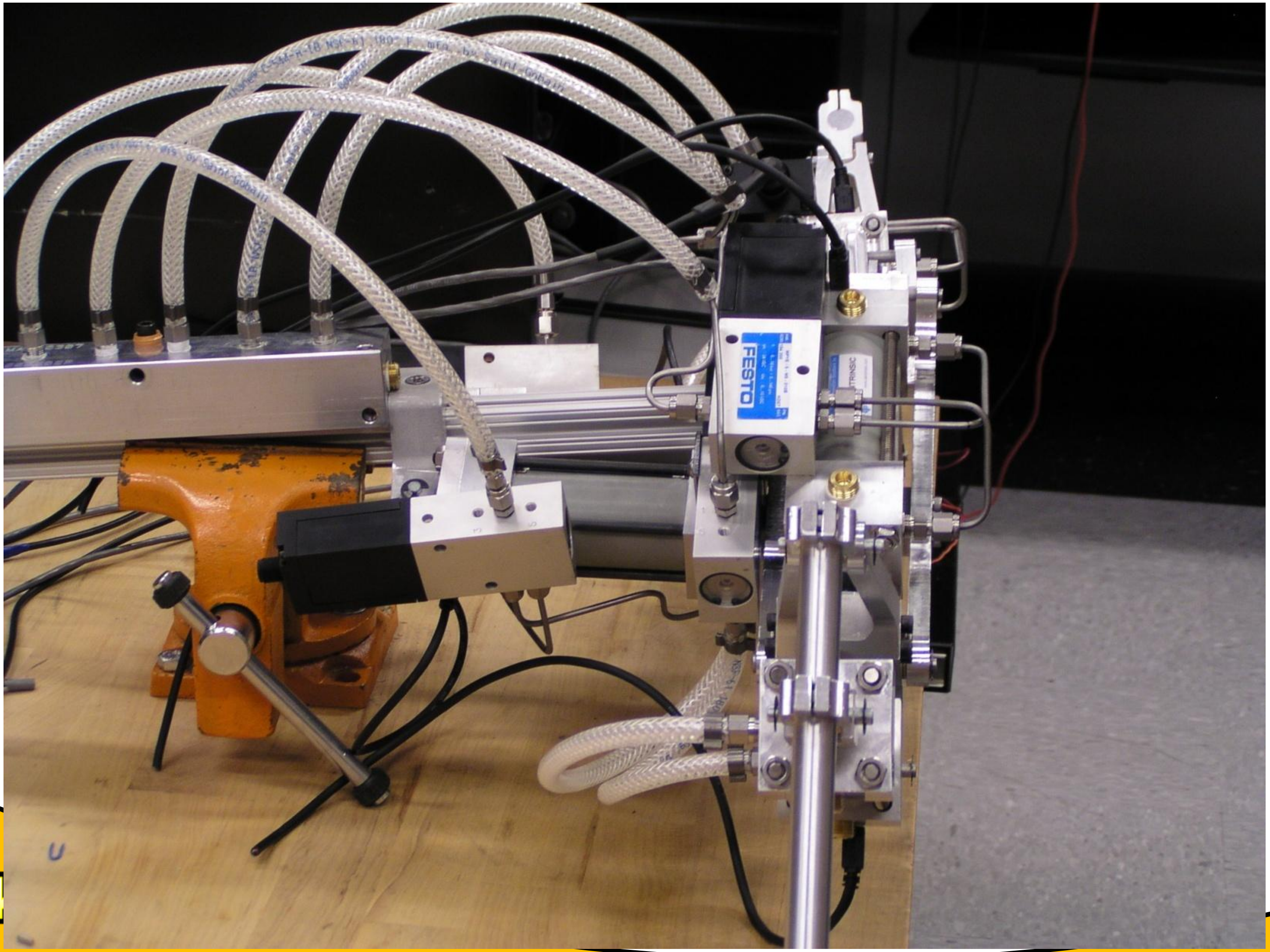
CRC: V2.0

Evolution



