

# Lab 6: System Identification

EECS 16B Spring 2023



Slides: <http://links.eecs16b.org/lab6-slides-sp23>

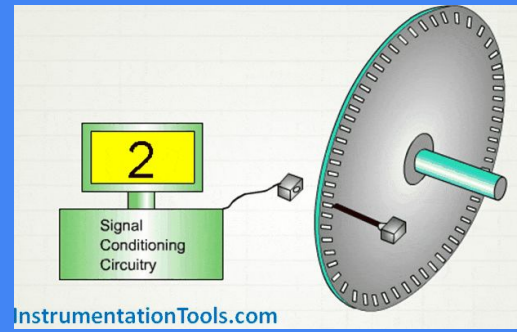
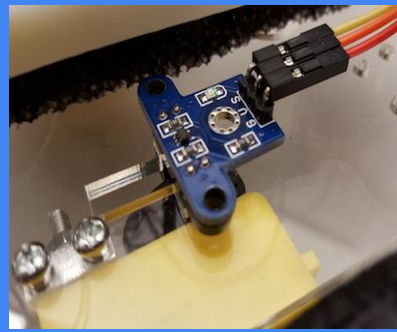
# Administrivia

- If you are outside Cory 125 running your car, put both your computer number and “outside” for computer number field on help request
- Lab Grades error: <https://links.eecs16b.org/lab-checkoff-error>
- **Ensure your lab report partner is added to the Gradescope submission! Resubmissions require you to re-add your team member (past due 3/10)**

# Lab 6 Overview

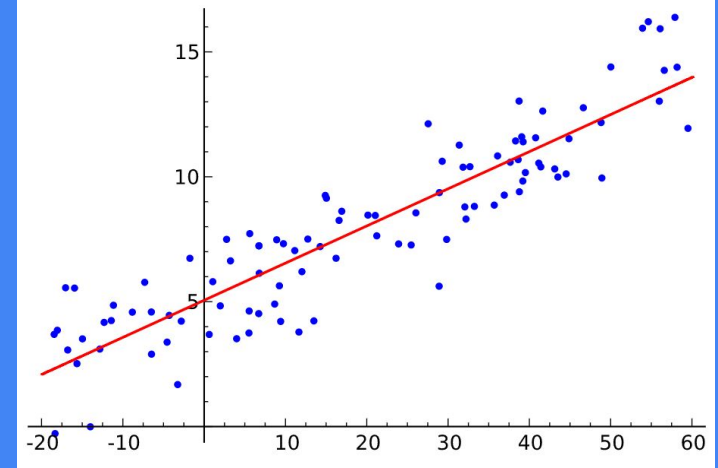
- Sensor Verification
- Model Characterization
  - Data Collection: coarse and fine data
  - Linear Parameter Estimation: least-squares regression analysis
- Determine optimal operating velocity for the car
- Next lab
  - Controls: Design and test open-loop and closed-loop controllers

# Review: Encoders



- Beam of light between 2 “legs”
- As wheel turns, rotates encoder wheel with it
  - Encoder wheel has many holes in it
  - As wheel rotates, spokes block and holes unblock the beam of light
- Can calculate velocity of car from rate of encoder value change
- 3 pins
  - “G” = ground, connect to breadboard 0V negative rail
  - “V” = voltage, connect to breadboard 3.3V positive rail from output of 3.3V regulator, NOT Arduino’s 3.3V pin
  - “S” = encoder signal; input to voltage divider whose output goes to Arduino pins (2 and 3)

# SIXT33N Car Model and Least-Squares



Source: thoughtco

# Car Model

$$\text{Left Side: } v_L[i] = d_L[i+1] - d_L[i] = \theta_L u_L[i] - \beta_L$$

$$\text{Right Side: } v_R[i] = d_R[i+1] - d_R[i] = \theta_R u_R[i] - \beta_R$$

$i$  - current timestep

$v[i]$  - discrete time velocity

$d[i]$  - total number of ticks advanced

$u[i]$  - system input (in PWM, controlled by changing **duty cycle**)

$\theta$  - relates change in input PWM to change in velocity

$\beta$  - velocity offset that encompasses real world imperfections like static friction

Read the [lab note](#) for how we solve for  $\theta$  and  $\beta$  and least-squares review!

