

Robot Motion Control

PIC + Motor + Encoder => Motion

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I, Robot



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Hal



C3P0 & R2D2

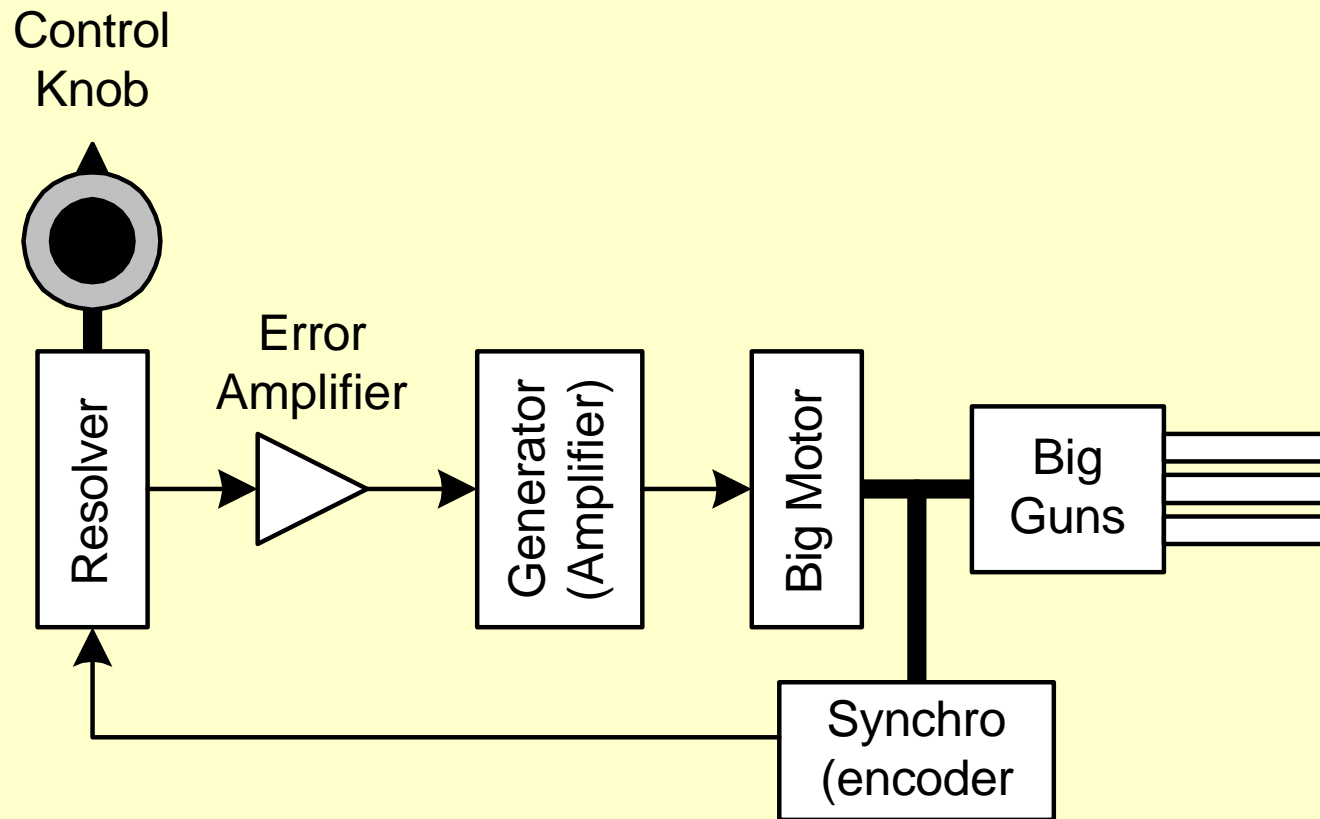


Johnny 5

Agenda

- Control Theory Origins
- Position and velocity control
- Real world: PIC + Motor + Encoder
- DC Motor & PWM models
- Simple velocity control: velocity profiles
- Reality, hidden gotchas and tricks