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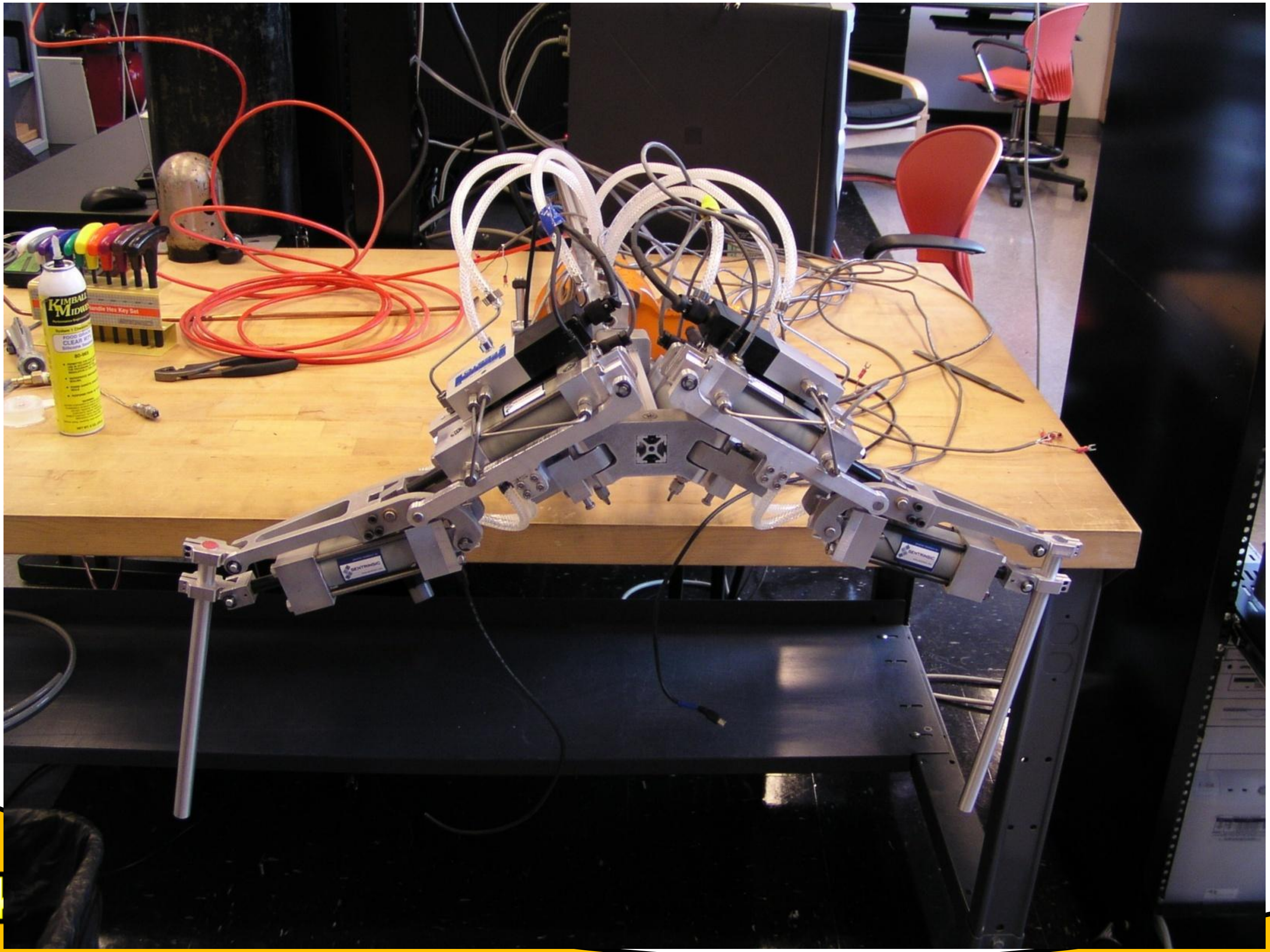
CRC: V2.0