# Least Squares Review

$$D_{data} \vec{p} \approx \vec{s}$$
$$\begin{bmatrix} u[0] & -1 \\ u[1] & -1 \\ u[2] & -1 \\ \vdots & \vdots \\ u[\ell-1] & -1 \end{bmatrix} \begin{bmatrix} \theta \\ \beta \end{bmatrix} \approx \begin{bmatrix} v[0] \\ v[1] \\ v[2] \\ \vdots \\ v[\ell-1] \end{bmatrix}$$

- We rearrange our encoder model to resemble a linear equation:
  - Our equation takes the form:  $A\mathbf{x} = \mathbf{b}$
  - We can solve this equation using Linear Least Squares, to find the best fit parameters

$$\mathbf{x} = (A^T A)^{-1} A^T \mathbf{b}$$

$$\vec{p} = (D_{data}^T D_{data})^{-1} D_{data}^T \vec{s}$$

- We know  $u[i]$  and  $v[i]$ , but want to find  $\theta$  and  $\beta$
- Numpy has helpful built-in functions:
  - `Numpy.linalg.lstsq` and `numpy.vstack/numpy.hstack` -> look at the documentation!
  - Transpose arrays with `array_name.T`

# Determine Operating Point

$$v_L[i] = d_L[i+1] - d_L[i] = \theta_L u_L[i] - \beta_L$$
$$v_R[i] = d_R[i+1] - d_R[i] = \theta_R u_R[i] - \beta_R$$

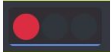

- We measure  $v$ , we know  $u$  (that's our input PWM)
  - We can find  $\theta$  and  $\beta$  from least squares
- Determine operating velocity point: What  $v^*$  should we use? Make sure you check that the chosen  $v^*$  works well with your model!
- Looking ahead to next lab ... open-loop control
  - We can figure out the input  $u$  we need to set to achieve a target velocity  $v^*$
  - Does open-loop control work well for systems with disturbances?



# Letting Your Car Run Free

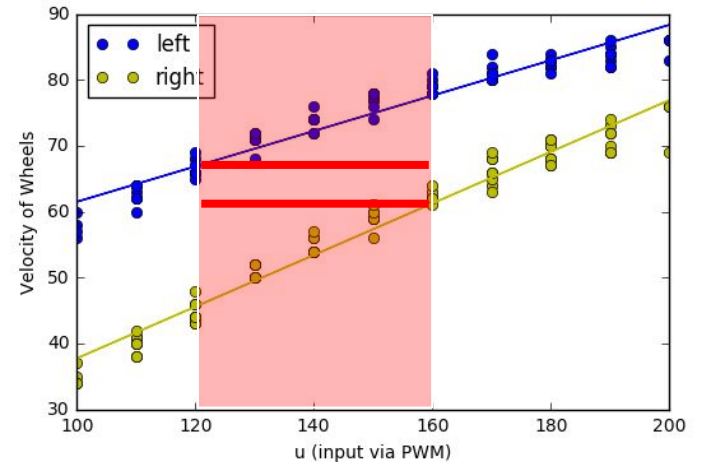


# Collecting “Coarse” Data

- Let car run outside and collect data
  - After a brief delay, the car will begin driving
    - Arduino LEDs countdown 
    - Power the circuit when you are outside
  - The Arduino will sweep through a wide range of PWM values
    - Should see it start fast, slow down, and speed back up before stopping
  - Car will not drive straight (most of the time) 
- After finishing, upload data from Arduino to your computer
  - All 3 Arduino LEDs should blink to indicate that data is available for download
  - DO NOT unplug the Arduino Vin and plug in the USB (yes, at the same time)
  - Type in anything to serial monitor and hit enter to see your data printed