Origins: Battleship Gun Pointing



Problem: Oscillation

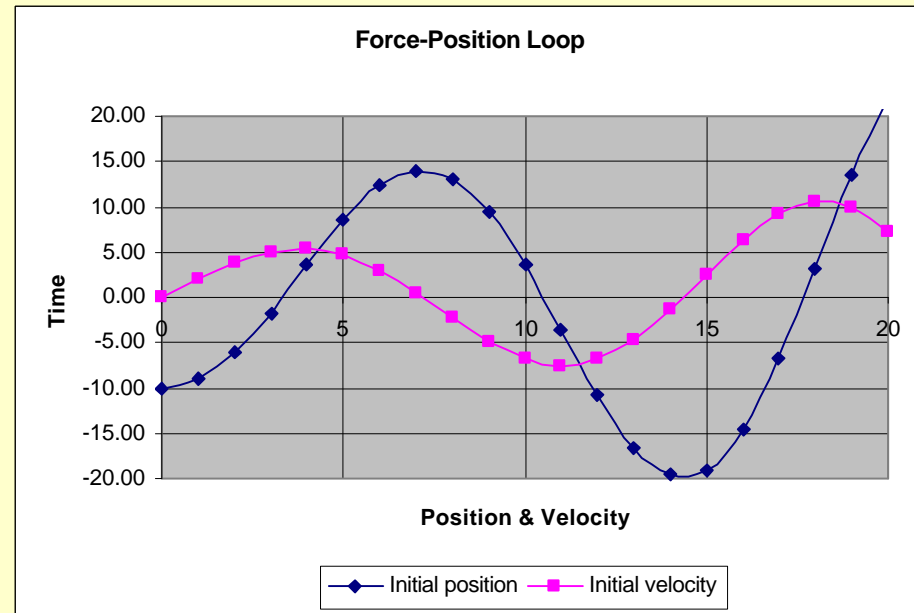
- Problem: gun platform oscillated
 - Oscillations increased to limits
 - Changing gains, etc. did not change problem
 - Oops
 - Bring in the theoreticians!

Solution: Velocity Feedback

- Simple solution: add velocity feedback
 - Initially done using simple RC circuits
 - RC circuits derived velocity from position
 - Impressive & mysterious!
 - Small circuit change makes big gun behave!

