University of BRISTOL

REVIEW & STATE SPACE INTRO

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https://unsplash.com/@cookaynne

Feedback (from you)

- 10/158 responses

- More guidance
- I'm still unsure what I should be doing
- More coverage of basic control concepts
- More linking back to previous learning

- I appreciate the mixture of theory and MATLAB
- Please be clear of when coursework is set
  - the lecturer has said it will be set on a certain day but it has not

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Mentimeter

(Start of lecture) Current feeling/comments...

fast
bold
inspiration
creative
leader
focus
transpiration

Menti

Control L3

Choose a slide to present

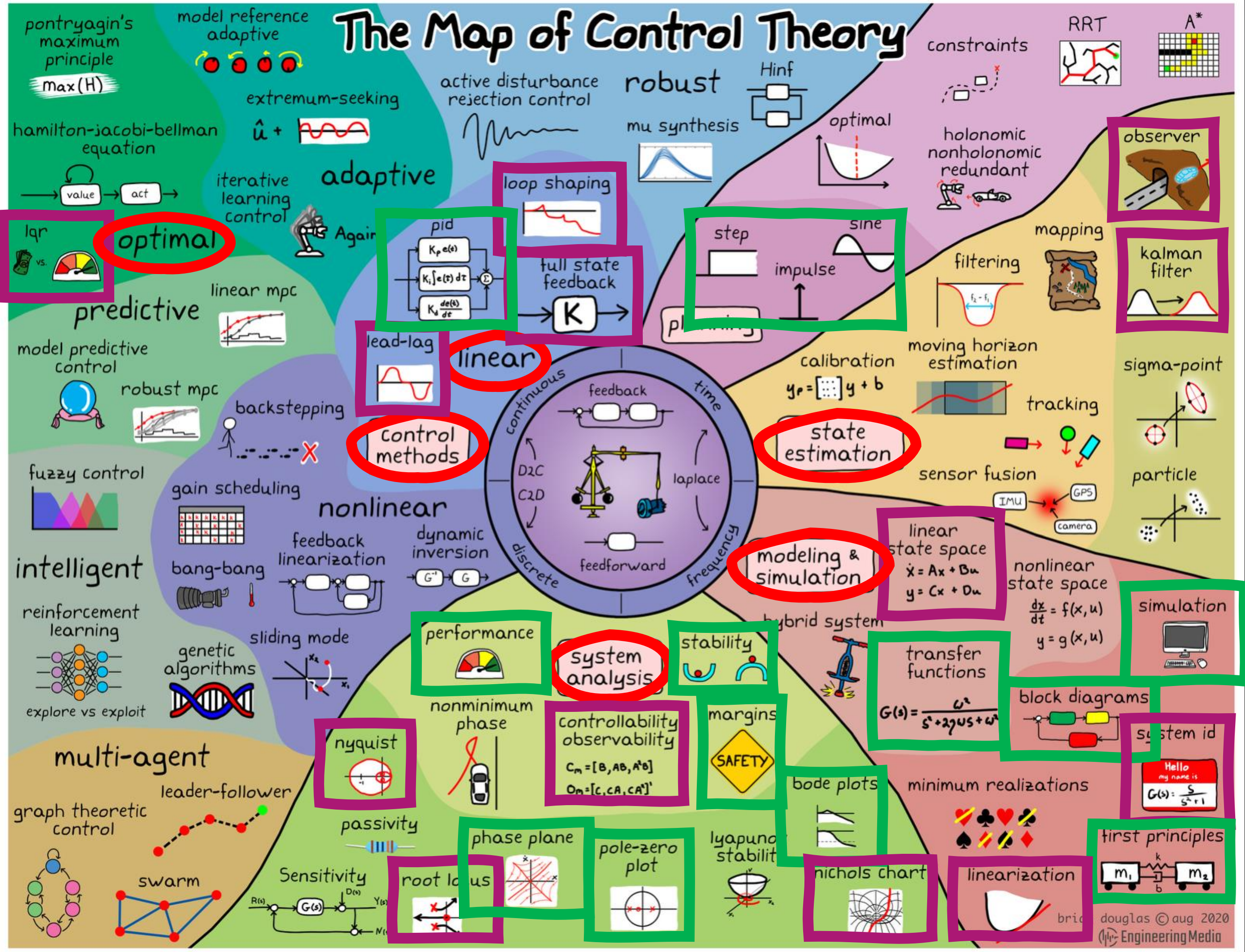
Current feeling...

