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Mobile Robot Programming Laboratory

Lab 2

Thursday Week 2

http://www.andrew.cmu.edu/course/16-362-862

Agenda Today

- Administrative Issues
- Lab 1 Retrospective
- (Some) Kinematics
- (Some) Control
- Overview of Lab 2

Agenda Today

- **Administrative Issues**
- Lab 1 Retrospective
- (Some) Kinematics
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Scores

- Perfect scores in labs are not expected (or needed) to do well in the course.
- Every group has one or two bad labs over the term.

My Office Hours

- NSH 3209.
- By appointment please.
- Tue 12-1 suggested
- alonzo@cmu.edu

Agenda Today

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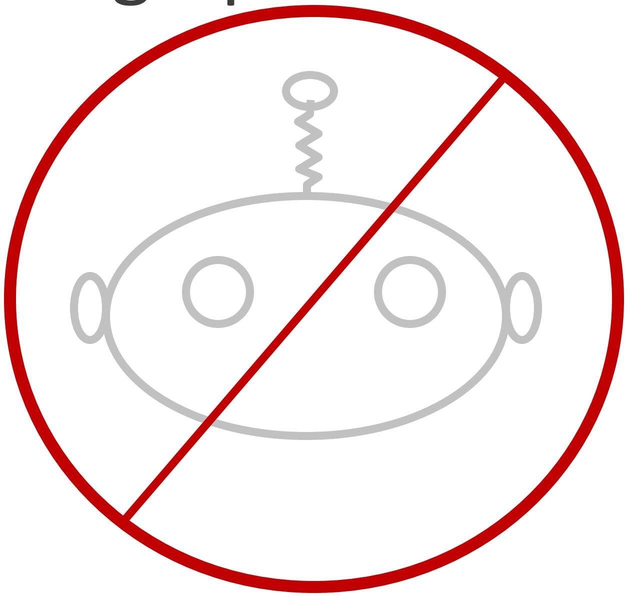
- Administrative issues.
- **Lab 1 Retrospective**
- (Some) Kinematics
- (Some) Control
- Overview of Lab 2

Main Points / Lessons Learned?

- Hardware is awful !
  - Doesn’t do what its told !
  - Doesn’t know what it did !
- Go and do cool graphics instead?



Main Points / Lessons Learned?

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- Development Process for Real Time Work
  - Slowly build up to the point where you throw the big ON switch.
    - Simulation first
    - Robot on blocks second.
  - Design debugging in from the start.
    - Recording and visualization of data is a powerful tool.
  - Simple simulation is easy to make and very useful.
  - This week: Taking notes (e.g. in the form of graphs) can be a productivity tool.

Main Points / Lessons Learned?

- Character of Real Time Code
  - Time is an explicit concern
    - Measure real time in many places.
    - Can control timing of things with pauses.
    - Sit and wait for data.
  - Time is very discrete (10 Hz).
  - Both too slow and too fast are bad things.
    - Sometimes need to make it fast, others make it slow
  - Cope with:
    - delays (in both directions).
    - Nondeterminism (randomness/chaos).