# Collecting Fine Data

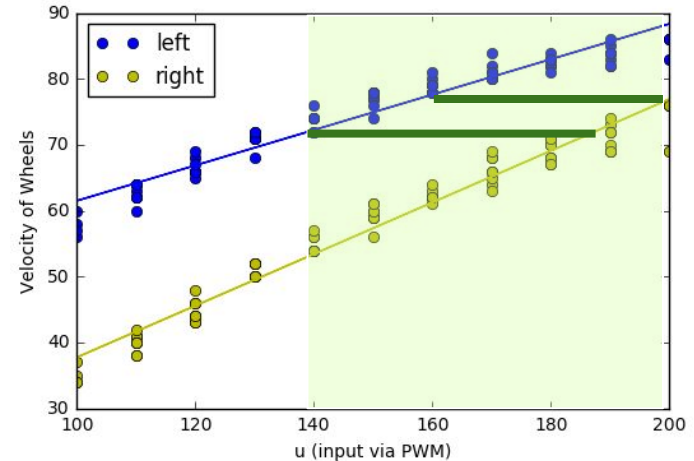
- After collecting “coarse” data, we will zoom into a linear range– where we can model the velocity response to PWM using linear parameters
- Choose a range of PWM values where both wheels can reach the same velocity for some PWM within the range



No overlapping range!

# Collecting Fine Data

- After collecting “coarse” data, we will zoom into a linear range– where we can model the velocity response to PWM using linear parameters
- Choose a range of PWM values where both wheels can reach the same velocity for some PWM within the range



Overlapping range! Yay!