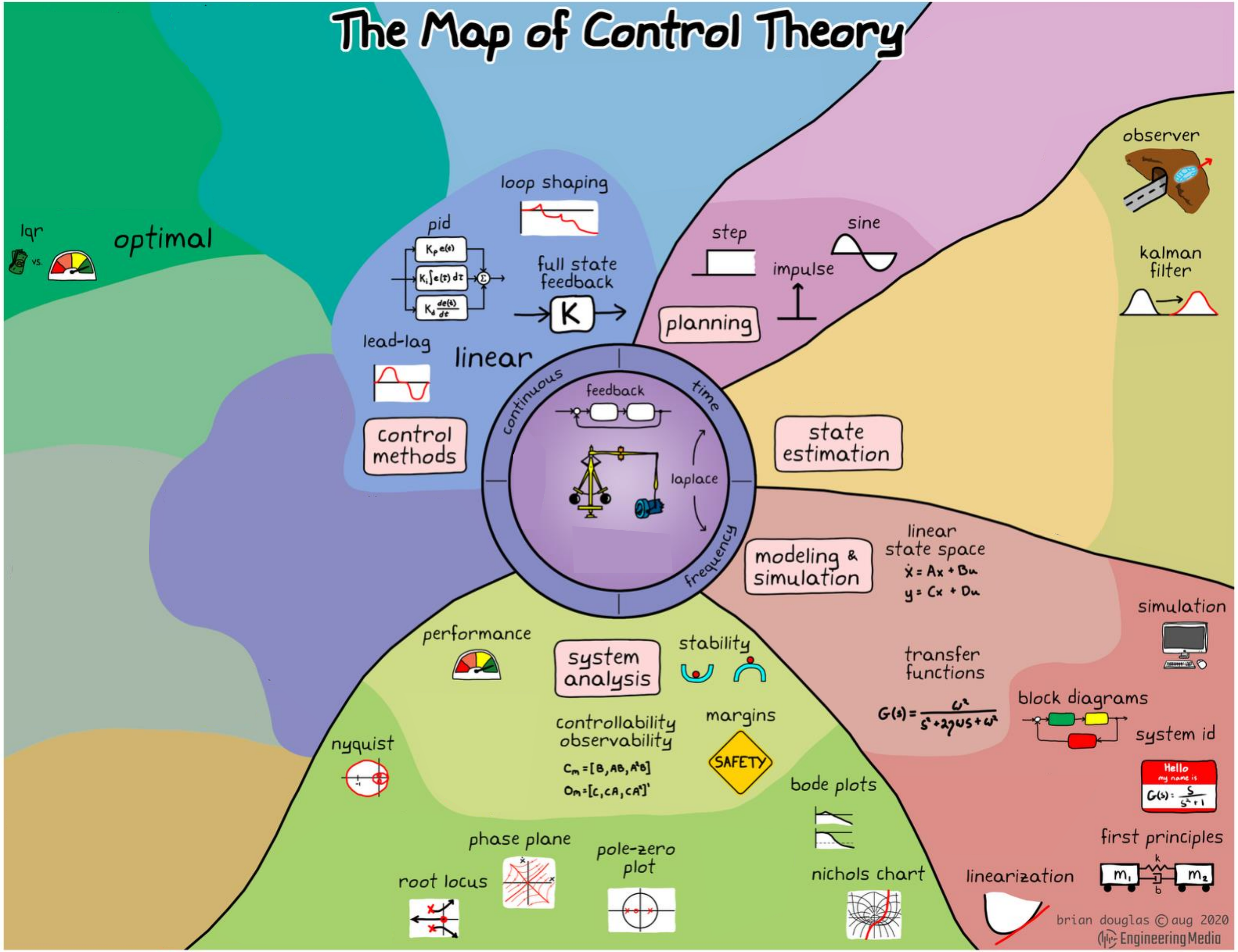
(After concept outline) Current feeling...

(After recap) Current feeling/comments...

