Control Systems
Lecture 1 Introduction

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Outline

Introduction

- System Dynamics
  - The present behavior depends on th past actions.
  - Not necessarily implies movement.
- Control
  - Select the actions to get a desired behavior.
  - Design a controller to generate these actions.
  - Tune the controller properties if there is changes.

Introduction

Control appears in 99 percents in industrial applications, in nature and also in life.

Control is everywhere $\Rightarrow$ No Control, No Life!

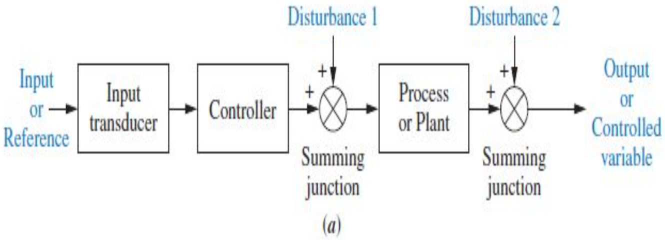
...and feedback is the key to success !

Dynamic Systems:

- A system is composed of many components.
- The information flows among them and also have some connection to the environment.

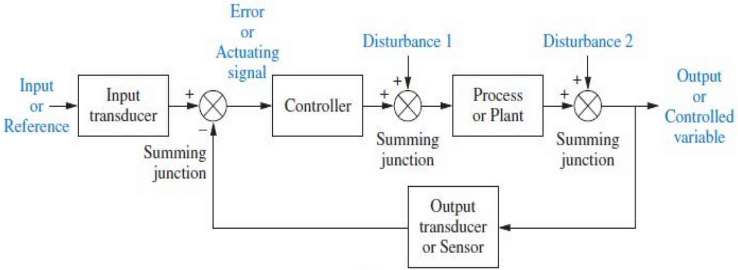
System Configuration

- Open loop control



System Configuration

- Closed loop control



(*b*)

Analysis and Design Objectives

- Analysis is the process by which a system's performance is determined. Ex. Evaluate its transient response and steady-state error to determine if they meet the desired specification.
- Design is a process by which a system's performance is created or changed.
  Ex. If a system's transient response and steady-state error are analyzed and found do not meet the specifications, then we change parameters or add additional components to meet the specifications.

....and what is transient response and steady-state error? Why we need to consider them in the design and analysis?

Analysis and Design Objectives

- Stability

Analysis and Design Objectives

Other considerations are

- Hardware selection: factors affected by hardwares cannot be ignored. Ex. motor sizing to fulfill power requirements and choice of sensors must be considered in the early stage.
- Finance: Control system designer cannot create designs without considering their economic impact.
  Ex. budget allocation
- Robust Design: Adaption to the changes of parameters.

Design Process

Determine physical systems and specifications from the requirements.

$\Downarrow$

Draw functional block diagram.

$\Downarrow$

Transform the physical system into a schematic.

$\Downarrow$

Develop a Mathematical model (block diagram, signal-flow diagram, state-space representation)

$\Downarrow$

Simplify the block diagram.

$\Downarrow$

Analyze and Design.

Computer-Aided Design

"All systems and control engineers know how to use MATLAB/SIMULINK"

Model Based Design

Model based design can improve productivity, cost and quality ..or it can make your product development miserable.
You must:

- Understand what you can do with the model in order to successfully adopt model based design.
- Know the limitations of your model.

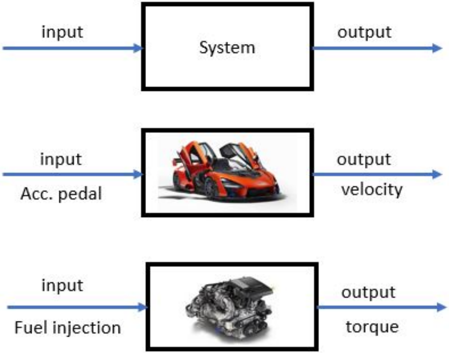
...as design and quality of models depends on this!

Model Based Design
Feedback Principle

What is (automatic) control?

Control of dynamical system via feedback

- Control: For control, we talk about cause which is something that we can manipulate. Cause $\rightarrow$ Effect.



Model Based Design

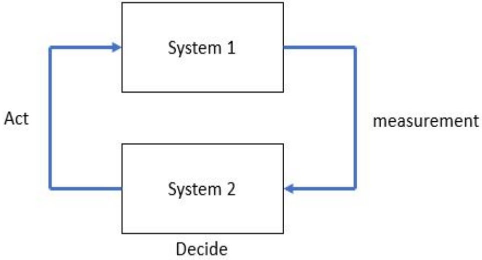
Feedback Principle

- Dynamics system = a system whose behavior changes with time. The output depends not only the current input but also the previous input.