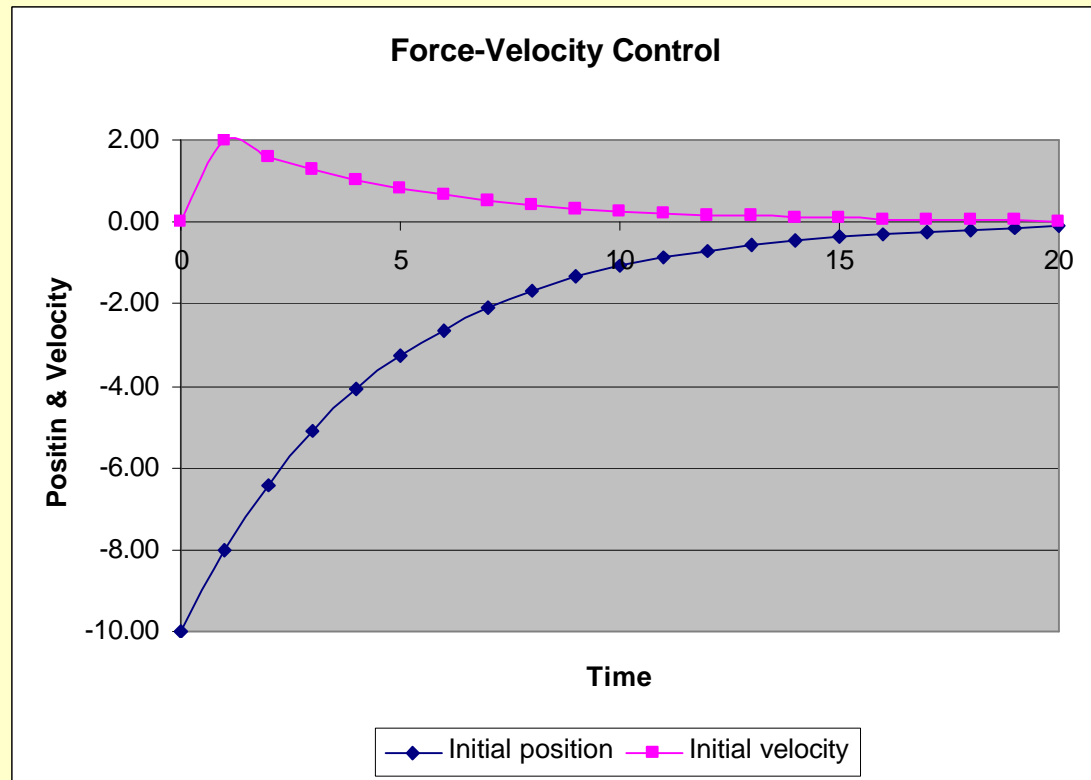
Force-Position Control

Error constant:		-0.10	Amps per inch of position error					
Motor constant:		2.00	in/sec/sec per Amp					
Time Step	Initial position	Initial velocity	Position error	Motor current	Acceleration	Velocity added	Final velocity	Position change
0	-10.00	0.00	-10.00	1.00	2.00	2.00	2.00	1.00
1	-9.00	2.00	-9.00	0.90	1.80	1.80	3.80	2.90
2	-6.10	3.80	-6.10	0.61	1.22	1.22	5.02	4.41
3	-1.69	5.02	-1.69	0.17	0.34	0.34	5.36	5.19
4	3.50	5.36	3.50	-0.35	-0.70	-0.70	4.66	5.01
5	8.51	4.66	8.51	-0.85	-1.70	-1.70	2.96	3.81
6	12.31	2.96	12.31	-1.23	-2.46	-2.46	0.49	1.73
7	14.04	0.49	14.04	-1.40	-2.81	-2.81	-2.31	-0.91
8	13.13	-2.31	13.13	-1.31	-2.63	-2.63	-4.94	-3.63
9	9.50	-4.94	9.50	-0.95	-1.90	-1.90	-6.84	-5.89
10	3.61	-6.84	3.61	-0.36	-0.72	-0.72	-7.56	-7.20
11	-3.59	-7.56	-3.59	0.36	0.72	0.72	-6.85	-7.20
12	-10.79	-6.85	-10.79	1.08	2.16	2.16	-4.69	-5.77
13	-16.56	-4.69	-16.56	1.66	3.31	3.31	-1.37	-3.03
14	-19.59	-1.37	-19.59	1.96	3.92	3.92	2.54	0.58
15	-19.01	2.54	-19.01	1.90	3.80	3.80	6.34	4.44
16	-14.56	6.34	-14.56	1.46	2.91	2.91	9.26	7.80
17	-6.76	9.26	-6.76	0.68	1.35	1.35	10.61	9.93
18	3.17	10.61	3.17	-0.32	-0.63	-0.63	9.97	10.29
19	13.46	9.97	13.46	-1.35	-2.69	-2.69	7.28	8.63
20	22.09	7.28	22.09	-2.21	-4.42	-4.42	2.86	5.07



