Systems and control theory

Katholieke Universiteit Leuven

July 8, 2015

Overview

Course overview

1. Introduction
2. Classification of systems
3. System modelling
4. Discrete time systems
5. Continuous time systems
6. Frequency response of dynamical systems
7. Discretizations of continuous time systems
8. Introduction to control
9. Design in the frequency domain and Nyquist stability criterion
10. Lead and lag compensators
11. PID control

Methodology and evaluation

- 20 lectures
- 8 excercise sessions
- Learning platform: Sofia
  www.sofialearn.com
  Course: Systems and control theory
  Material from the lectures (powerpoints, video's), assignments for exercise sessions and supplementary material (downloads, tutorials, books, links, journals, conferences)

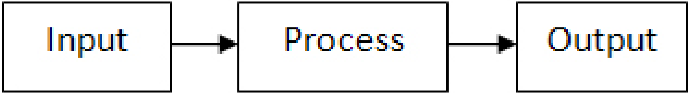
Exam

- Written exam
- You can bring: course book, calculator
- Duration: 4h

Introduction

Systems theory

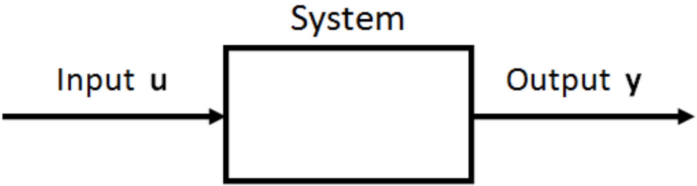
System theory occupies itself with the mathematical description and study of systems. Models describe the connections between input and output.



Next to inputs and outputs, states (denoted by $\mathbf{x}$) are a third type of variable used to describe a system. They represent the internal state of the system at a given time. The next state is a function of the previous states. The order of a system is the number of state-variables (i.e. the size of the vector $\mathbf{x}$).

Dynamical system

A dynamical system is a constantly changing system that connects outputs (denoted by $\mathbf{y}$) and inputs (denoted by $\mathbf{u}$).
The word dynamical refers to the fact that its current output depends on past input, contrary to static systems where the current output only depends on current input. This means that in a dynamical system the output changes with time if the system is not in a state of equilibrium.



Everything is a dynamical system.

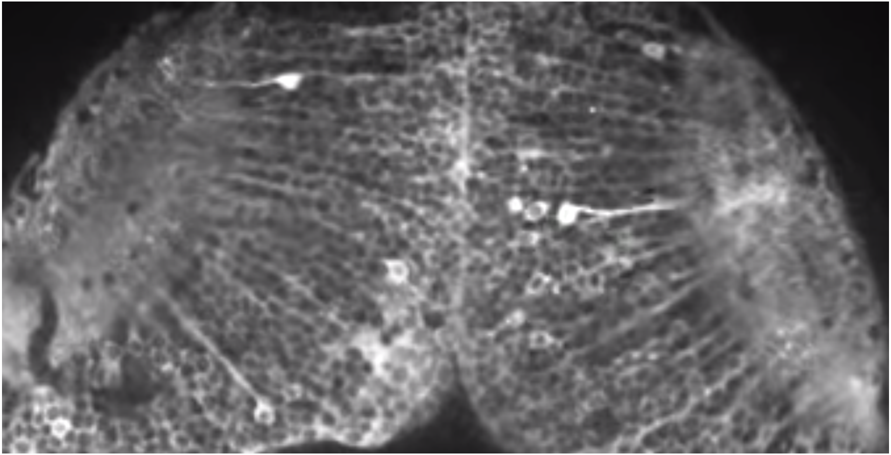
Millenium Bridge

Resonance on the Millenium Bridge in London due to the rithm of walking people.