# Powering the Car and Arduino

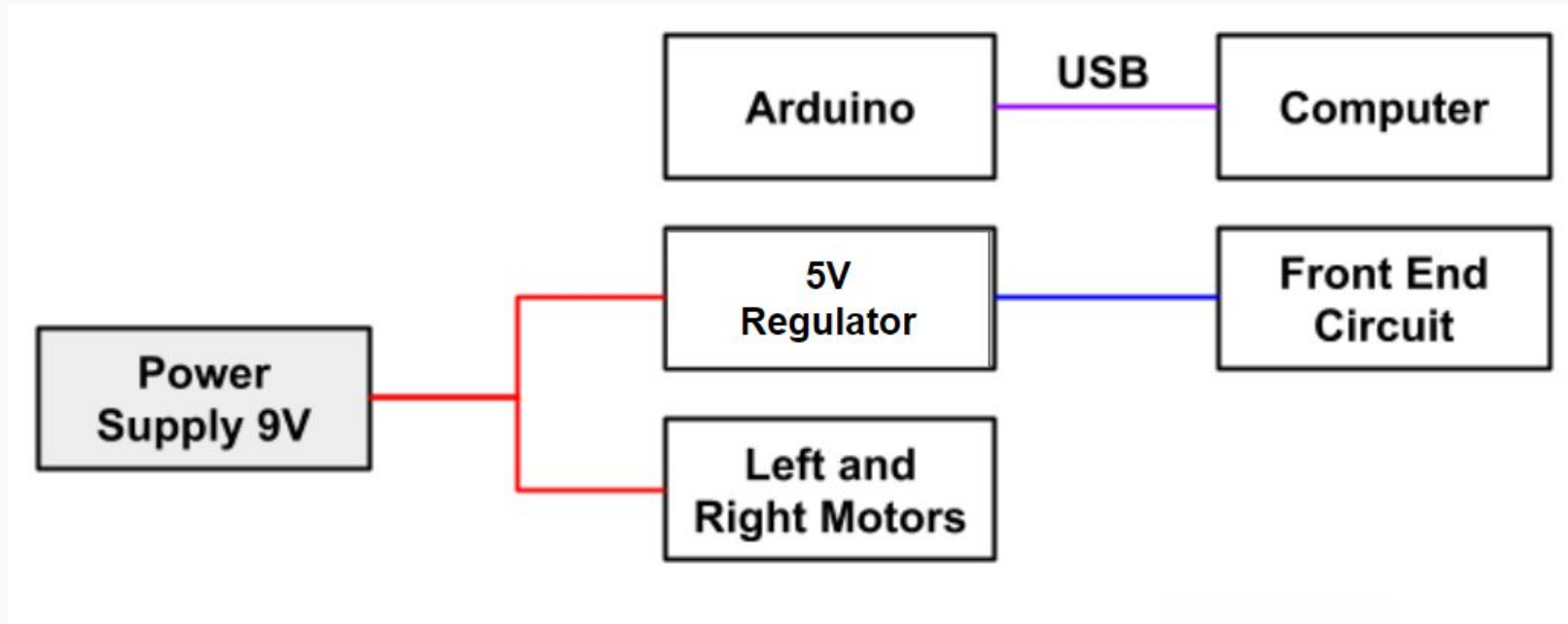
# Powering your car

- Use two 9V batteries
  - One for regulator circuits (and sometimes Arduino), one for motors
  - When using the batteries, the **RED** is 9V and **BLACK** is GND
- When at the lab benches, use power supply and NOT batteries
  - Save batteries for when you're letting the car drive around
  - You'll need to replace batteries if they drain too low (<~7V or when motors stop running)
- Unplug the batteries when not in use to avoid draining them!
- Remove battery clips after lab to avoid accidental shorts!

# Powering your Arduino

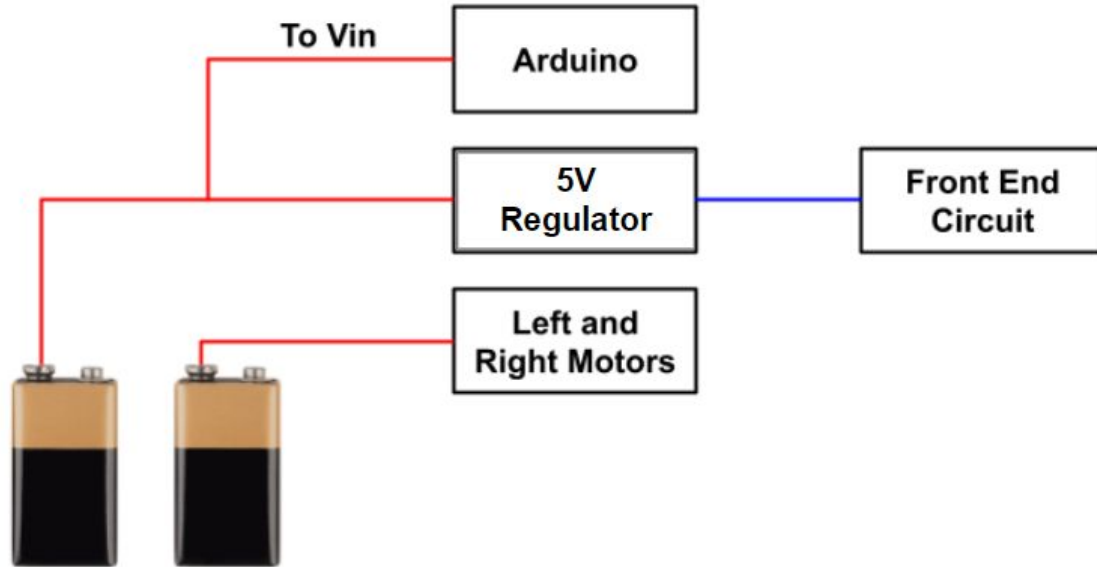
- Arduino has 2 input power options: USB and 7-12V pin
  - Tethered: Use USB when you're uploading code and downloading data
  - Mobile: Use Vin pin (connected to 9V from the regulator battery) when car is driving around
- **Ensure that you plug in BOTH USB and Power when collecting data**