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Coordinate Conventions

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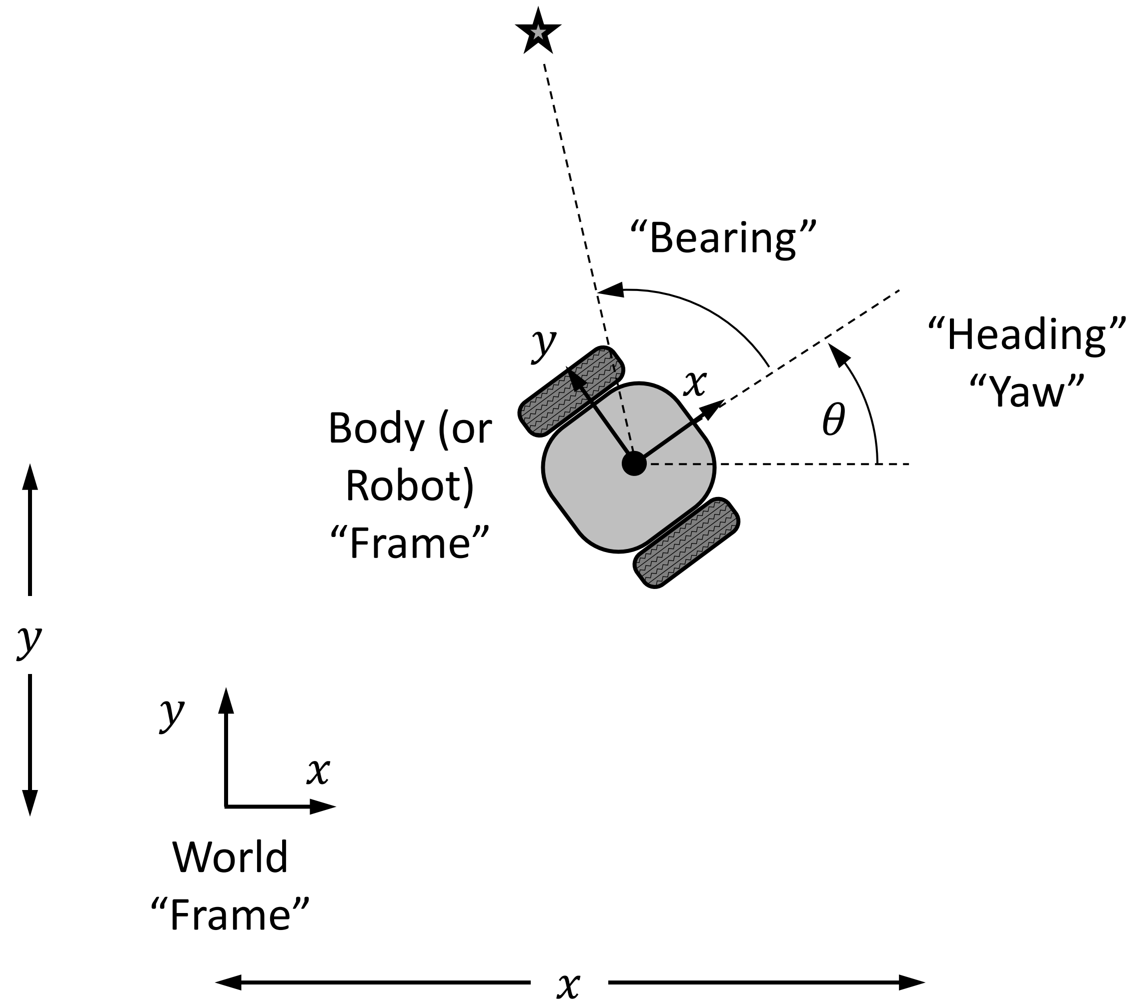
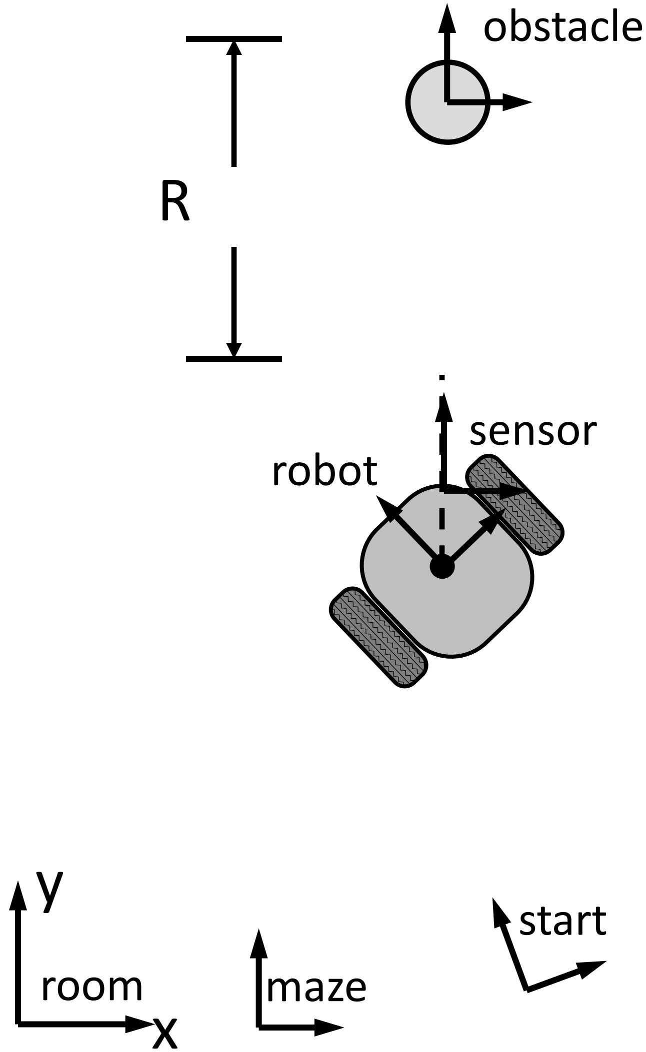