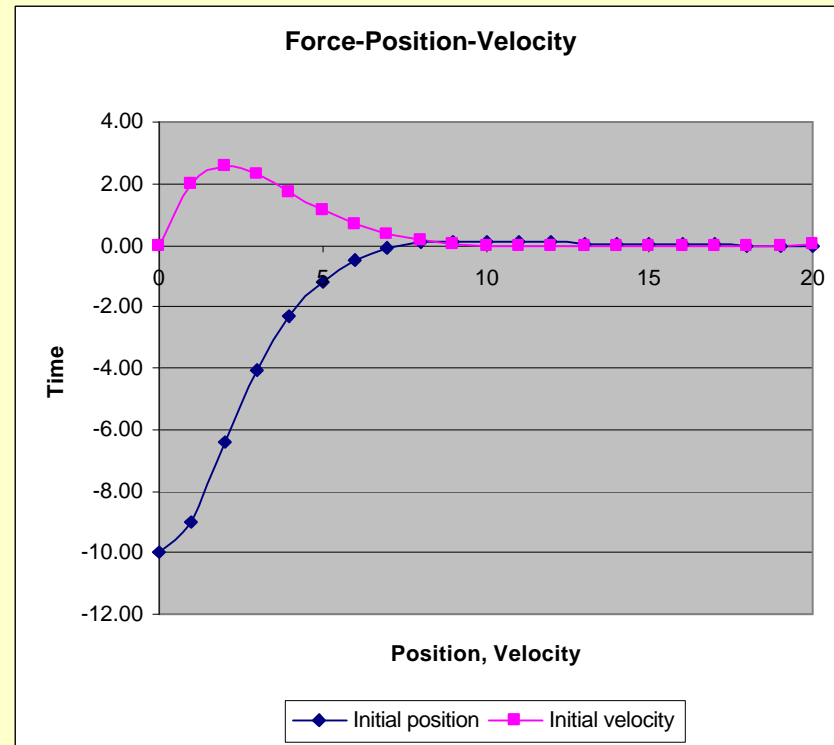
Force-Velocity Control

Error constant:		-0.20	in/sec per inch of error			
Time Step	Initial position	Initial velocity	Position error	Velocity	Position change	
0	-10.00	0.00	-10.00	2.00	2.00	
1	-8.00	2.00	-8.00	1.60	1.60	
2	-6.40	1.60	-6.40	1.28	1.28	
3	-5.12	1.28	-5.12	1.02	1.02	
4	-4.10	1.02	-4.10	0.82	0.82	
5	-3.28	0.82	-3.28	0.66	0.66	
6	-2.62	0.66	-2.62	0.52	0.52	
7	-2.10	0.52	-2.10	0.42	0.42	
8	-1.68	0.42	-1.68	0.34	0.34	
9	-1.34	0.34	-1.34	0.27	0.27	
10	-1.07	0.27	-1.07	0.21	0.21	
11	-0.86	0.21	-0.86	0.17	0.17	
12	-0.69	0.17	-0.69	0.14	0.14	
13	-0.55	0.14	-0.55	0.11	0.11	
14	-0.44	0.11	-0.44	0.09	0.09	
15	-0.35	0.09	-0.35	0.07	0.07	
16	-0.28	0.07	-0.28	0.06	0.06	
17	-0.23	0.06	-0.23	0.05	0.05	
18	-0.18	0.05	-0.18	0.04	0.04	
19	-0.14	0.04	-0.14	0.03	0.03	
20	-0.12	0.03	-0.12	0.02	0.02	



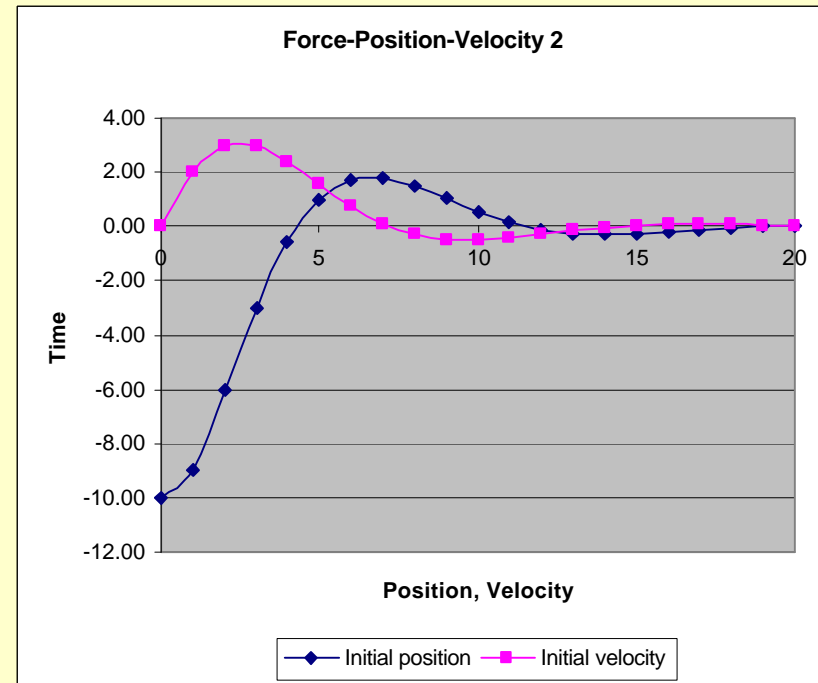
Force-Position with Velocity

Position Error constant:		-0.20					
Velocity Error constant:		-0.60					
Time Step	Initial position	Initial velocity	Position error	Acceleration	Velocity change	Ending Velocity	Average Velocity
0	-10.00	0.00	-10.00	2.00	2.00	2.00	1.00
1	-9.00	2.00	-9.00	0.60	0.60	2.60	2.60
2	-6.40	2.60	-6.40	-0.28	-0.28	2.32	2.32
3	-4.08	2.32	-4.08	-0.58	-0.58	1.74	1.74
4	-2.34	1.74	-2.34	-0.58	-0.58	1.16	1.16
5	-1.17	1.16	-1.17	-0.46	-0.46	0.70	0.70
6	-0.47	0.70	-0.47	-0.33	-0.33	0.37	0.37
7	-0.10	0.37	-0.10	-0.21	-0.21	0.17	0.17
8	0.07	0.17	0.07	-0.12	-0.12	0.05	0.05
9	0.13	0.05	0.13	-0.06	-0.06	0.00	0.00
10	0.12	0.00	0.12	-0.02	-0.02	-0.03	-0.03
11	0.10	-0.03	0.10	0.00	0.00	-0.03	-0.03
12	0.07	-0.03	0.07	0.00	0.00	-0.03	-0.03
13	0.04	-0.03	0.04	0.01	0.01	-0.02	-0.02
14	0.02	-0.02	0.02	0.01	0.01	-0.01	-0.01
15	0.01	-0.01	0.01	0.00	0.00	-0.01	-0.01
16	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Force-Position with Velocity 2