https://www.youtube.com/watch?v=eAXVa__XWZ8

Neuronal acitvity

Real-time visualization of neuronal activity in the zebrafish brain



https://youtu.be/_rGEkYfQVwY

Drumstick hitting a cymbal

Drumstick hitting a cymbal at 1000 frames/sec

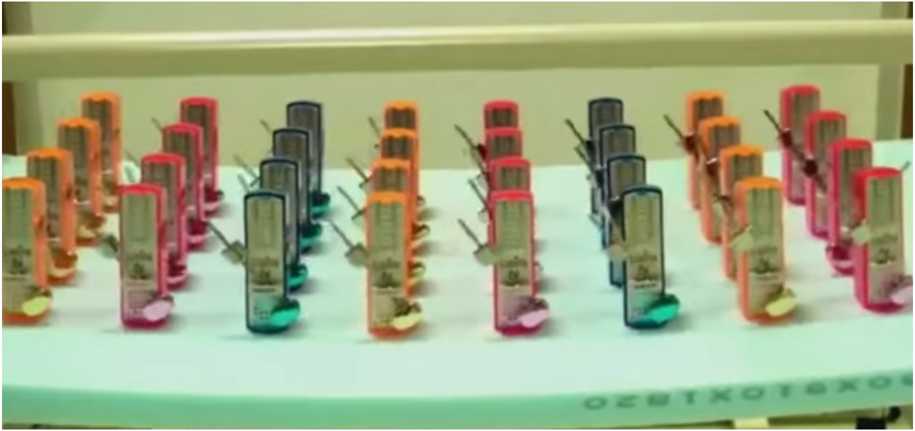
https://youtu.be/kpoanOlb3-w

Pilot making a risky maneuvre

Experienced pilot making a risky maneuvre

https://youtu.be/gGnyWgXnZ6g

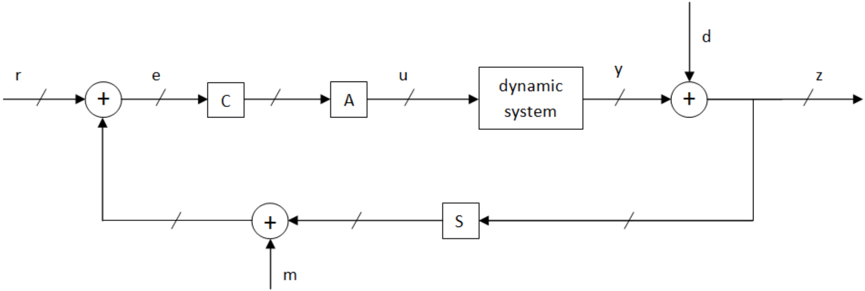
Synchronized metronomes



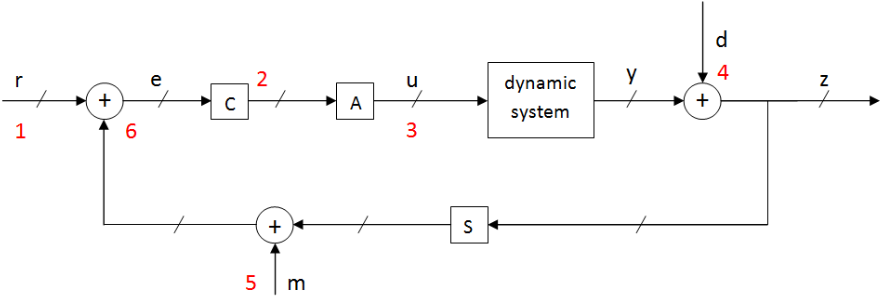
https://www.youtube.com/watch?v=5v5eBf2KwF8

Control theory

Control theory deals with the behavior of dynamical systems and how their behavior is modified by feedback.
The output is compared to the reference input and this *'error'* is used to adjust the system.



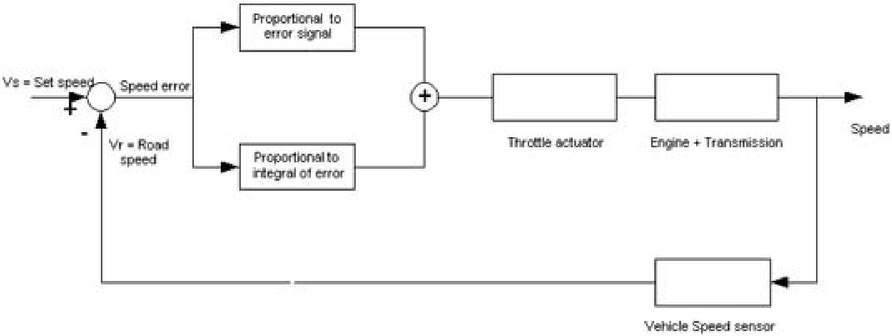
Control theory



1. reference signals: the desired output signals
2. controller with model (controller = dynamic)
3. actuators that control the system
4. Noise
5. Measurement noise
6. Negative feedback → system = stable

