Robotics: Principles and Practice

Module 1: Introduction and Robot Components

Lecture 6: Control Systems

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Control Systems

Controllers

Plural: there may be different controllers for different sub-systems in the robot

- Enable the robot to be autonomous
- Autonomy is the ability to make one's own decisions and act on them, based on
  - Sensor inputs
  - Stored knowledge
- Autonomy can be complete or partial
- There are different approaches to the organization of controllers and sub-systems

See later in this lecture

Control Theory Terminology

Goal

- Get some process or plant to a desired state
- Maintain that state

"plant" is a term used to refer to the system being controlled
e.g., water tank, pipeline, mobile robot

Example states:

Water level in a tank
Temperature of water in a tank
Flow rate of a pipeline
Speed of a mobile robot
Position of a mobile robot
Orientation of a mobile robot

These are referred to as "process variables"

Control Theory Terminology

Strictly speaking, "a plant in control theory is the combination of process and actuator"
https://en.wikipedia.org/wiki/Plant_(control_theory)

- Plant: the process or device to be controlled
- Process variable (PV): the actual state of the process or plant
- Set point (SP): the desired state of the process or plant
- Error: the difference between PV and SP

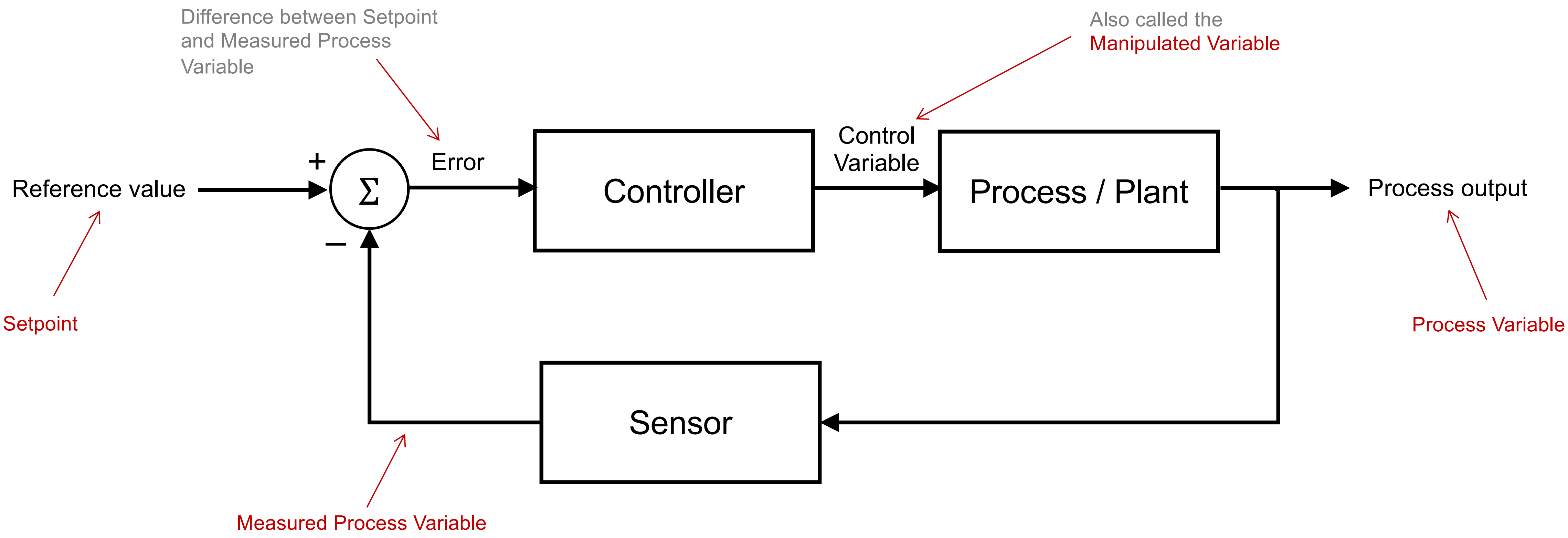
Control Theory Terminology

- Effector: a mechanism that changes the state of the process or plant (i.e. control action)
- Sensor: a mechanism that measures the state of the process or plant
- Control variable: the input to the effector
- Controller:

Can be a physical device (e.g., a mechanical governor) or software implementing a control algorithm

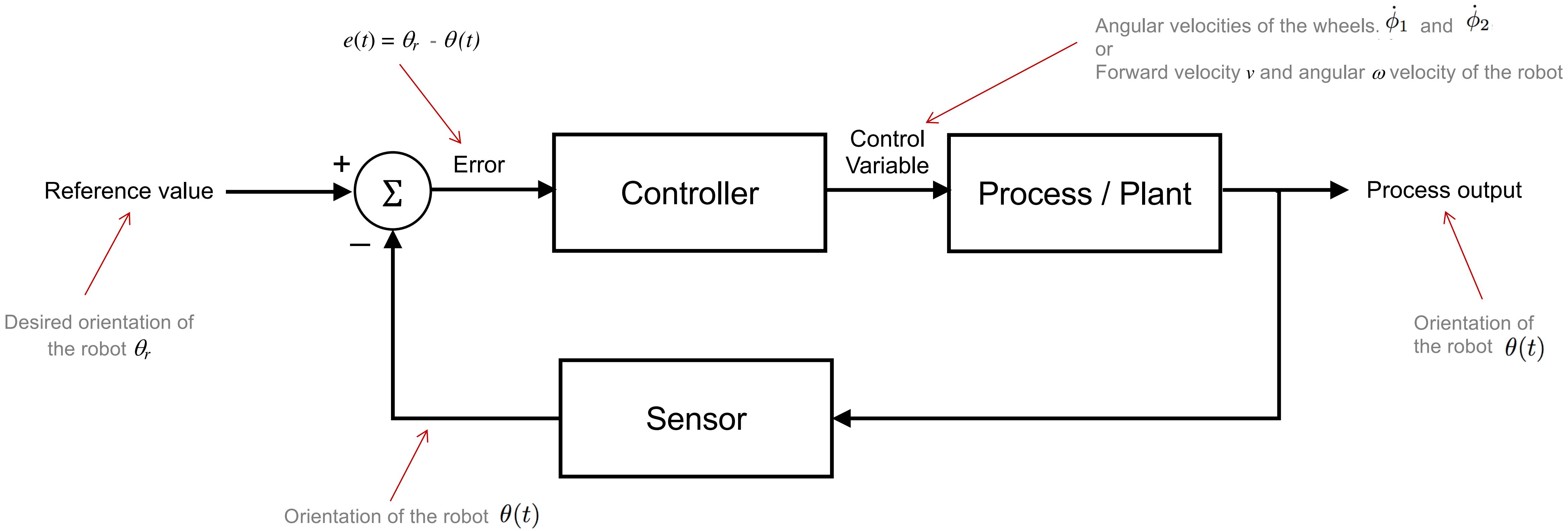
A mechanism to identify the value of the control signal that reduces the error to zero as quickly as possible, without overshoot, in a stable manner