Position Error constant:		-0.20					
Velocity Error constant:		-0.40					
Time Step	Initial position	Initial velocity	Position error	Acceleration	Velocity change	Ending Velocity	Average Velocity
0	-10.00	0.00	-10.00	2.00	2.00	2.00	1.00
1	-9.00	2.00	-9.00	1.00	1.00	3.00	3.00
2	-6.00	3.00	-6.00	0.00	0.00	3.00	3.00
3	-3.00	3.00	-3.00	-0.60	-0.60	2.40	2.40
4	-0.60	2.40	-0.60	-0.84	-0.84	1.56	1.56
5	0.96	1.56	0.96	-0.82	-0.82	0.74	0.74
6	1.70	0.74	1.70	-0.64	-0.64	0.11	0.11
7	1.81	0.11	1.81	-0.40	-0.40	-0.30	-0.30
8	1.51	-0.30	1.51	-0.18	-0.18	-0.48	-0.48
9	1.03	-0.48	1.03	-0.01	-0.01	-0.49	-0.49
10	0.53	-0.49	0.53	0.09	0.09	-0.40	-0.40
11	0.13	-0.40	0.13	0.14	0.14	-0.27	-0.27
12	-0.14	-0.27	-0.14	0.13	0.13	-0.13	-0.13
13	-0.27	-0.13	-0.27	0.11	0.11	-0.03	-0.03
14	-0.30	-0.03	-0.30	0.07	0.07	0.04	0.04
15	-0.25	0.04	-0.25	0.03	0.03	0.08	0.08
16	-0.18	0.08	-0.18	0.00	0.00	0.08	0.08
17	-0.09	0.08	-0.09	-0.01	-0.01	0.07	0.07
18	-0.03	0.07	-0.03	-0.02	-0.02	0.05	0.05
19	0.02	0.05	0.02	-0.02	-0.02	0.02	0.02
20	0.04	0.02	0.04	-0.02	-0.02	0.01	0.01



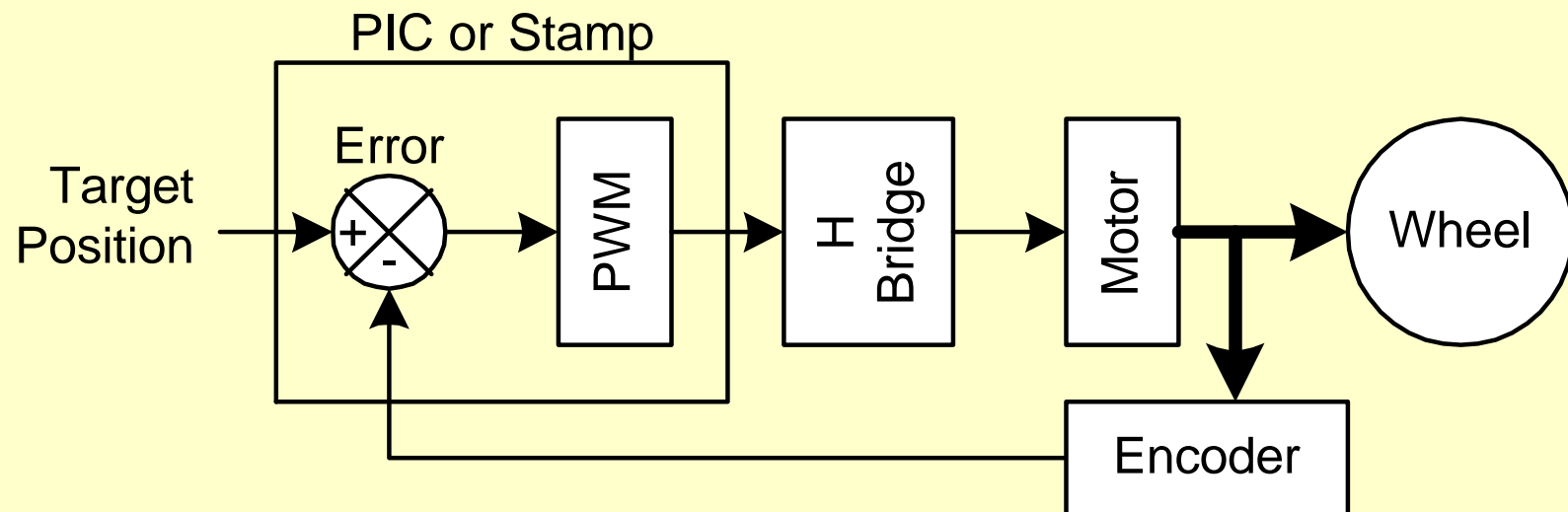
Notes on Control

- Force- position control oscillates
- Velocity control is generally stable
- Position with velocity feedback works too
 - If perfectly tuned, it looks like velocity control
 - If not enough velocity FB, you get ringing
 - A little overshoot is good: quicker to target