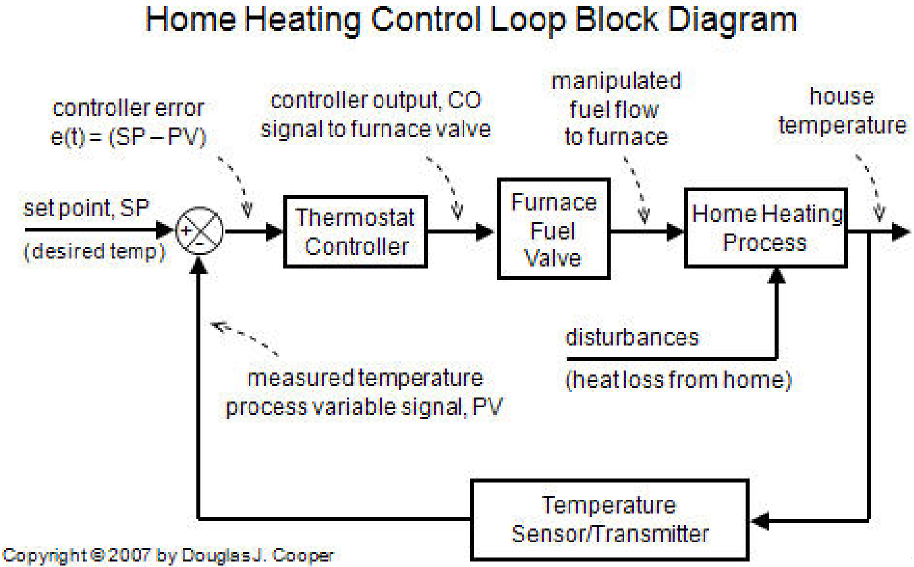
Example

Speed control system

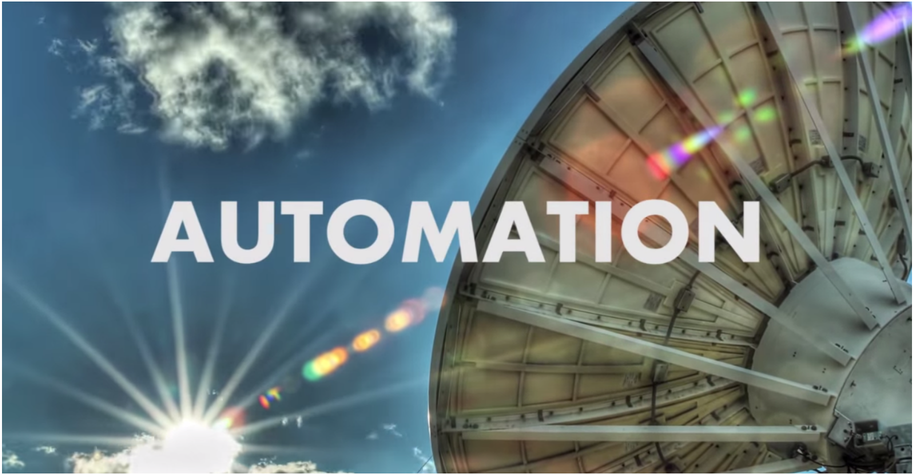


Example

Temperature control system



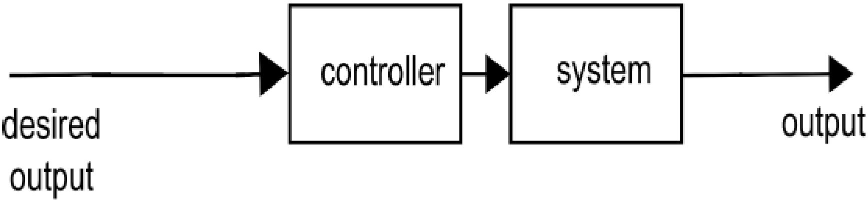
Automation



https://youtu.be/XJLMW61303g

Open loop

In an open loop system, the output is not fed back into the controller.
Therefore, the controller cannot *'see'* the effect of its actions.
This way it is hard to get the desired output.