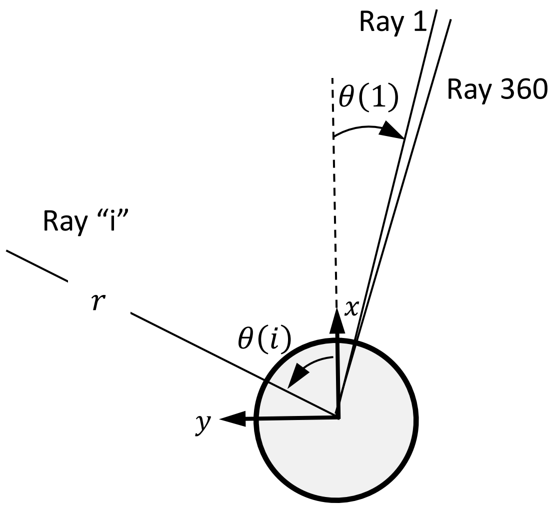
Frames Conceptualization

- Imagine them stuck inside your robot or objects of interest.
  - The floor is an object of interest
- They move with respect to each other.
- Imagine them "stamped" on the floor to remember historical poses of things.

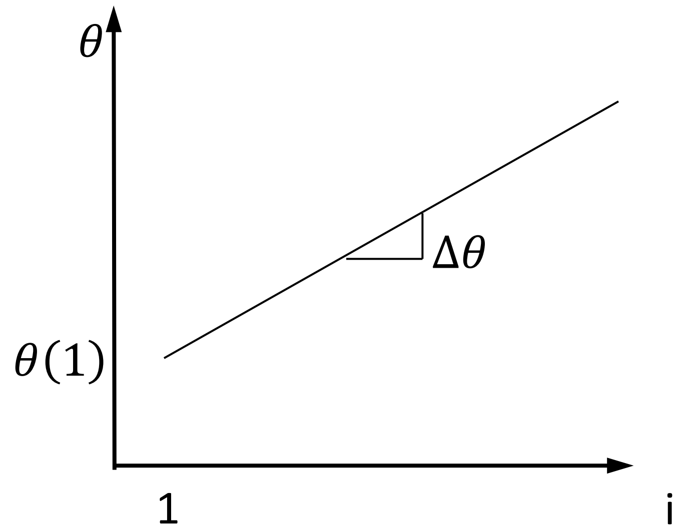


Planar Rangefinder

I to θ and (R, θ) to (x,y)



$$\theta(i) = \theta(1) + (i-1)\Delta\theta$$
$$x(i) = r\cos[\theta(i)]$$
$$y(i) = r\sin[\theta(i)]$$



- I to θ : Angle is linear function of index "i"
  - Where does index 1 [$\theta(1)$] point ?
  - What is the angular spacing ($\Delta\theta$) between pixels ?
- (R, θ) to (x,y) → Use sines and cosines
- Normally, if there are n fence "posts", there are n-1 fence "spaces".
- But when the fence is a circle, there are n spaces. IOW, $\Delta\theta$ = 1 degree.
- Note: It all really depends on the timing of range measurements inside the sensor. In our case, we have verified that:
  - 1) Pixel 1 and pixel 360 are separated by 1 degree.
- So, the above formula for $\theta(i)$ is correct.