For simplicity, the dynamics is described by differential equation as follow

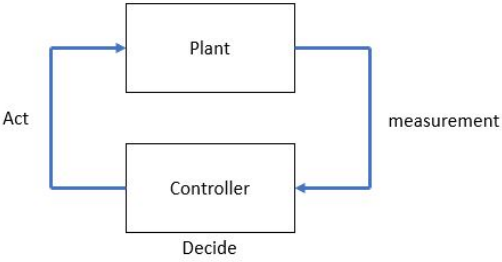
$$\frac{dv}{dt} = -\frac{a}{m}v + \frac{b}{m}u$$
$$y = v$$

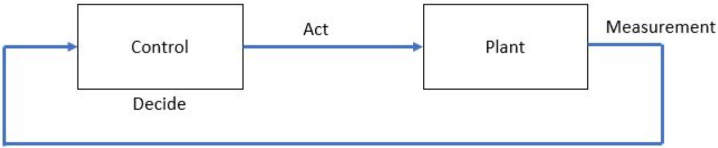
- Feedback: For simplicity, system 2 depends on system 1 which depends on system 2



Model Based Design

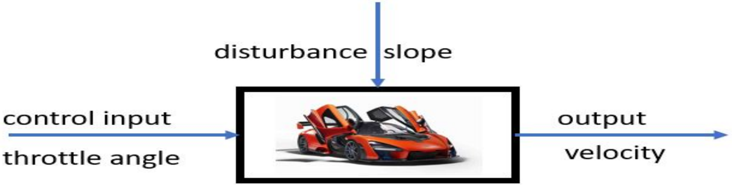
Feedback Principle





Model Based Design

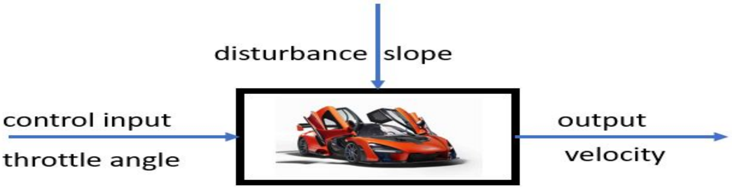
Feedback Principle



- Specification: Keep the vehicle's velocity constant
- Control signal: throttle angle
- Disturbance: road slope
- output

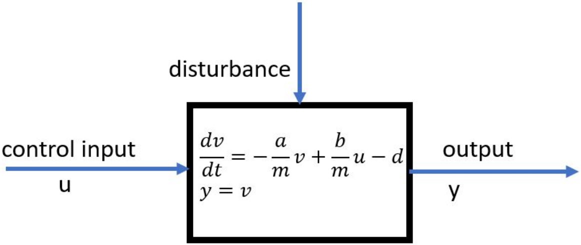
The control problem is to manipulate the throttle angle in such the way that the velocity is constant no matter how the road topography changes.

Example: Simplified Cruise Control

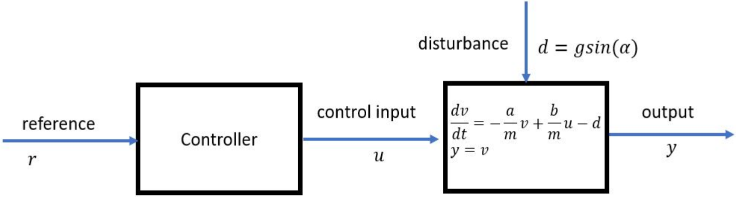


The plant is given by

$$\frac{dv}{dt} = -\frac{a}{m}v + \frac{b}{m}u - g\sin\alpha$$
$$y = v$$



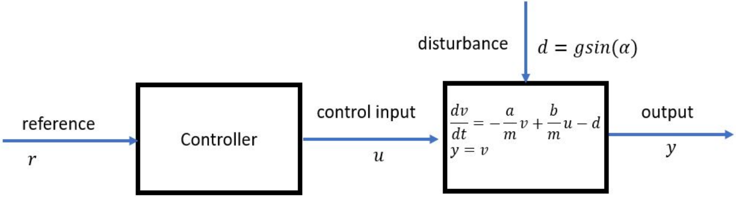
The open loop control looks like this



Model Based Design

Example: Simplified Cruise Control

Open loop control



Specification: $v = r$

- Reference velocity $r = 30m/s$

Assumptions for control design:

- Flat road: $\alpha = 0$
- At steady state: $0 = -a\frac{a}{m}v + \frac{b}{m}u$

Control design

$u = \frac{a}{b}r \rightarrow v = r$

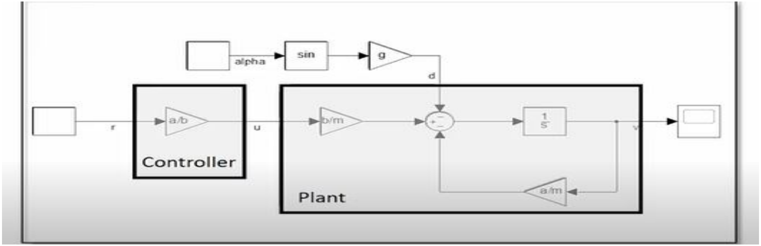
Try to use Simulink for verification

- What would happen if there is a slope?
- What would happen if we add more passengers?