For example: try pouring water in a glass without looking.

Open loop

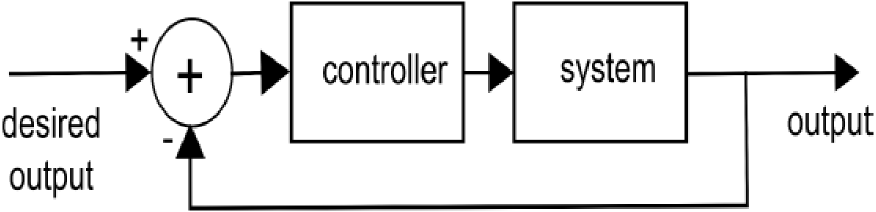
Take for example the following system:

- You are pouring a glass of water, but you **cannot look at the glass**.
- You know the desired output is a full glass of water within a reasonable time.
- The input can have two values: on or off (assume you are using a quite primitive tap).
- You can imagine it will not be easy to do this successfully.

The solution is evident: look at the glass while pouring!

Closed loop

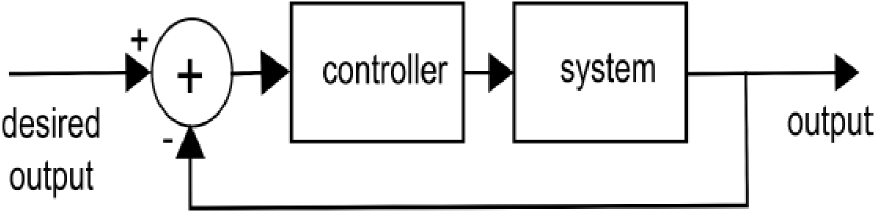
In a closed loop system, the actuating error signal, which is the difference between the input signal and the feedback, is fed to the controller so as to reduce the error and bring the output to the desired value.



Closed-loop always implies the use of feedback control.

Feedback

Feedback systems maintain the prescribed relationship between the output and the reference input by comparing them and using their difference.

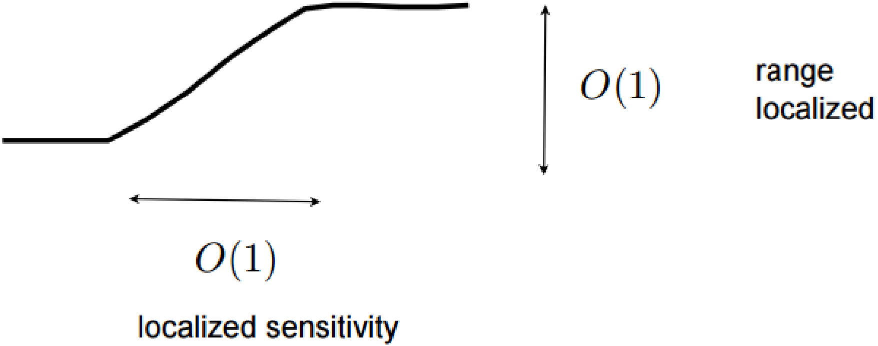


There are two types of feedback systems. The output can either be added to the reference input (positive feedback) or substracted from it (negative feedback).

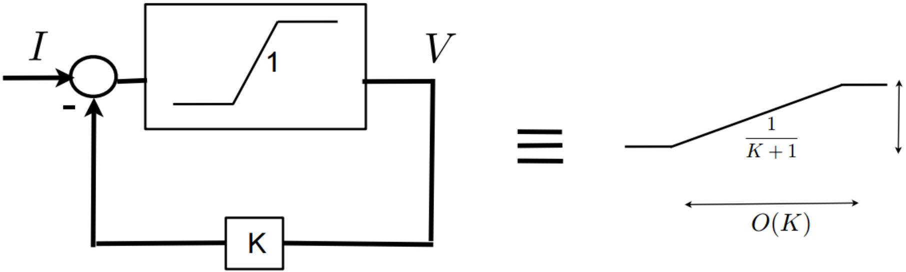
Slides courtesy of prof. Rodolphe Sepulchre