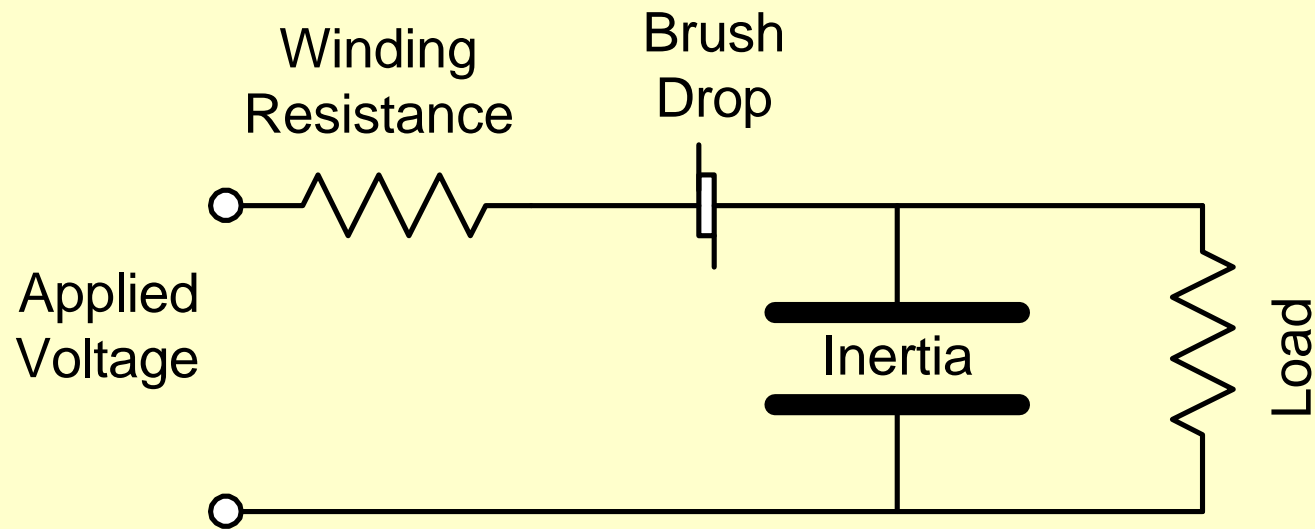
Implications: Stepper Motors

- Force-Position is like a spring and a weight
 - Inherently oscillatory
- Stepper motors are force-position
 - Step change => magnetic force to move, hold
 - Natural ringing: torsional oscillation
 - Typically rely on external friction to damp
- Brushless DC motor = stepper w/ big steps