Planar Rangefinder

I to θ and (R, θ) to (x,y)

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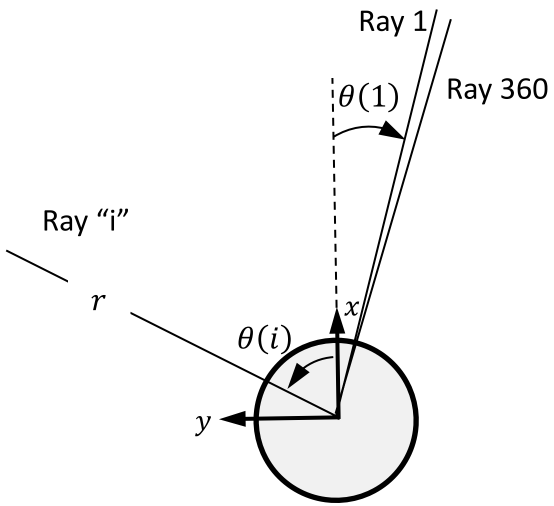

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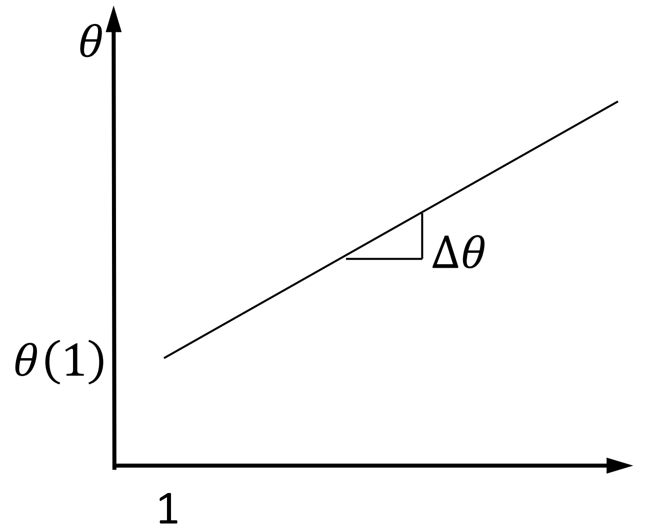


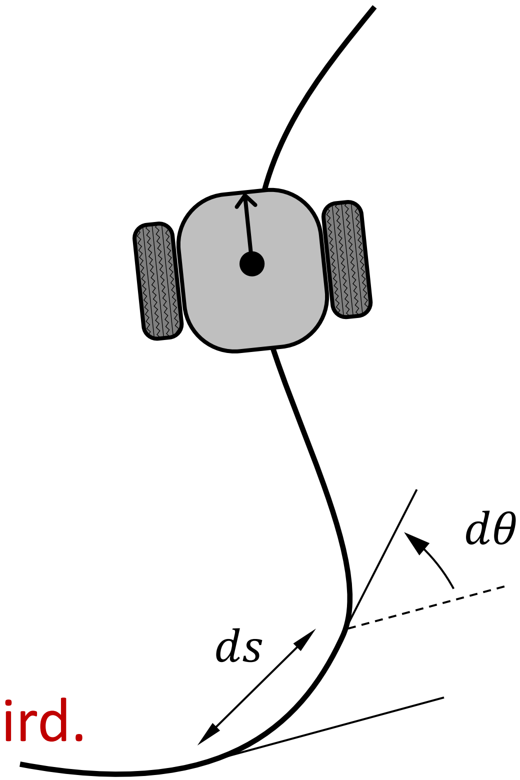
- To keep things simplest, **define the sensor forward axis to be parallel to the robot forward axis**.
- The direction of the first pixel $\theta(1)$ is a different matter. We will directly model the fact that the range data scan is not exactly aligned with the sensor housing.
- Because the sensor "fires" too early, the lidar data (i.e. ray 1) is rotated 5 degrees **clockwise** [$\theta(1)$=-5.0*pi/180] with respect to the robot forward axis.
  – For now (Sept 7, 2017) , this is not the case in the simulator, but it will be fixed in next update.
  – Rotating the sensor clockwise (and not modelling it) causes objects to appear to be moved to the left (i.e. clockwise) by their radius times the rotation angle of the sensor.
    - Generally physically moving a sensor moves the measurement (data) in the opposite direction. E.G. if you raise the sensor that measures the height of the building, the building appears shorter.
    - However, adding an offset to the measurement itself simply adds the same offset to the data. E.G. If the sensor that measures the building always includes an extra meter, the building appears taller. Try not to confuse these two issues.