Range-localized sensitivity is a nonlinear behavior

$$V = sat(I)$$



Black principle: negative feedback 'linearizes'

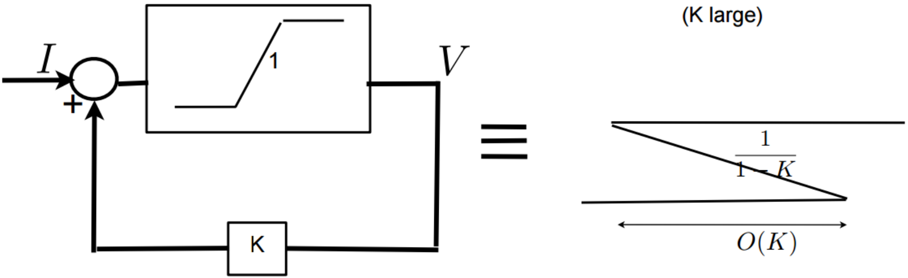


$V = sat_1(I - KV) \equiv V = sat_{\frac{1}{1+K}}(I)$

Sensitivity domain is spread by negative feedback

(The essence of control theory)

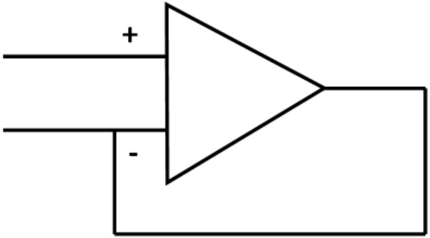
Black principle: positive feedback 'quantizes'



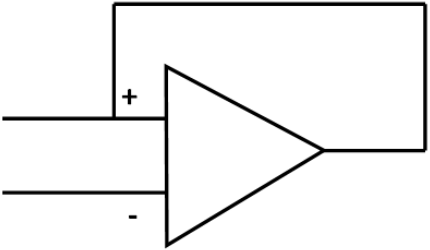
$$V = sat_1(I + KV) \equiv V = \begin{cases} +1 & I \geq -1 - K \\ \text{-1} & I \leq K - 1 \end{cases}$$

Sensitivity domain is spread by negative feedback

Black feedback principle

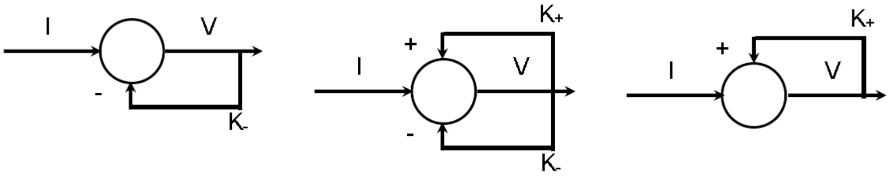


1. Negative feedback linearizes
2. Continuous behavior
3. Analog technology
4. Output primarily reflects the input
5. Loops enhance or amplify the changes between input and output

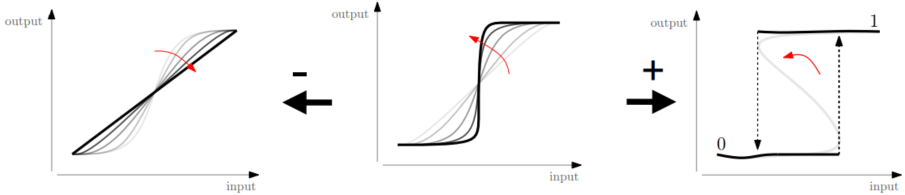


1. Positive feedback quantizes
2. On-Off behavior
3. Digital Technology
4. Output primarily reflects memory of the past
5. Loops tend to dampen or buffer the changes between input and output

Balanced feedback 'localizes'