Evolution



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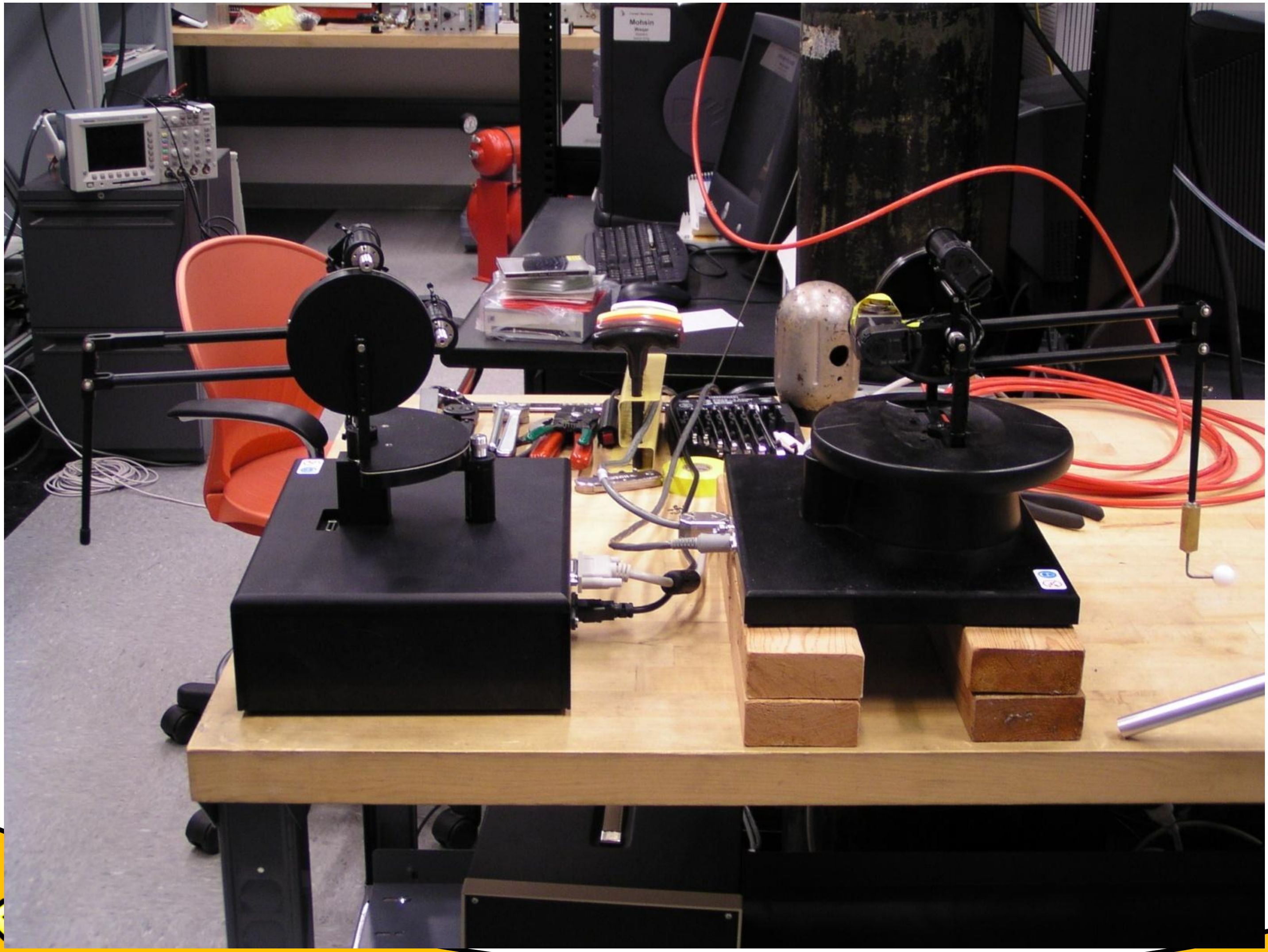
CRC: V2.0