Closed-loop Feedback Control



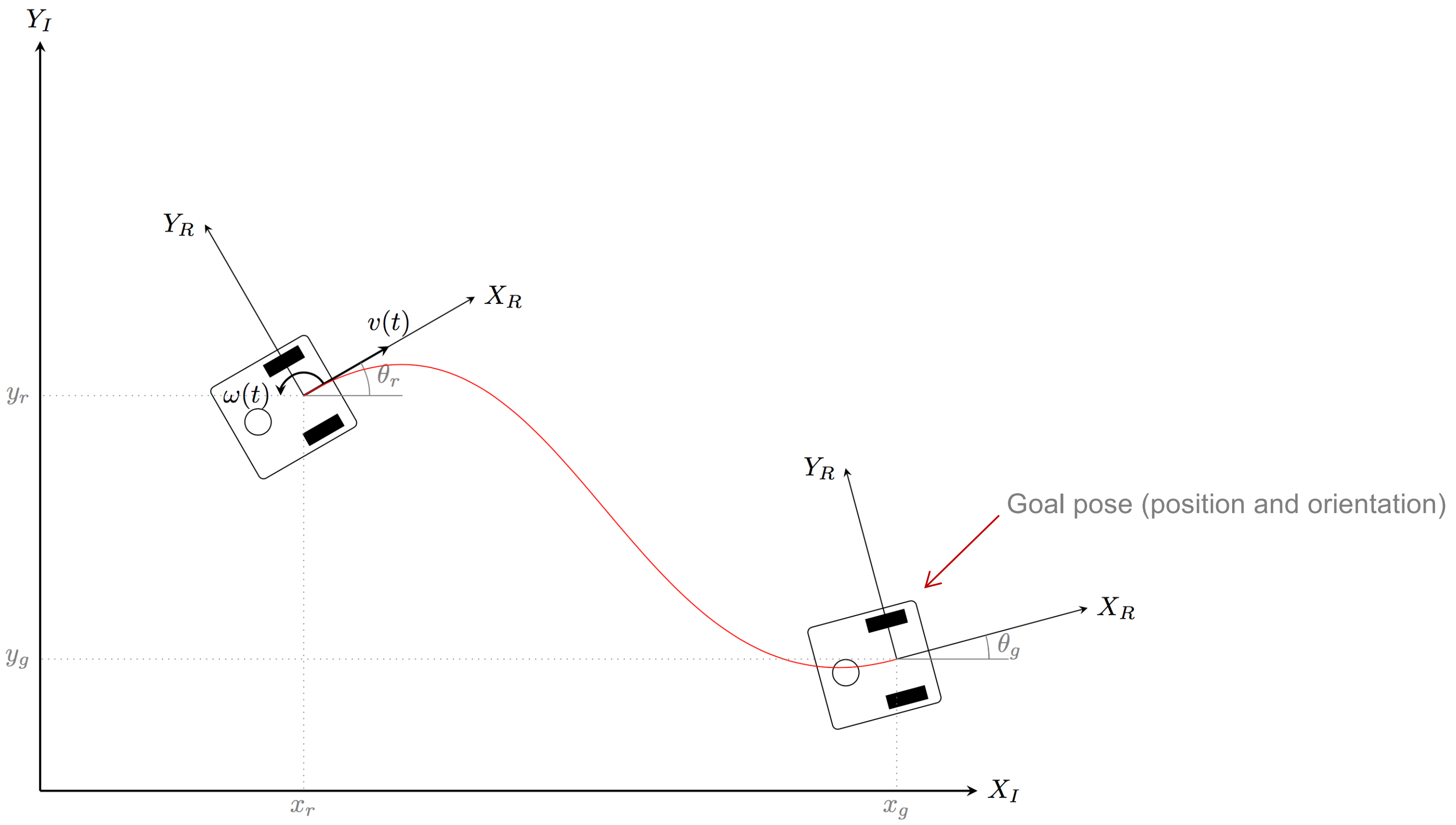
Closed-loop Feedback Control

For example, controlling the orientation of a mobile robot



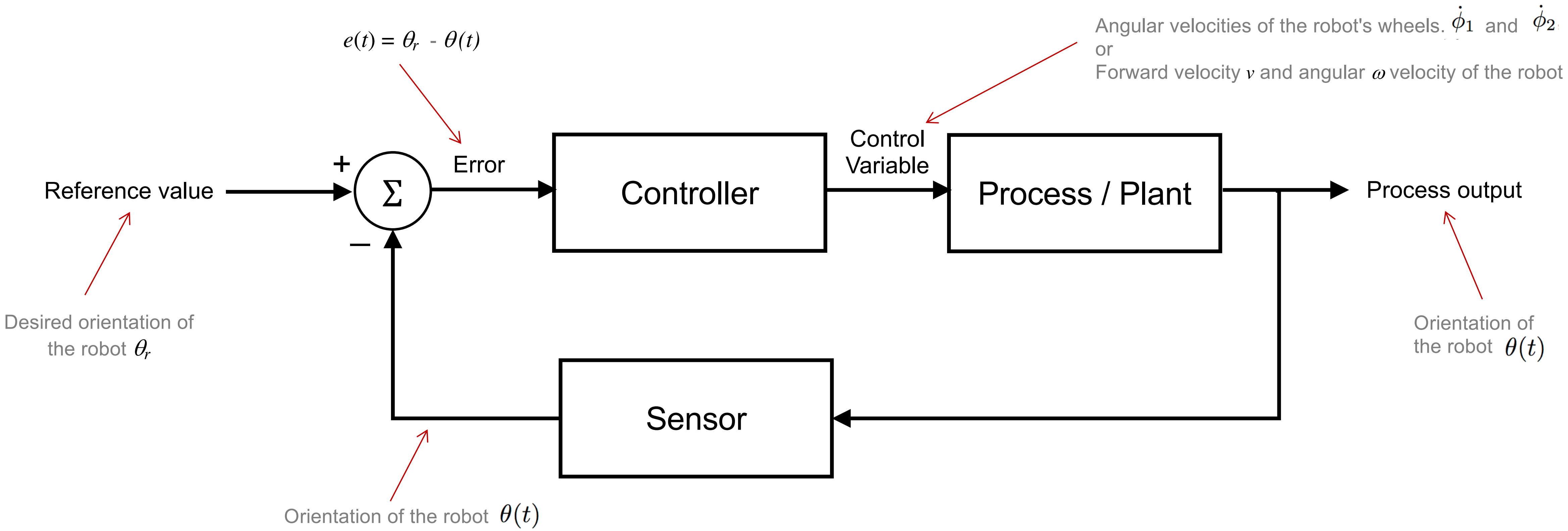
Closed-loop Feedback Control

For example, controlling the orientation of a mobile robot



Closed-loop Feedback Control

For example, controlling the orientation of a mobile robot