Path definitions

- Linear velocity $V = \frac{ds}{dt}$
- Angular velocity $\omega = \frac{d\theta}{dt}$
- Curvature $\kappa = \frac{d\theta}{ds}$
- Note that, by chain rule:

$$\frac{d\theta}{dt} = \left(\frac{d\theta}{ds}\right)\left(\frac{ds}{dt}\right)$$

$$\omega = \kappa V$$

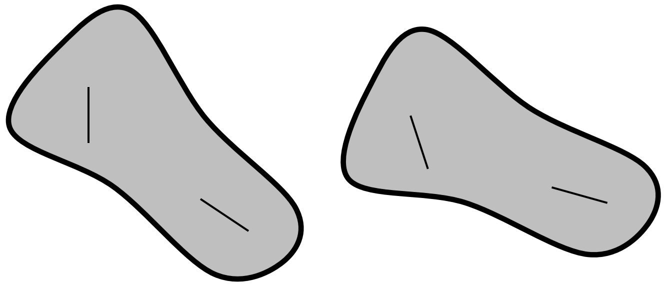


- If you know any two, can solve for the third.
  - Corollary: You can decide on shape κ and speed V independently. Once you decide on both, V and ω are then dependent.
- Also *radius of curvature* $R = 1/\kappa$ is the radius of the circle that corresponds to the arc.

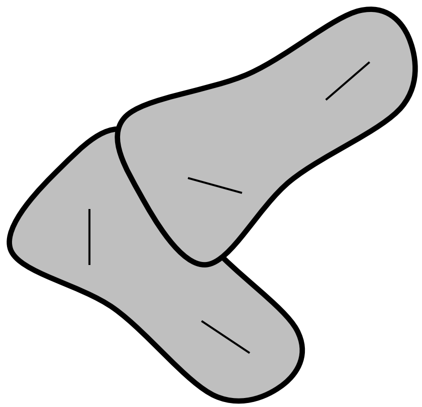
Recall: Rigid body motion

- Stmt #1: All points on a rigid body must have the same angular velocity.
- Stmt #2: Different points on a rigid body may have different linear velocity.

- Two special case exceptions to Stmt #2:
  - 1) Body is translating.
    - Then V vector of those points Is the same.
  - 2) Different points are equidistant from instantaneous center of rotation (ICR).
    - Then |V| of those points is the same.



