IMPACT: a strategic partnership for sustainable development in marine systems and robotics

Marine Systems & Robotics
Unit 03
Control Systems

http://impact.uni-bremen.de/

Control is Everywhere

- The modern world is driven by control systems.
- A roboticist must understand control systems for all disciplines



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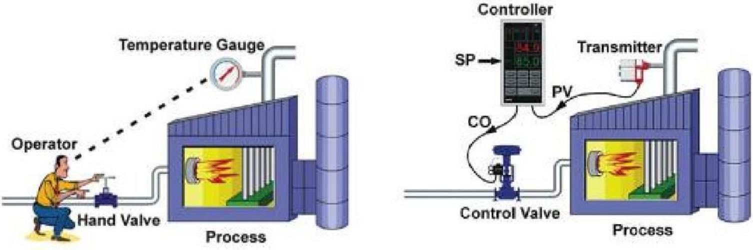
Control systems

- Control systems are responsible for determining the appropriate system response to measurements from the environment.

Control systems



Conceptual Control Components

- **Reference** - desired state (target or goal)
- **Controller** - issues commands (signals)
- **Plant** - actuators
- **Disturbances** - changes in the plant and controller system (including errors)
- **Measurements** - actual states
- **Error** - difference between desired and actual states

Controllers generally attempt to drive a plant to a desired state.

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Control loop

- A control loop is the fundamental building block of a control systems.
- It consists of all the physical components and control functions necessary to automatically adjust the value of a measured process variable (PV) to equal the value of a desired set-point (SP).

Classification of control systems

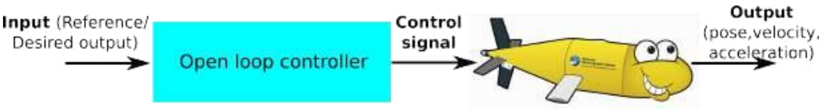
- Open Loop Control
- Closed Loop Control

Open Loop Control

- Changes the output from the controller based on a model of the plant.
- Only used to control simple systems with known dynamics.
- Does not account for disturbances.

Open Loop Control

Systems in which the output has no effect on the control action are called open-loop systems.



Open Loop Control

Advantages

- Simple construction
- Easy to maintain
- Less expensive
- Convenient when it is difficult to measure the output precisely (e.g. a washer)

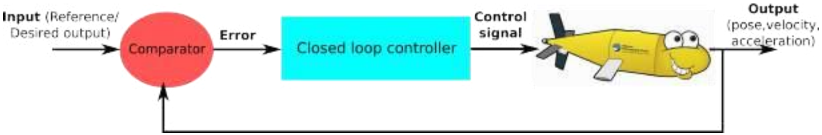
Disadvantaged

- Disturbances and changes in calibration cause errors and the output may be different from what desired.

Closed Loop Control

- Changes the output from the controller based on the measured state of the plant.
- Able to compensate for both changes in command and disturbances to the system.
- Most common modern approach to control.

Closed Loop Control



Closed Loop Control

Advantages

- High accuracy
- Less sensitive to disturbances
- Controllable transient response
- Controllable steady-state error

Disadvantages

- Can become complex and expensive
- Possibility of instability
- Need for output measurement

Robust Control Applications

- Position control
- Motion control
- Force control

Robot Control Goals

- **Ensure stability** - System maintains desired operating point, does not oscillate around it in an unstable way.
- **Improve performance** - Respond rapidly to changes to reach/return to desired state.
- **Guarantee robustness** - System tolerates disturbances in dynamics.

Underwater Robots

- Landers
- Remotely Operate Vehicles (ROVs)
- **Autonomous Underwater Vehicles (AUVs)**
- **Autonomous Underwater Vehicle-Manipulators**




Control Challenges in Underwater

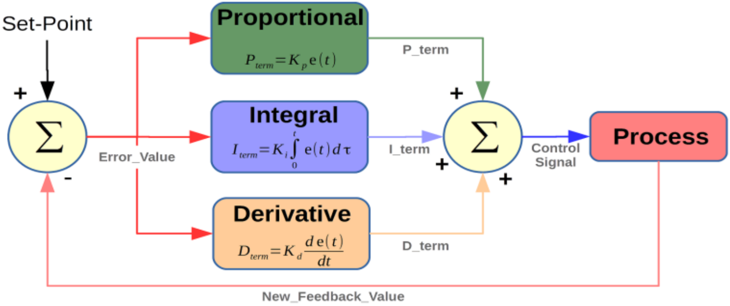
- Highly nonlinear, time-varying dynamic behavior of the robots.
- Uncertainties in the hydrodynamic coefficients.
- Ocean currents, waves ...