Closed-loop Feedback Control

Control variable is a function of the error: $f(e)$

e = error between

desired value (i.e. the setpoint)

and

the actual value (i.e. the measured process value)

PID Controller

Which function?

f = "proportional to e"

f = "proportional to the accumulation of e" ← Integral

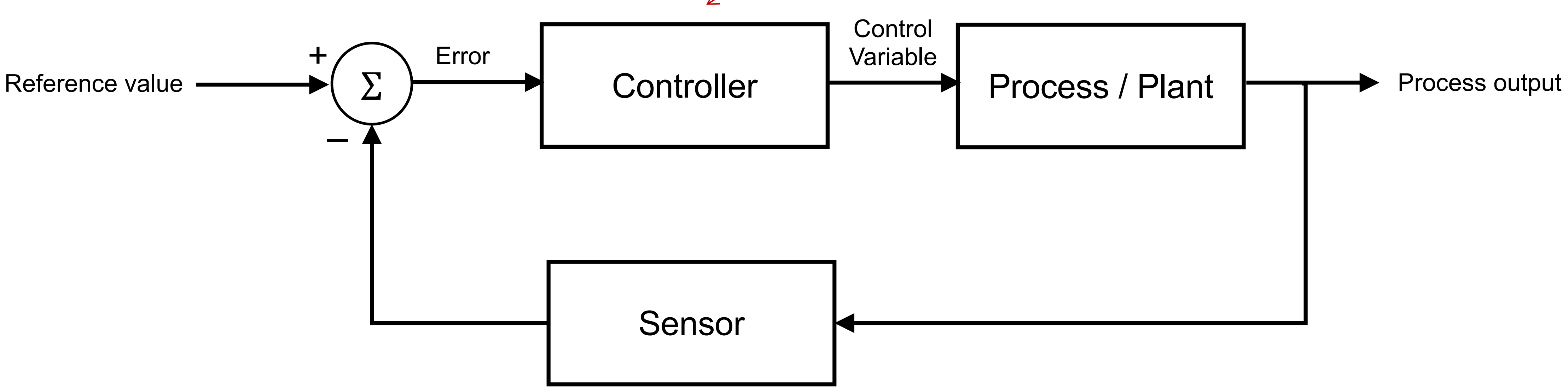
f = "proportional to the rate of change of e" ← Derivative