The open loop works fine when we have the full knowledge of the system.

Try to use Simulink for verification

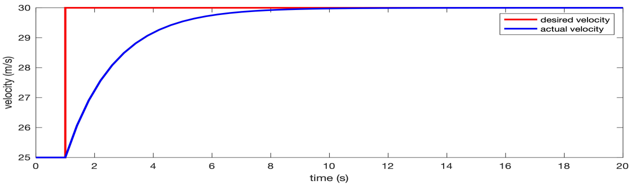
- Open loop



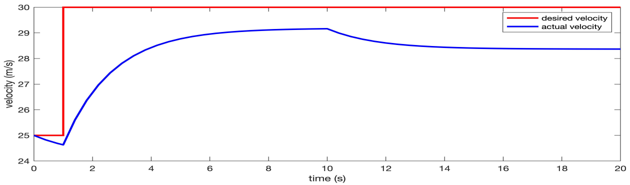
Feedback Control Approach

Example: Simplified Cruise Control

- Step response: 25 m/s to 30m/s,
  $m = 1000kg$, $a = 600Ns/m$, $b = 10kN/rad$ and $g = 9.82m/s^2$



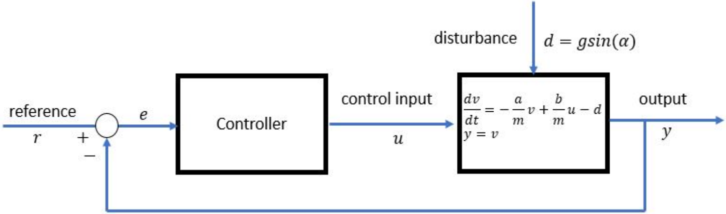
what will happen if there is slop?



Model Based Design

Example: Simplified Cruise Control

- Specification: Keep the vehicle's velocity constant
- Closed loop control
- Measurement: velocity



Specification: $v = r$

- Reference velocity $r = 30m/s$

control design: P-Controller

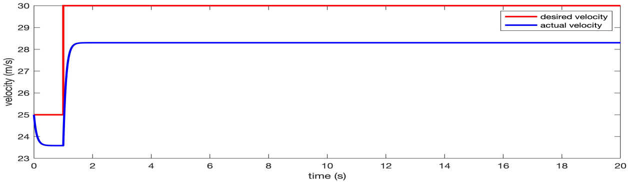
$u = K_p e = K_p(r - y)$

Control design: PI-controller

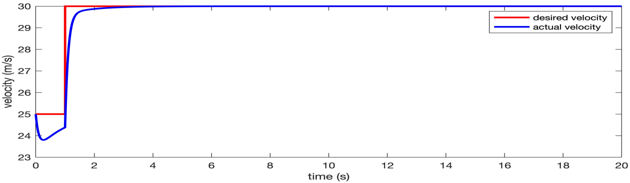
$u = K_p(r - y) + K_i \int_0^t e d\tau$

Closed loop Control

- Proportional control (P Control). For some value of k, we obtain the following result.



- Proportional and Integral Control (PI control)



Remark: This example illustrated the possibilities with closed loop control.

- Design of dynamics (stabilization, speed-up the response time).
- Robust to uncertainty (disturbance, parameter variations)

...but there are some challenges

- Destabilization
- Measurement noise

...Furthermore, open loop control can be considered when we have a stable system and we have good knowledge about the disturbances and model parameters.

Feedback control is a hidden technology.

Control objectives (specification)

- Qualitative - minimize energy (achieving as good result as possible, do not use much fuel,)
- Quantitative - response time (time should be less than a certain value,

Description of the system/plant

- Level abstraction (system level, component level, or even more details)
- Modeling physical modeling or from the measurement data

Model Based Design

Design controller

- Select technique - open loop or closed loop
- Classical methods or state-space methods
- Choose parameters (trail-and-error, design method, optimization)

Analyze the performance

- Analysis
- Simulation
- Experiments

(meet objective ? Yes->done, No ->iteration)

Classical control methods (Ex. PID)

- works well for simple systems
- can be tuned based on trail-and-error or engineering intuition.
- do not require model of the systems

...but

- are typical iterative
- are difficult to use for larger-scale systems (complex systems) with multi inputs and outputs(MIMO)

State-space method

- Can easily handle larger-scale systems (complex systems) with multi inputs and outputs (MIMO)
- tuning can be formed as an optimization problem
- are easy to implement
- require a mathematical model of the system

and some others...