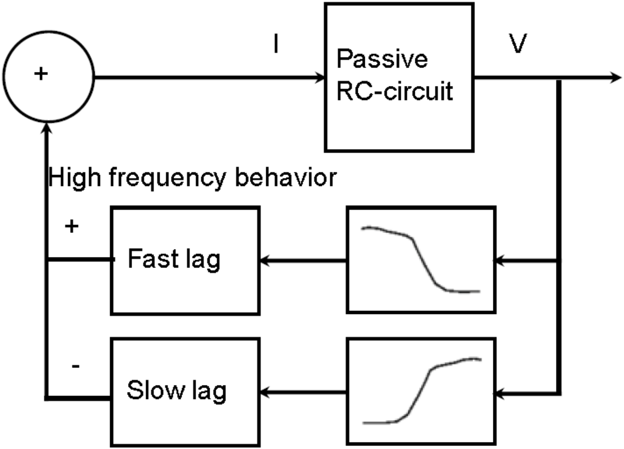
'linear'	'localized'	'memory'
$\|k\|$ large	$\|k\|$ small	$\|k\|$ large



$$\overleftrightarrow{O(k)}$$

$$k \approx K_+ - K_-$$

Robust space + time localization by feedback



Low frequency behavior

Necessary localization in same frequency range!

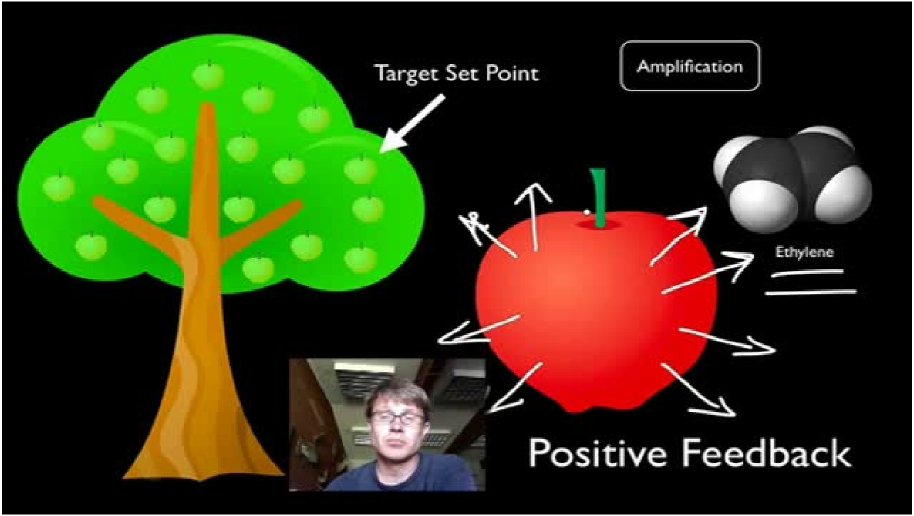
Guitar feedback

https://youtu.be/luURyH9fzhk

What if there was no feedback?