Today

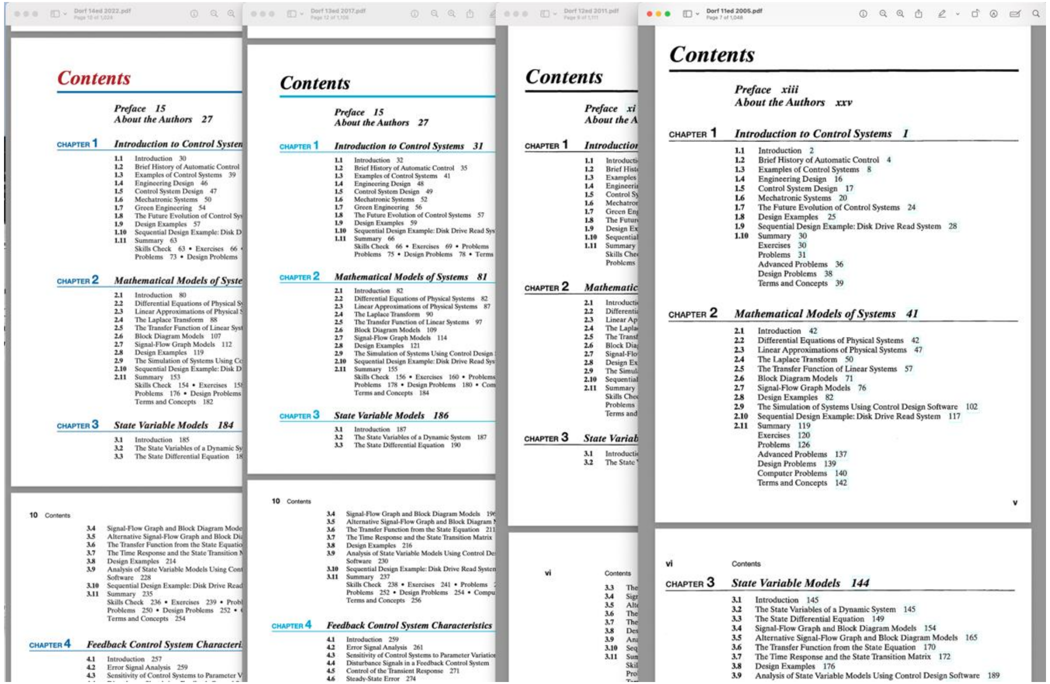
- Review syllabus
  - What did I assume you knew?
  - What did you actually know?
  - What do you want a refresher on?
  - What else do you want clarity on?
- Review delivery approach
  - What do you think so far? (Be honest).
  - How shall we proceed?
- Review and recap as necessary
- Introduce State Space models and control


The Map of Control Theory
pontryagin's maximum principle
max(H)
model reference adaptive
extremum-seeking
hamilton-jacobi-bellman equation
value
act
iterative learning control
adaptive
active disturbance rejection control
robust
Hinf
mu synthesis
constraints
RRT
A*
optimal
holonomic
nonholonomic
redundant
observer
lqr
vs.
optimal
loop shaping
pid
full state feedback
K
step
sine
impulse
mapping
filtering
kalman filter
predictive
linear mpc
model predictive control
robust mpc
lead-lag
linear
continuous
feedback
time
calibration
moving horizon estimation
sigma-point
backstepping
control methods
D2C
C2D
laplace
state estimation
tracking
fuzzy control
gain scheduling
nonlinear
sensor fusion
IMU
GPS
camera
particle
feedback linearization
dynamic inversion
discrete
feedforward
frequency
modeling & simulation
linear state space
nonlinear state space
intelligent
bang-bang
simulation
reinforcement learning
genetic algorithms
sliding mode
performance
system analysis
stability
transfer functions
explore vs exploit
nonminimum phase
controllability observability
margins
SAFETY
block diagrams
multi-agent
nyquist
bode plots
minimum realizations
leader-follower
graph theoretic control
passivity
phase plane
pole-zero plot
first principles
Sensitivity
swarm
nichols chart
linearization
douglas © aug 2020
Engineering Media


The Map of Control Theory
optimal
lqr
vs.
loop shaping
pid
$K_p e(t)$
$K_i \int e(\tau) d\tau$
$K_d \frac{de(t)}{dt}$
full state feedback
K
lead-lag
linear
control methods
step
sine
impulse
planning
continuous
time
feedback
laplace
frequency
state estimation
observer
kalman filter
modeling & simulation
linear state space
$\dot{x} = Ax + Bu$
$y = Cx + Du$
simulation
transfer functions
$G(s) = \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$
block diagrams
system id
Hello
my name is
$G(s) = \frac{s}{s^2+1}$
first principles
m_1
m_2
k
b
linearization
performance
system analysis
stability
controllability
observability
$C_m = [B, AB, A^2B]$
$O_m = [C, CA, CA^2]'$
margins
SAFETY
nyquist
bode plots
phase plane
pole-zero plot
root locus
nichols chart
brian douglas © aug 2020
Engineering Media

Recommended text: access and mapping

- Dorf mapping doc on Bb
  - But last 4 versions (and more?) are largely identical
- Doc includes access and etiquette guidance



Of the greater teachers—
when they are gone,
their students will say:
we did it ourselves.