Evolution



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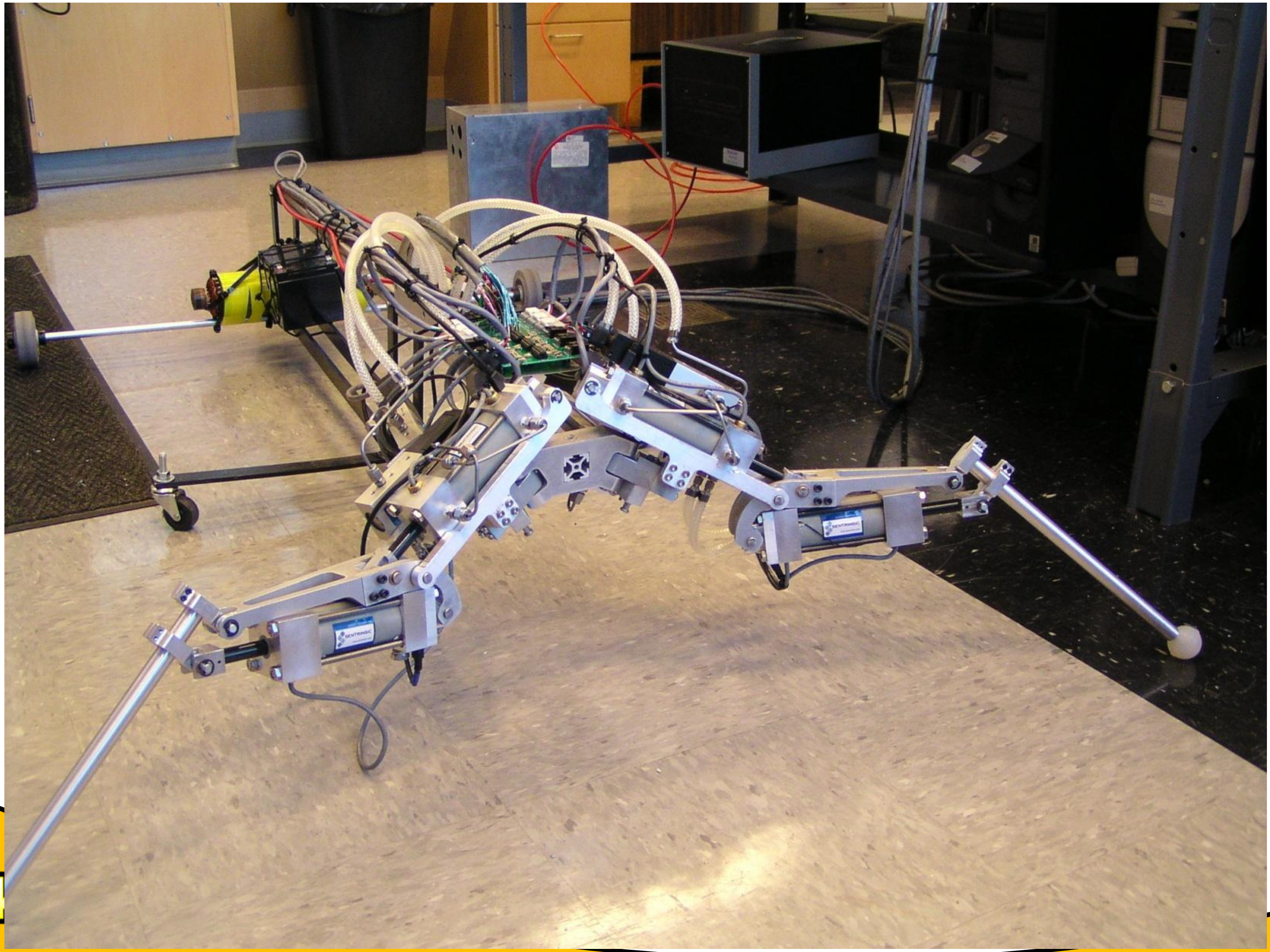
CRC: V2.0

Evolution



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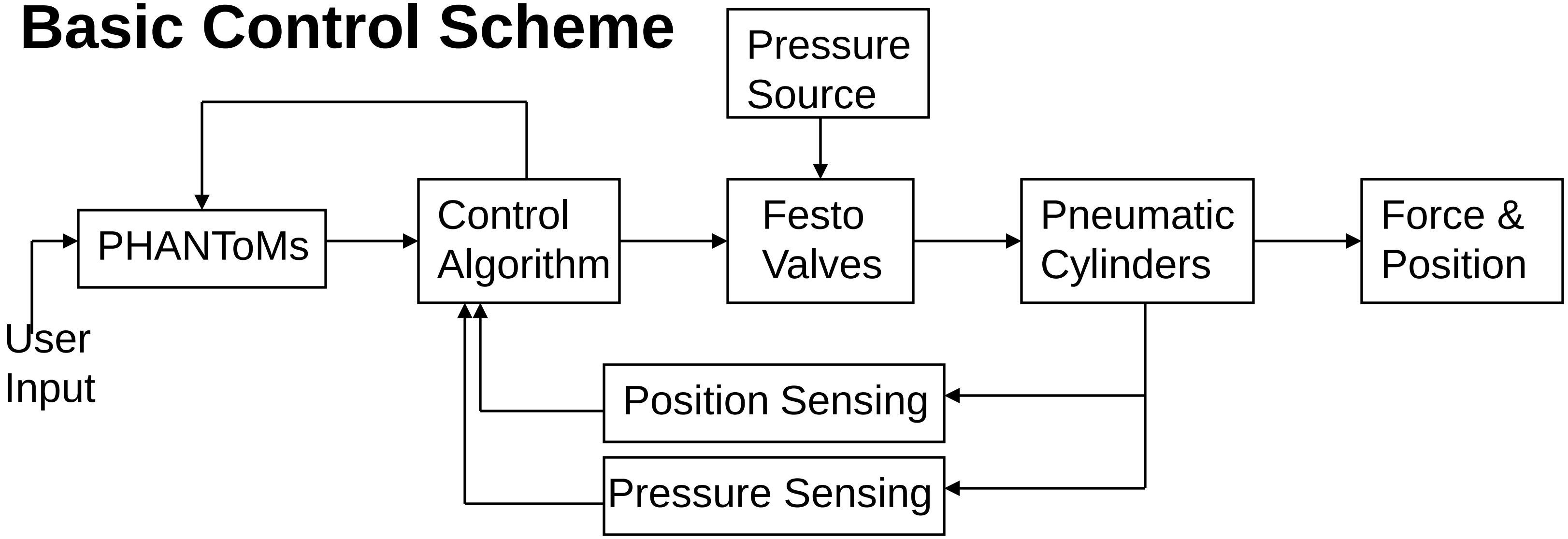
CRC: Compact Rescue Crawler