Consider Rotation of Lines
- Same angle



Consider Translation of Lines
- Big Difference

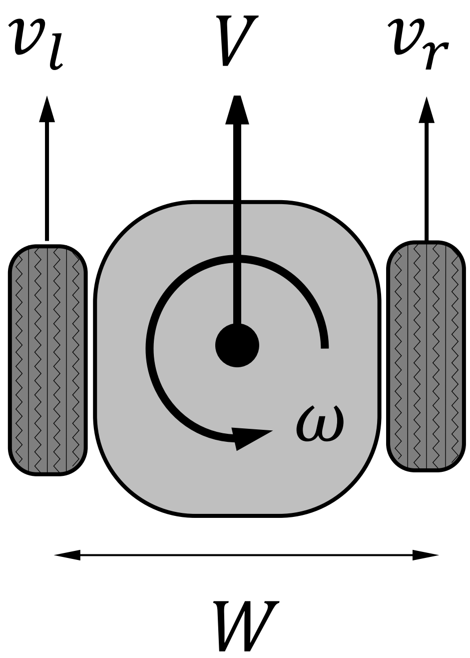
WMR Kinematics

- Forward Kinematics

$$v_r = V + \frac{W}{2}\omega$$
$$v_l = V - \frac{W}{2}\omega$$

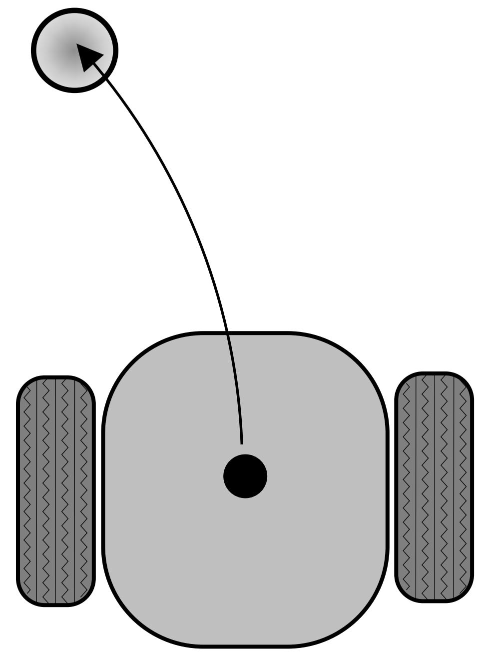
- Inverse Kinematics

$$V = \frac{(v_r + v_l)}{2}$$
$$\omega = \frac{(v_r - v_l)}{W}$$



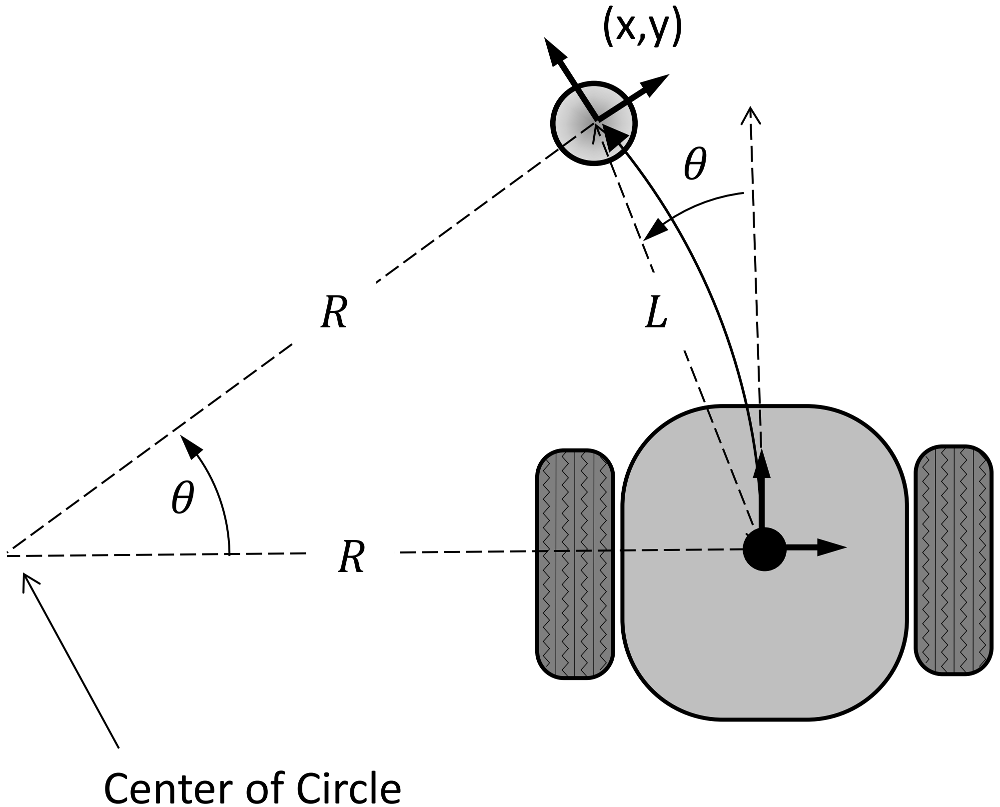
Trajectory generation

- There is an explicit formula…
- Fit a circle?
- Or.. (simpler) recall
  - $\kappa = \frac{d\theta}{ds}$
  - and estimate s



Trajectory Generation

- Fit Circle: Here is some useful geometry….
  - L = from sensor
  - sinθ = ?
  - cosθ = ?
  - Square and add to get L
- Simpler: Approximate curvature:
  - y and y are known
  - $d\theta$ is also θ = θ(i) ~ y/x
  - y/x ~ y/L
  - L = from sensor ~ s
  - $\kappa = \frac{d\theta}{ds} = \frac{y}{L*L}$
- Good enough: Use a proportional gain:
  - $\kappa = k_p * d\theta$
- For this lab, you can assume the sensor is right at the center of the robot.
  - Actually true on the Raspbot robots.