# Tethered Powering: uploading code

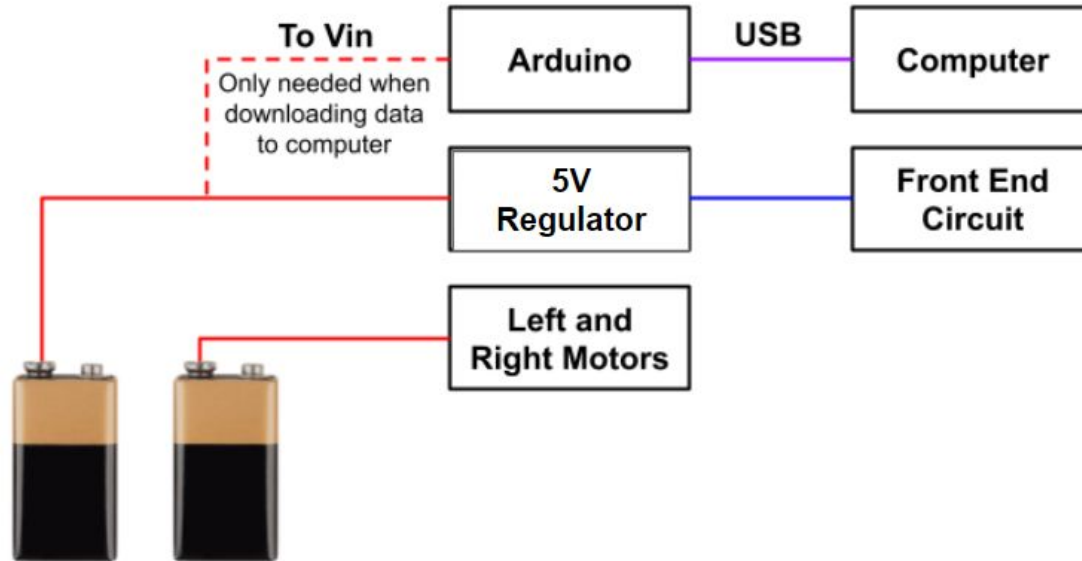




# Mobile Powering: driving car around



# Data Recovery: downloading data



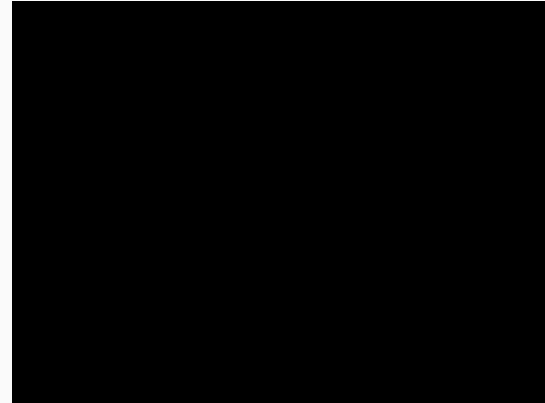
# Analyzing Data

- How well does your model fit your data?
  - Do the lines look like they match up with the dots?
  - Do the velocities of the wheels make sense?
  - Are there different ranges of velocities where our linear model fits better than others?
- Common Bugs
  - Data is flat despite wheels turning → rerun encoder tests
  - Isolate issues by using symmetry to your advantage if one side works → swap components to see if it is a circuit, wire, encoder, or Arduino pin issue

# Tips, Tricks, and Warnings



- Collect data in wide, flat area (hallways outside Cory 125)
  - Try to reposition car so that it doesn't hit any walls
  - If car is going to hit a wall, quickly pick it up and change its direction before it collides
- Car's orientation
  - **When the car is moving, the castor wheel should always be at the back of the car**



# Important Forms/Links

- Help request form: <https://eecs16b.org/lab-help>
- Checkoff request form: <https://eecs16b.org/lab-checkoff>
- Extension Requests: <https://eecs16b.org/extensions>
- Makeup Lab: <https://makeup.eecs16b.org>
- Slides: [links.eecs16b.org/lab6-slides-sp23](https://links.eecs16b.org/lab6-slides-sp23)
- Anon Feedback: <https://eecs16b.org/lab-anon-feedback>
- Lab Grades error: <https://links.eecs16b.org/lab-checkoff-error>