Dedicated to

Lynda Ferrera Bishop

and

Joy MacDonald Dorf

In grateful appreciation

Dedicated to the memory of

Professor Richard C. Dorf

SB

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Mentimeter

(After concept outline) Current feeling/comments...

Menti

Control L3

Choose a slide to present

Current feeling...

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This hour - recap

- 1. Mathematical modelling
  - ODEs
  - LTI ODEs
  - Linearisation
  - Frequency domain methods
- 2. Feedback control
  - PID control
  - Block diagrams

- In Bb/Control/Recaps/link
  - Recap slides
  - Problem sheets
  - MATLAB code

See slides and code in MATLAB drive

More practice:

- Modelling (ODEs → TFs): Dorf ch2 (any version!)
- PID control: Brian Douglas – Understanding PID control

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Mentimeter

(After recap) Current feeling/comments...

SB

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Control L3

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STATE SPACE MODELS

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Overview

See slides and code in MATLAB drive

State Space – Steve's version

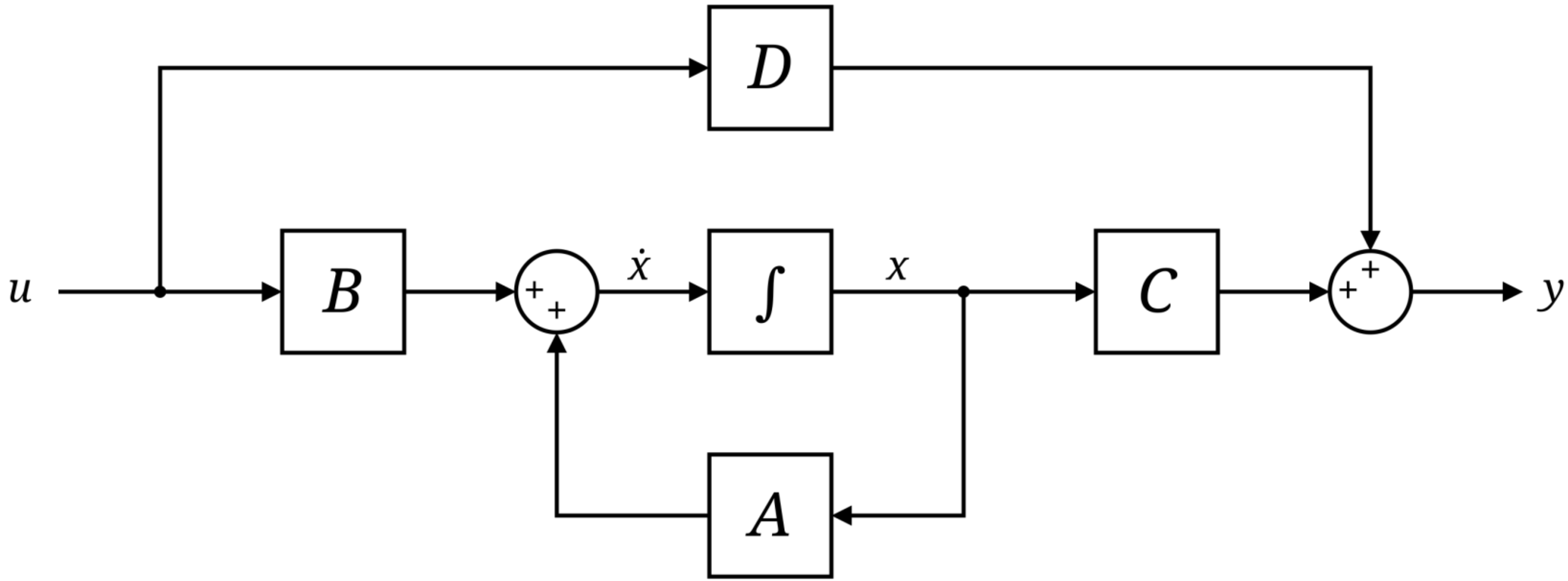
$$\dot{\mathbf{x}}(t) = \mathbf{A}(t)\mathbf{x}(t) + \mathbf{B}(t)\mathbf{u}(t)$$