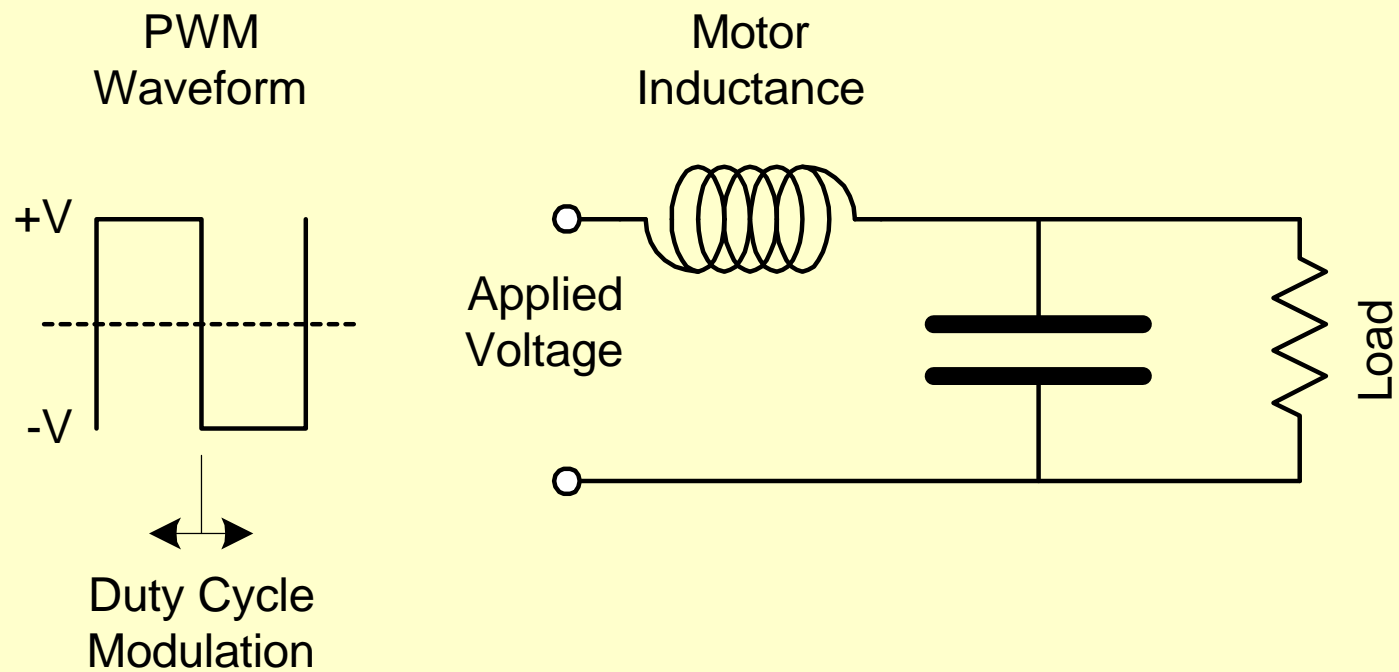
Robots: PIC+Motor+Encoder



DC Motor Electrical Model



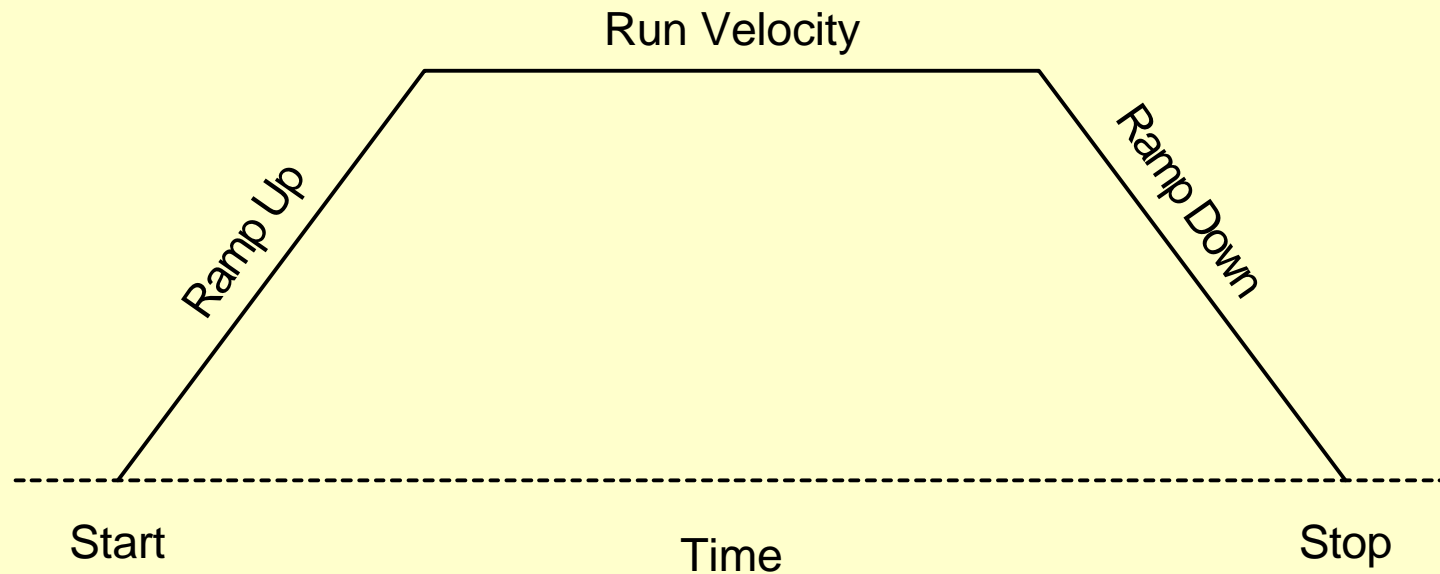
How PWM Works



PWM+Motor => Velocity

- PWM generates a voltage ~ duty cycle
- Applying a voltage to a motor = velocity
 - Velocity constant = emf voltage/1000 RPM
- PWM + motor => velocity control
 - Not exact: drops with load due to winding res.

Simple Control: Velocity Profiles



Simple Control: Velocity Profiles

- Distance = ramp distances + run distance
- Set run velocity
- Calculate ramp times => ramp distances
- Calculate run distance = total – ramps
- Calculate run time
- Tweak as you run to stay on profile

Reality & Hidden Gotchas

- Velocity measurement and noise
- H bridges & current limit
- Backlash and friction

Velocity Measurement

- Typical: derive from encoder differences
 - Problem: few counts/sample => noise
 - Tradeoff: sample slower vs bandwidth
- Other techniques nice but...
 - Pure velocity feedback = add a 2nd motor/gen
 - Use a high resolution (expensive) encoder
 - Use a 360 degree pot + ADCs + aspirin.....