. . . or a combination of these

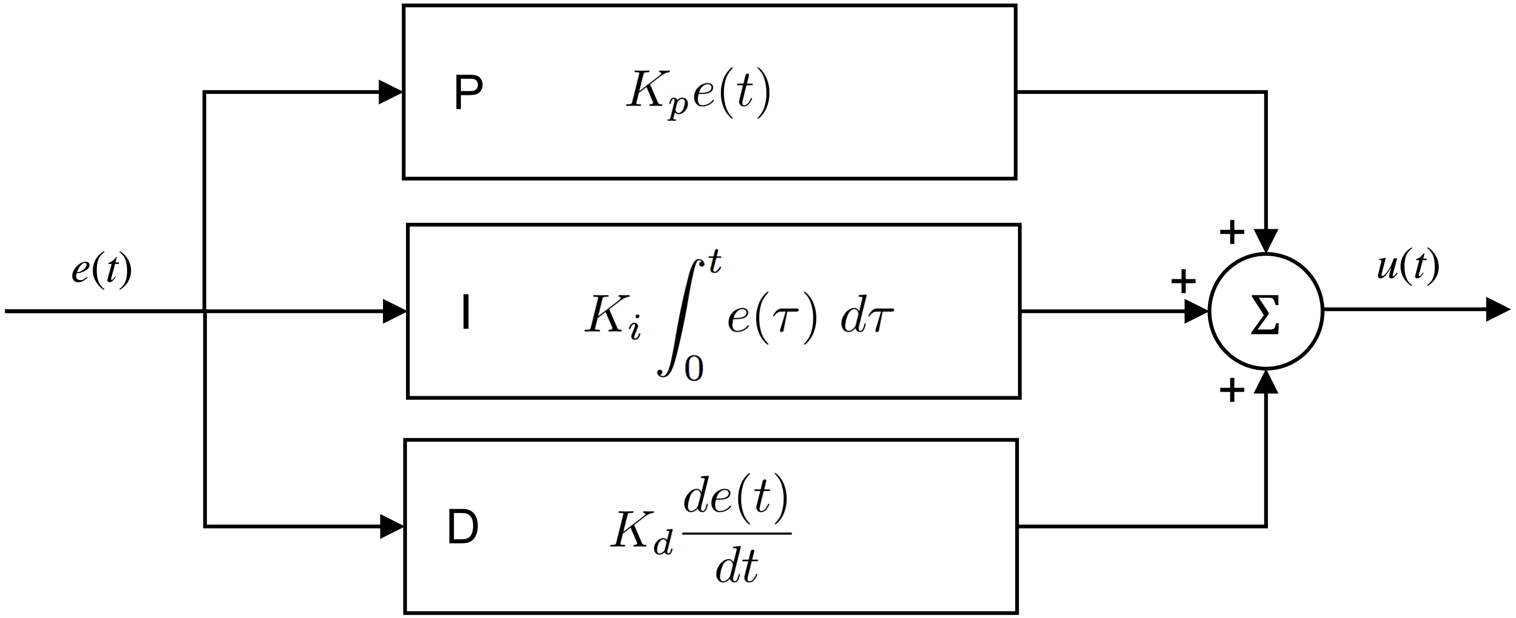
Each component is modulated by a respective gain: K_p, K_i, K_d