$$\mathbf{y}(t) = \mathbf{C}(t)\mathbf{x}(t) + \mathbf{D}(t)\mathbf{u}(t)$$

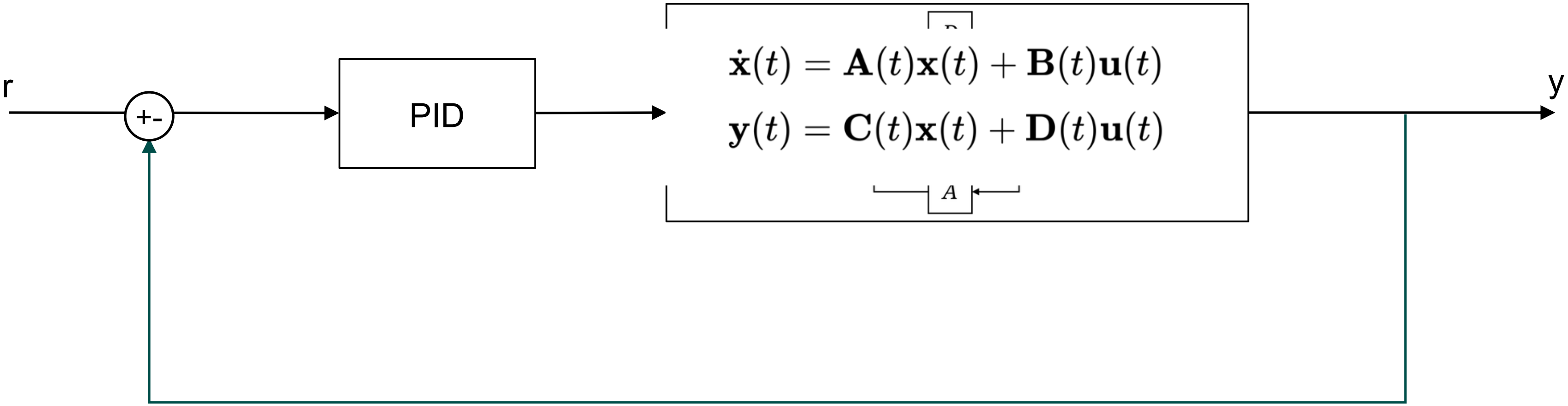
where:

$\mathbf{x}(\cdot)$ is called the "state vector", $\mathbf{x}(t) \in \mathbb{R}^n$;
$\mathbf{y}(\cdot)$ is called the "output vector", $\mathbf{y}(t) \in \mathbb{R}^q$;
$\mathbf{u}(\cdot)$ is called the "input (or control) vector", $\mathbf{u}(t) \in \mathbb{R}^p$;
$\mathbf{A}(\cdot)$ is the "state (or system) matrix", $\dim[\mathbf{A}(\cdot)] = n \times n$,
$\mathbf{B}(\cdot)$ is the "input matrix", $\dim[\mathbf{B}(\cdot)] = n \times p$,
$\mathbf{C}(\cdot)$ is the "output matrix", $\dim[\mathbf{C}(\cdot)] = q \times n$,
$\mathbf{D}(\cdot)$ is the "feedthrough (or feedforward) matrix" (in cases where the system model does not have a direct feedthrough, $\mathbf{D}(\cdot)$ is the zero matrix), $\dim[\mathbf{D}(\cdot)] = q \times p$,
$\dot{\mathbf{x}}(t) := \frac{d}{dt}\mathbf{x}(t)$.

Continuous time-invariant	$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$ $\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t) + \mathbf{D}\mathbf{u}(t)$



Remember! This is the dynamics of whatever system you put into it.
Could be a ‘plant’ on its own, i.e.:



What does it look like?

$$\dot{\mathbf{x}}(t) = \mathbf{A}(t)\mathbf{x}(t) + \mathbf{B}(t)\mathbf{u}(t)$$
$$\mathbf{y}(t) = \mathbf{C}(t)\mathbf{x}(t) + \mathbf{D}(t)\mathbf{u}(t)$$

$$\begin{bmatrix} \dot{\alpha} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} -0.313 & 56.7 & 0 \\ -0.0139 & -0.426 & 0 \\ 0 & 56.7 & 0 \end{bmatrix} \begin{bmatrix} \alpha \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} 0.232 \\ 0.0203 \\ 0 \end{bmatrix} [\delta]$$

$$y = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \alpha \\ q \\ \theta \end{bmatrix}$$

(CTMS pitch model)

What does it look like?

- Quanser model on MATLAB Drive

Looking ahead