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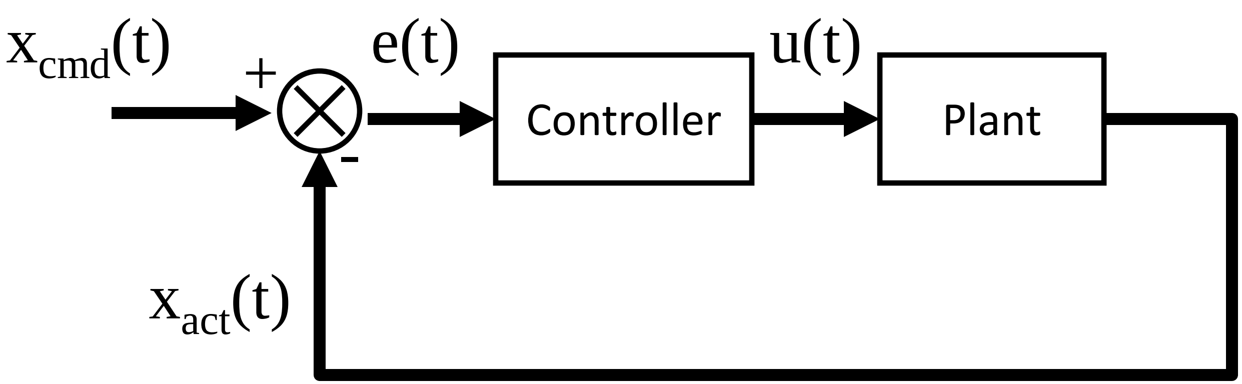
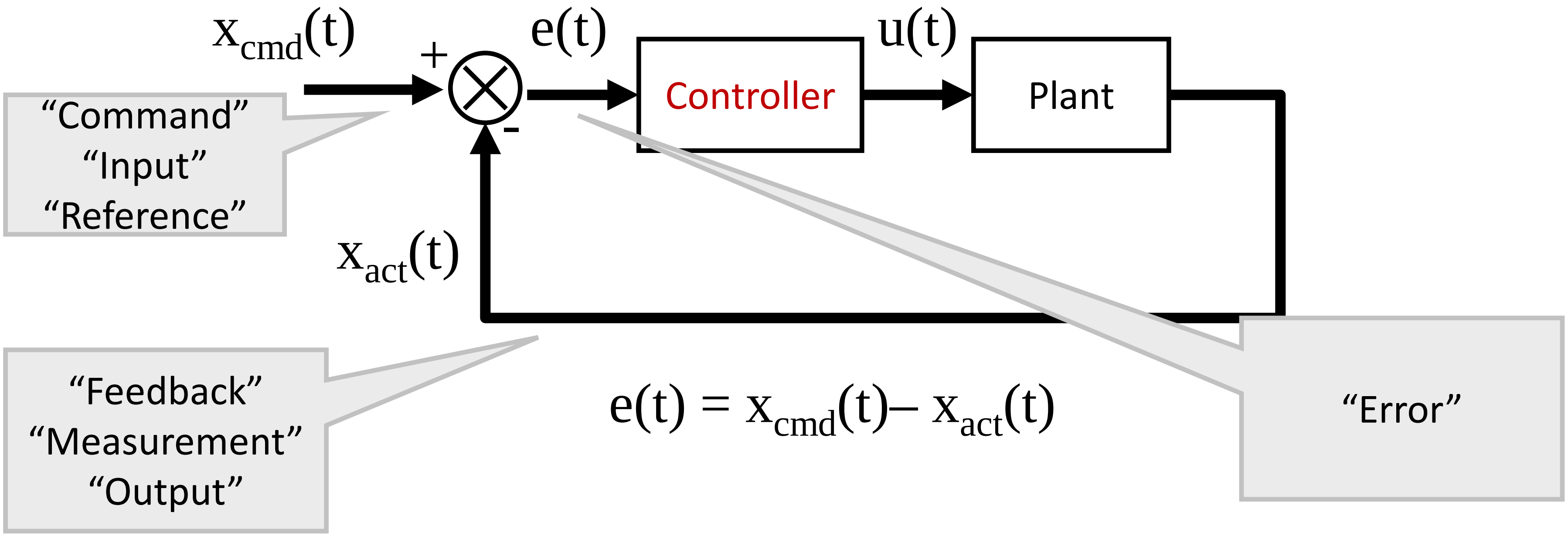
FeedBack Control Primer