PID Controller

Classical control theory uses a PID controller: proportional, integral, derivative



PID Controller



$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\ d\tau + K_d \frac{de(t)}{dt}$$

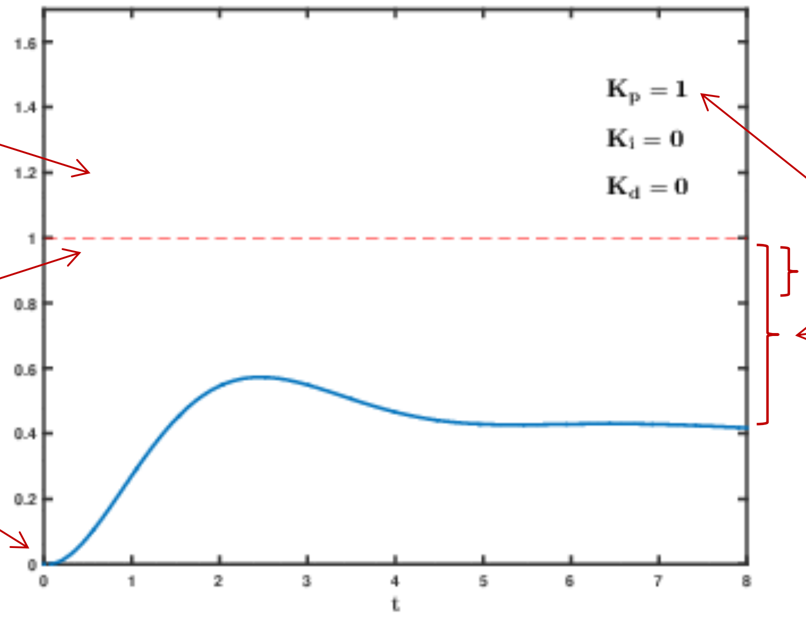
PID Controller

Effect of varying the three gains

The overshoot can be reduced by lowering the K_p but this will increase the time it takes to reduce the error

Setpoint

Initial state of the process variable



https://en.wikipedia.org/wiki/PID_controller

Note that there is a steady-state error for pure proportional control,

(i.e. when the gains of the integral and derivative terms are zero).

The integral term eliminates this.

PID Controller

Take-home message

The key to effective PID control is to use the right gain values

but

identifying them is difficult

Control Strategies

Control strategies ← Also referred to as Paradigms of Robotics

- Hierarchical / deliberative
- Reactive
- Hybrid
- Behaviour-based

Control Strategies

The paradigms are described in two ways

- By the relationship between the three commonly accepted primitives of robotics

  1. Sense
  2. Plan
  3. Act

- By the way sensory data is processed and distributed through the system

  1. Local to each control function
  2. Integrated into a global model and subsets distributed to the control function

Control Strategies

Control strategies

- Hierarchical / deliberative
- Reactive
- Hybrid
- Behaviour-based

ROBOT PRIMITIVES	INPUT	OUTPUT
SENSE	Sensor data	Sensed information
PLAN	Information (sensed and/or cognitive)	Directives
ACT	Sensed information or directives	Actuator commands

R. Murphy, Introduction to AI Robotics, MIT Press, 2000.

Control Strategies

Control strategies

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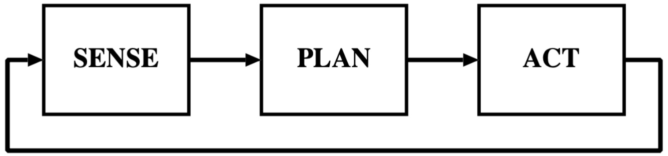

Focus is on planning: at each step, the robot explicitly plans the next move

PLAN-SENSE-ACT (P-S-A)

Sense data gathered into one global world model

Very hard problem; solutions tend to be brittle due to

- the frame problem
(the problem of representing what remains unchanged as a result of an action or an event) and