https://youtu.be/C221sI1W9Gk

Feedback loops in biology

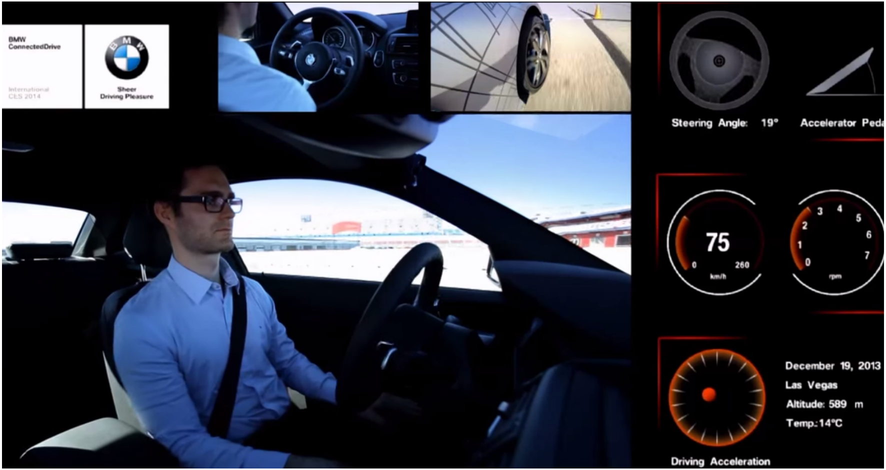


https://www.youtube.com/watch?v=CLv3SkF_Eag

Dance of the Flying Machines

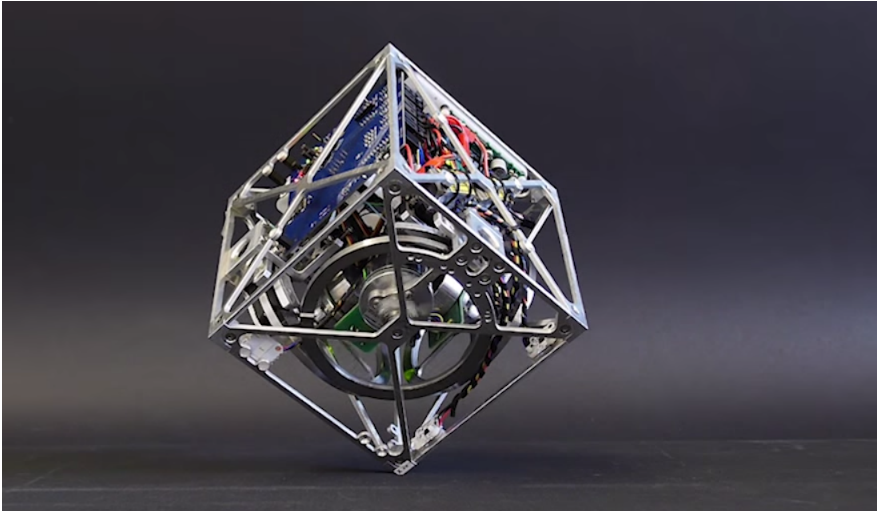
https://youtu.be/NRL_1ozDQCA

Automated driving with precision at the physical limits



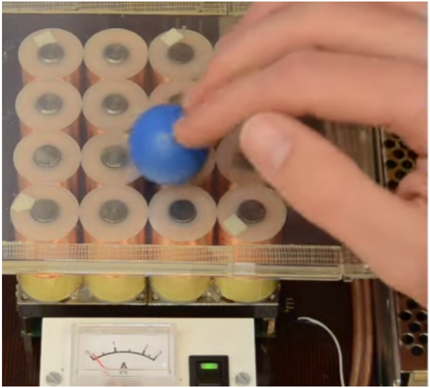
https://youtu.be/1FVglbJZ_tg

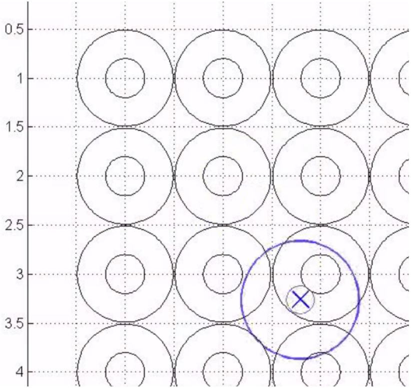
The Cubli: a cube that can jump, balance and 'walk'



`https://youtu.be/n_6p-1J551Y`

Magnetic manipulator Magman and Matlab





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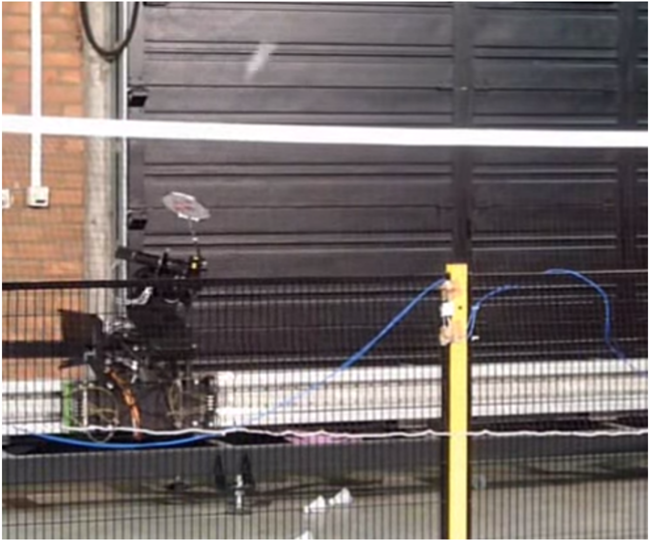
Badminton robot



https://youtu.be/LSax71cn6A4

Raffaello D'Andrea: The astounding athletic power of quadcopters