- Contrast with "open loop" (send and forget) control.
- Philosophy: You can't predict the future well in most cases (disturbances, model errors).
- Approach: Actively monitor what is going on and correct for errors that <u>were not</u> or <u>could not</u> be predicted.
- Basic issue: u(t) (control) is not x(t) (state). Often u(t) is related to derivatives of x(t). IOW, the system has dynamics.



$$e(t) = x_{cmd}(t) - x_{act}(t)$$

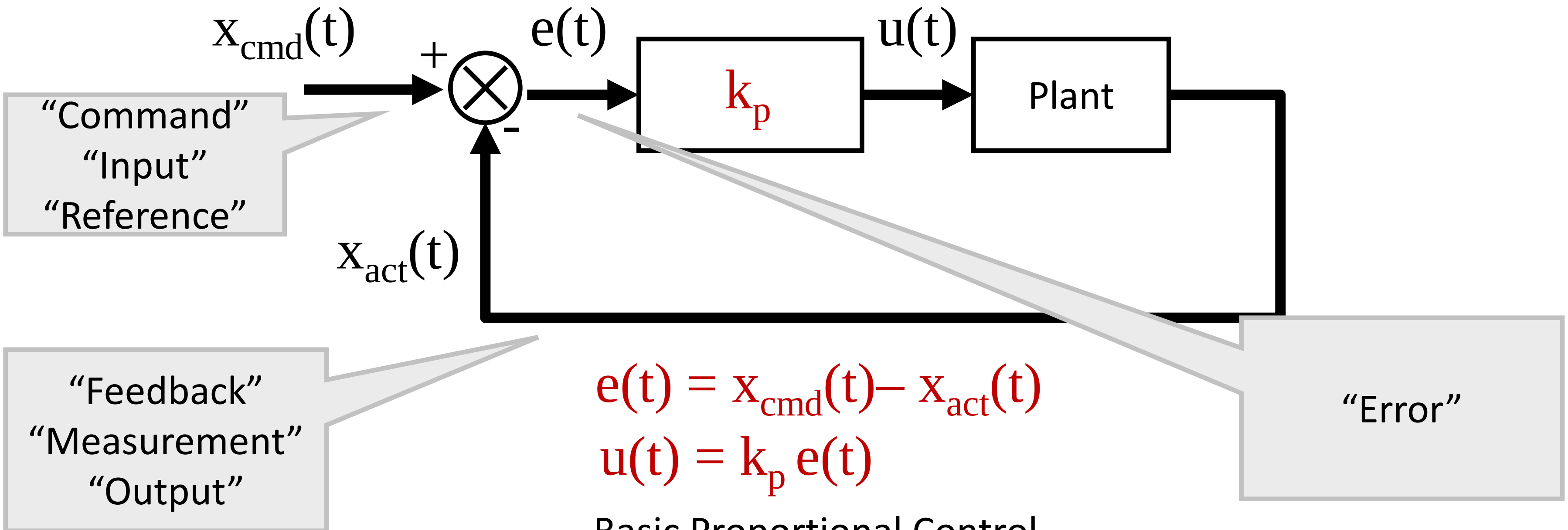
“Controllers”



$$e(t) = x_{cmd}(t) - x_{act}(t)$$

- “Controller” can mean everything but the plant, or just the box above.
- So… What’s in the “controller” box? → next slide.

"Controllers"

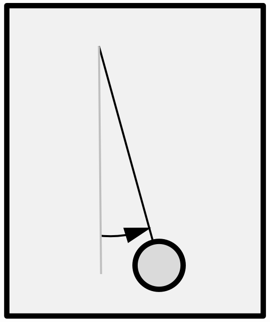


$$e(t) = x_{cmd}(t) - x_{act}(t)$$

$$u(t) = k_p\, e(t)$$

Basic Proportional Control

Example: For a pendulum, the physics are such that gravity opposes any "error" deviation from equilibrium. Gravity acts like a proportional controller and inherently "stabilizes" things - causing the pendulum to come to rest at equilibrium.



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Preparation

- Did everyone read lab 2 before today?

Lab 2 Challenge – Basic Idea

- Process range image to find index i of object.
- Use R(i) and θ(i) to find the (x,y) of object
- Compute curvature from x,y, choose some v
- Compute omega from K,V
- Compute Vl and Vr from V and omega
- Send command out.
- Repeat.

Lab 2 Preparation

- Click for Lab2 Writeup