- the need for a closed world assumption
(the assumption that all objects in the world are known)

Prevalent from 1967 – 1990

Control Strategies

Control strategies

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ROBOT PRIMITIVES	INPUT	OUTPUT
SENSE	Sensor data	Sensed information
PLAN	Information (sensed and/or cognitive)	Directives
ACT	[redacted] directives	Actuator commands

No direct coupling of sensor data action

R. Murphy, Introduction to AI Robotics, MIT Press, 2000.

Control Strategies

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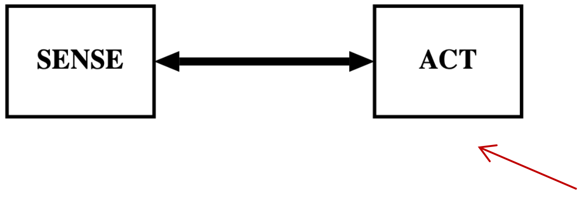

Based on biological evidence that sensed information can be directly coupled to an action

Multiple instances of Sense-Act couplings called sensorimotor contingencies or behaviours

Each behaviour operates in parallel

Final action is based on combination of behaviours

SENSE-ACT (S-A)

Advantage: fast execution time

1988 - 1992

Control Strategies

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No planning

ROBOT PRIMITIVES	INPUT	OUTPUT
SENSE	Sensor data	Sensed information
[redacted]		
ACT	Sensed information [redacted]	Actuator commands

R. Murphy, Introduction to AI Robotics, MIT Press, 2000.

Control Strategies

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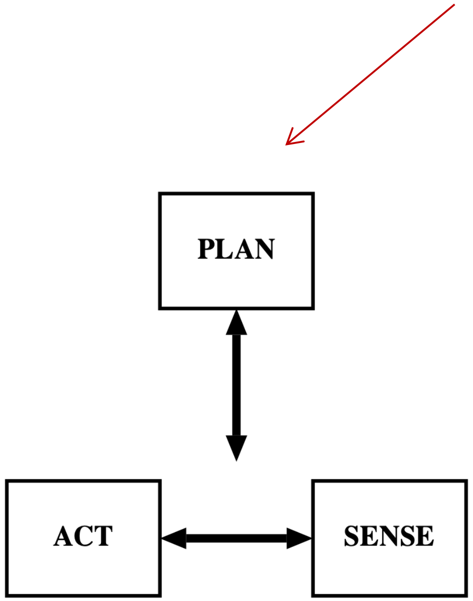

The robot first plans (deliberates) how to best decompose a task into subtasks (also called "mission planning").

The robot then decides what behaviors are needed to accomplish each subtask.

Then the behaviors start executing according to the reactive paradigm.

PLAN, SENSE-ACT (P, S-A)

i.e. planning is done at one step, then sensing and acting are done together

Sensor data is routed to each behavior that needs that sensor, and is also available to the planner for construction of a task-oriented global world model.

Each function performs computations at its own rate; deliberative planning (computationally expensive) may update every 5 seconds.

Reactive behaviors often execute ~20 ms.

1992 -

Control Strategies

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SENSE-ACT (behaviors)	Sensor data	Actuator commands

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Control Strategies

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Flexible, adaptive extension of the reactive strategy

1. The ability to react in real-time
2. The ability to use representations to generate efficient (not only reactive) behavior
3. The ability to use a uniform structure and representation throughout the system

(More in Module 7)

Reading

C. Bartneck, T. Belpaeme, F. Eyssel, T. Kanda, M. Keijsers, S. Šabanović, Human-Robot Interaction – An Introduction, Cambridge University Press, 2020. Chapter 3: How a Robot Works.

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M. Mataric, The Robotics Primer, MIT Press, 2007. Chapters 3 and 10.

R. Murphy, Introduction to AI Robotics, MIT Press, 2000. Part I Robotic Paradigms: Overview.