Velocity Measurement Trick 1

- Don't measure counts, measure time
 - Measure the time between counts
 - Good job for hardware: 10 MHz + counter, etc.
 - Calculate $1/X$ to get effective frequency
 - Average over several counts
- See relevant application note

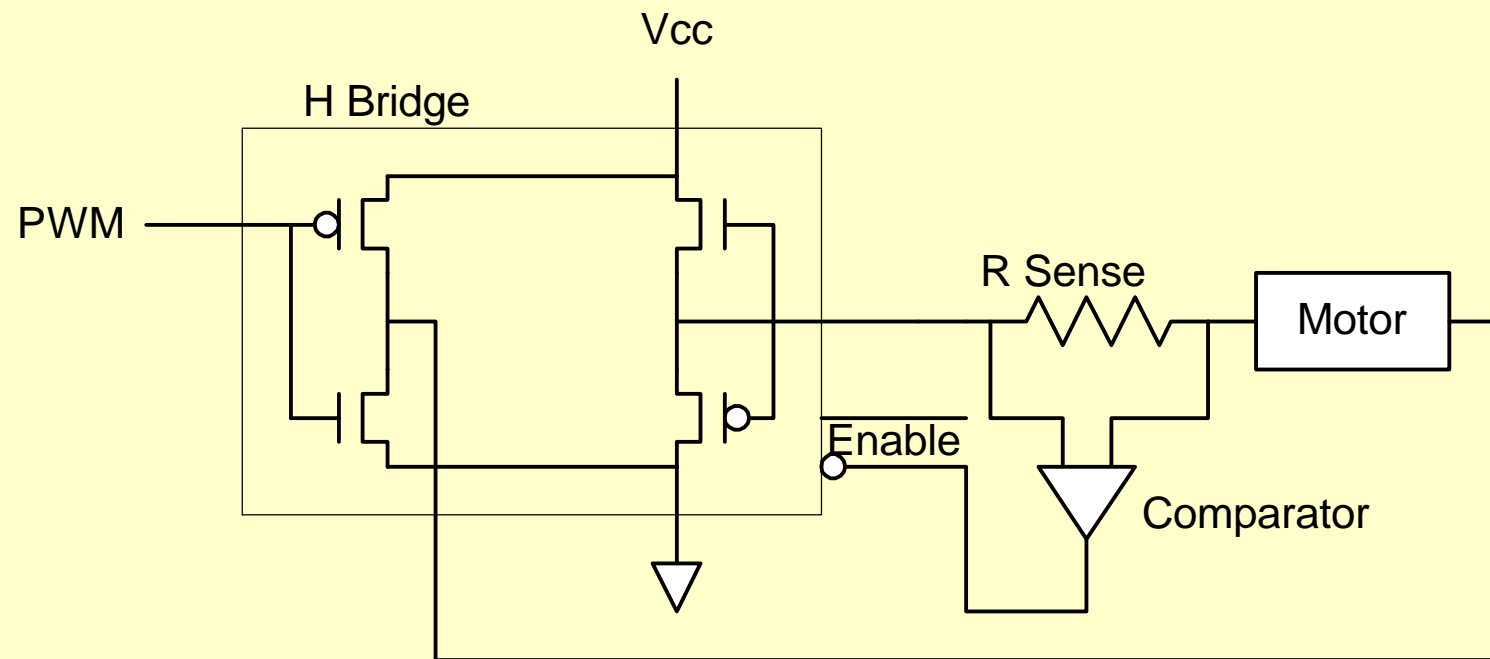
Velocity Measurement Trick 2

- Digitize the raw encoder analog signals
 - Analog signals will be sin/cosine waves
 - Threshold converts to 0/90/180/270 degrees
 - Digitize sine/cosine waves = ADC
 - Do table lookup + calc to get actual angle
- I used this in an R&D disk servo
 - 1.5 meter/sec speed, 0.10 micron resolution

H Bridges & Current Limit

- Burning out H bridges a common problem
- Solution: put a current limit in
- Measure motor current (not H bridge)
- When motor current = peak, turn off bridge
- Turn back on again at lower level
 - Use some hysteresis

H Bridge Current Limit



Backlash & Friction

- Backlash = gears not in continuous contact
 - See it when you change direction
 - Makes for jumpiness and wear
- Friction: viscous and Coulomb
 - Viscous = like syrup = proportional to speed
 - Coulomb = stick/slip
 - Also makes for jumpiness

END