Most common control system

- Linear controllers
  - PID controllers (P/PI/PD) - most commonly used
  - LQR controller - optimal control
  - Gain scheduling - use a family of linear controllers to control a nonlinear system
- Nonlinear controllers
  - Sliding mode controller - nonlinear controller that alters the dynamics of the system by using a discontinuous control signal

PID components

The PID algorithm consists of three basic coefficients: **proportional, integral and derivative** which are varied to get optimal response.



Underwater robots controller steps

Linear controllers

1. Linearize the system (Feedback linearization)
2. Decompose the MIMO system into SISO components (considering each DOF of the system independently).
3. Design a feedback controller for every SISO system.
4. Analyze performances.

Non-linear controllers

1. Implement controller
2. Analyse performances.

A feedback controller design

PILIM Control- a cascaded controller applied for each independent Degree-Of-Freedom (DOF).

Considerations:

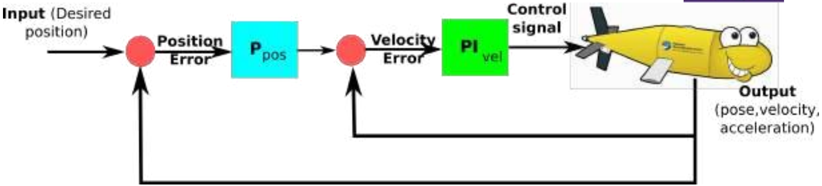
- Assuming that the vehicle moves at fairly low speed, the dynamic model can be represented independently for each degree-of-freedom by linear decoupled equations.

- Basic of this controller is a PID control law.

PILIM controller

Two control loops:

- one for position control.
- another control loop for velocity.



PILIM controller

Tuning this controller is difficult!

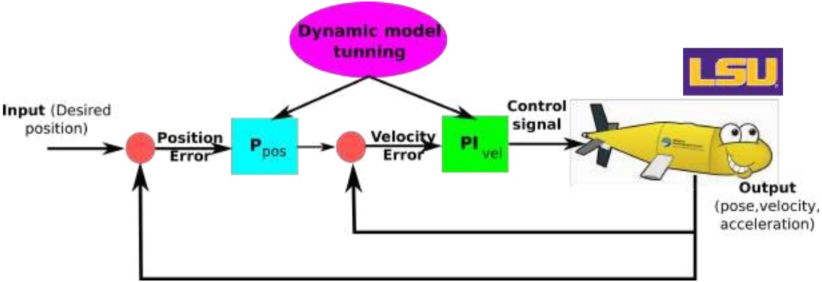
- At least 4 parameters to tune for each DOF!
- Changing the payload of the robot needs changing the parameters.
- Strong water currents results in the need to change the parameters.

Solutions:

1. Tune for the worst-case scenario => Inefficient (waste of battery life)
2. Adaptive tuning

Adaptive PILIM Controller

- Change the parameters of the controller based on an idealized model of the behavior of the robot.



Adaptive PILIM Controller

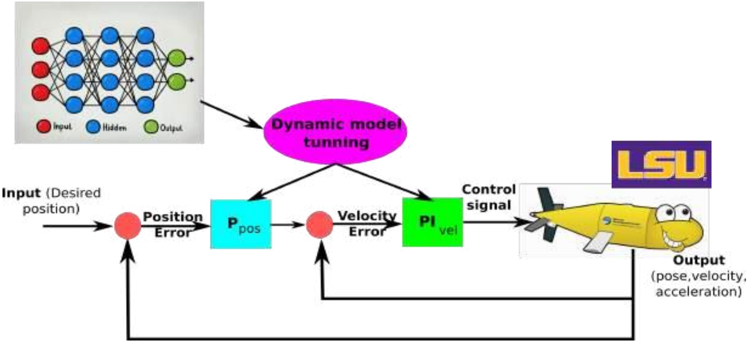
Challenges:

- The ideal behavior is very difficult to obtain because we do not know clearly the characteristics of the environment and we make a lot of assumptions about the characteristics of the robot (to simplify things)

Solution:

- What if we could observe the behavior of the robot apriori and draw some conclusions?
- The Machine-Learning Era

Neural-Network Adaptive PILIM Controller



Challenges:

- Computational power of the robots
- Not enough data.

Questions ?