Basic Control Scheme



CRC: Compact Rescue Crawler

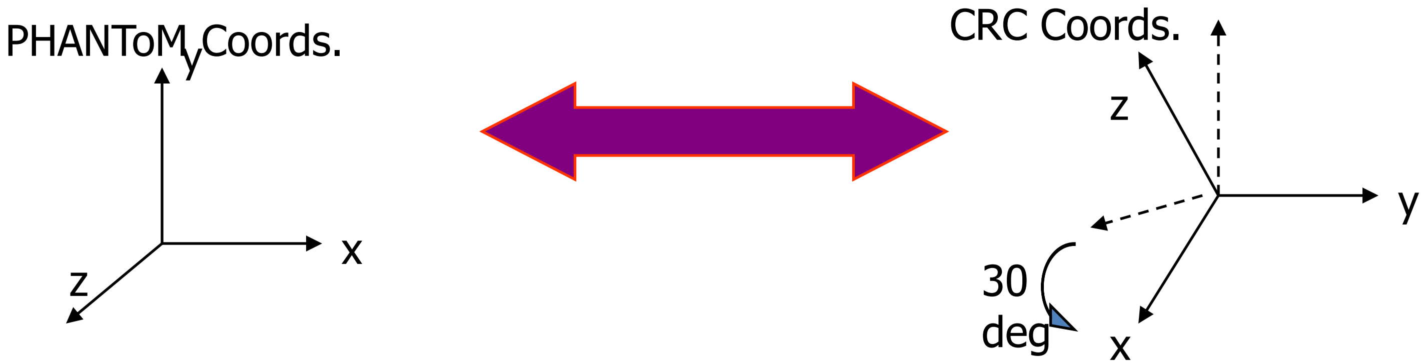
Control Step 1

- PHANToM output position signal must be read by main control algorithm
- Inputs from user to the PHANToM controller determine the final position of the leg
- User input must direct the path of the end of the leg, or foot.

CRC: Compact Rescue Crawler

Control Step 2

- Position inputs (X,Y,Z) are read and converted from PHANToM space coordinates to CRC space



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CRC: Compact Rescue Crawler

Control Step 3

- Position commands converted from x,y,z to joint space (angle commands)
- Angle commands converted into stroke length commands in cylinder space
- Stroke lengths (0 – 1.5”) scaled to 0-10V command

CRC: Compact Rescue Crawler

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Control Step 4

- Position feedback from current stroke lengths are unbiased and rescaled to 0-10V
- 0-10V feedback is compared with 0-10V position signal to create an error signal for each cylinder
- Error signal is sent through a discrete PID gain block to create a signal to the valve spool

$$e = v_{desired} - v_{actual}$$

$$u = K_p \cdot e + K_i \cdot \int e\,dt + K_d \cdot de/dt$$

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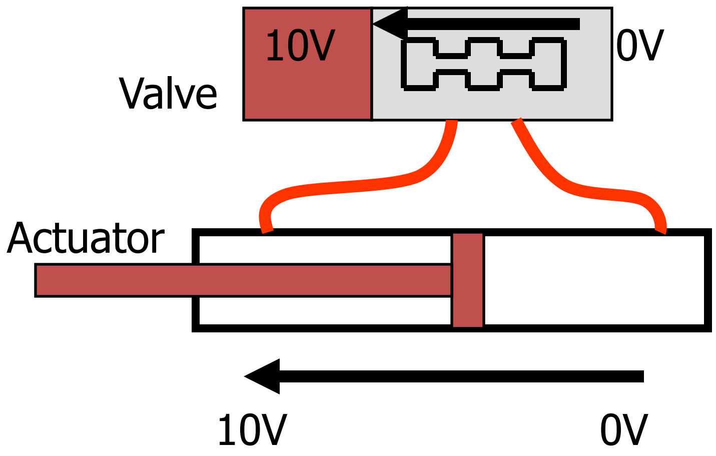
CRC: Compact Rescue Crawler

Control Step 4

- PID adjusted error signal is sent to the valves as the spool reference position
- Spool moves to position based on error signal, allowing pressure and flow to adjust stroke length to zero error.



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