→ Introduction to robotic agents

Autonomous agents: traditional definition

'Computational system, situated in a given environment that has the hability to perceive that environment using sensors and act in an autonomous way in that environment using its actuators to fullfil a given function.

→ Requisites

Percieve environment, decide actions to execute, execute the actions using actuators, communicate (?) and perform a complex function (?).

Agent vs objects: agents decide what to do, react to sensors and control actuators, object methods are called externally.

Robotics: science and tech. to build, project, program and use robots. Study of robotic agents. Increased complexity: environments, perception, action, architecture, navigation, interaction.

Robot: Humanoids + automata. Programmable, mechanically capable, flexible. Eletromecanical device which can perform tasks on its own or with guidance.

Physical agent (with body) that generates intelligent / autonomous connection between perception and action. Autonomous system in physical world which may sense its environment and act on it to achieve goals.

→ Robotic architecture

An architecture provides a principled way of organizing a control system. Besides structure, it imposes constraints on the way the problem can be solved.

↳ Issues:

- Representation (unified, heterogeneous, multiple or variable)
- Control and coordination (centralized or distributed)
- Learning
- Timely performance (real-time constraints)
- Biological and psychological inspiration
- Evaluation.

↳ Spectrum of architectures

- **Deliberate control**: 'think hard, then act'
- **Reactive control**: 'don't think, (re)act'
- **Hybrid control**: think and act in parallel.

Typical organizations:

- hierarchal / deliberative
- reactive
- behaviour based
- Hybrid

↳ Deliberative: action results from reasoning over the world model, perception is not directly tied to action. (internal would and external world).

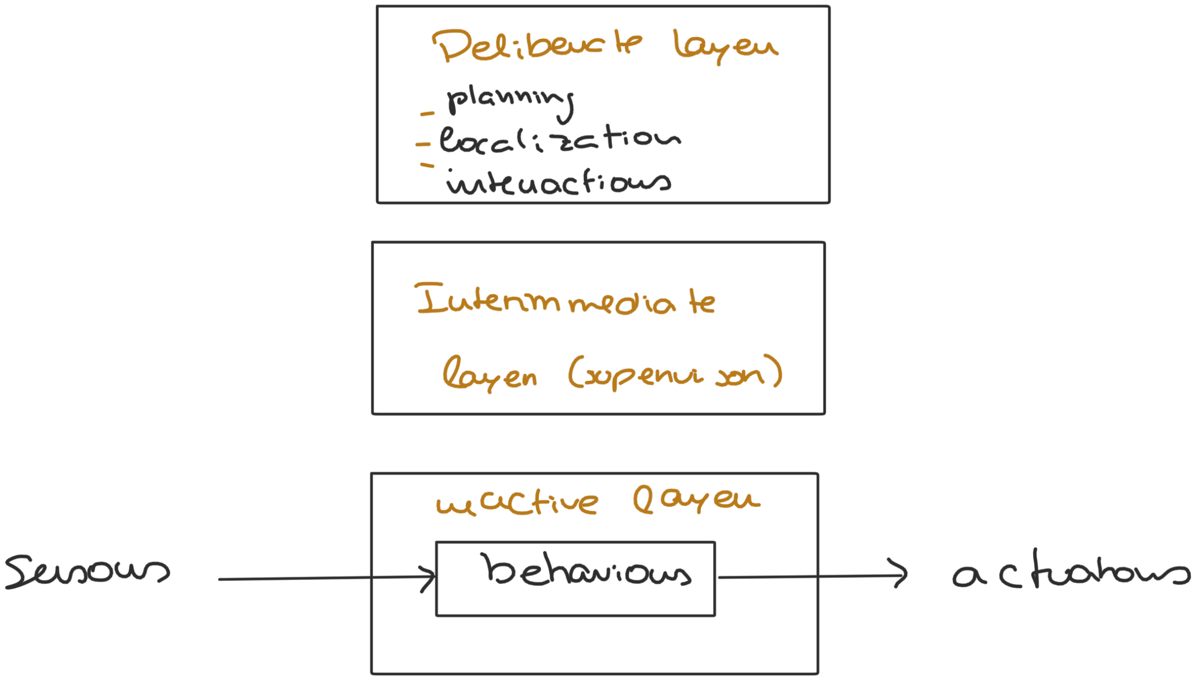
↳ Reactive: The environment lacks temporal consistency and stability, the robot's immediate sensing is adequate for the task at hand. Difficult to localize robot. No value in symbolic world knowledge.

Deliberate vs Reactive:

Thinking is slow, reaction must be fast, thinking allows looking ahead (planning), thinking too long is dangerous, accurate info to think.

↳ Behaviour: Behaviour implemented as control laws. Each behaviour receives inputs and sends outputs, many may receive input from the same sensors to same actuators. Behaviours are encoded to be simple and added incrementally.

↳ Hybrid: Combine the best of reactive and deliberate. Part of the robot 'brain' plans, the other deals with immediate reaction. Challenge is to bring the two parts together. This requires the third part of the brain, often these are called "three-layer systems".



→ The BDI model

- Three "mental attitudes":
  - Beliefs are info the agent has about the world
  - Desires are all the possible states off affairs the robot wants to accomplish
  - Intentions are those states the robot has decided to work towards.

→ Sensors

Sensorial information: self perception (how am I doing), location (where am I), environment perception (where can I go).

↳ Navigate:

• follow fixed path: line sensors reflection on an object, detection depends on the color of the object.

• react to surroundings: mechanically actuated switch, ultra-sound (based on reflection $u = \frac{1}{2} c \cdot t_{echo}$) or infra-red (sharp sensor, distance info).

• follow a path in a map: laser range finder (laser scans space ahead/around, measuring obstacle distance), position (GPS - absolute position, relative, requires line of sight), mobile phone location (based on services).

ranging

localization

• sense myself:

- position (odometry): use of data from motion sensors to estimate change in position over time; relative position, errors accumulate

wheels/motors - optical encoder: pulses generated by the interference of two patterns of stripes. Encoder categorized by p.p.r (pulses per revolution), where number of pulses is proportional to displacement. Signal is converted to digital and Quadrature allows to detect the orientation of the movement and multiply encoder resolution.

wheels/motors - absolute encoder: optical disk with Gray Code, output is shaft position (angle) in binary code.

wheels/motors - magnetic encoder: similar to optical using magnets (unaffected by dust, moisture, shock). Bycicle computers work in similar fashion.

- hall effect: based on hall effect, production of voltage difference, permanent magnet attached to shaft, orientation of the magnetic field is detected by an array sensor.

- accelerometers: inertial mass principle. Detection by changes on capacity and resistance.

orientation - compass: magnetic field detection in 2 axes with the use of trigonometry.

orientation - gyroscope: based on inertia principle. Detect changes in orientation.

- use external references

- RFID location: set of RFID tags installed in the floor, allowing position knowledge.

- Charging and location: coils on floor can charge and locate.

- trilateration: computing position by measuring distance to 3 reference points.

- visible light positioning (VLP): widespread use of LED for illumination, uses perspectives.

→ Sensor classification

- Proprioceptive / exteroceptive:

  - proprioceptive information internal to the robot (ex: motor speed, battery voltage, ...)
  - exteroceptive info external to the robot (distance to objects, light intensity, ...).

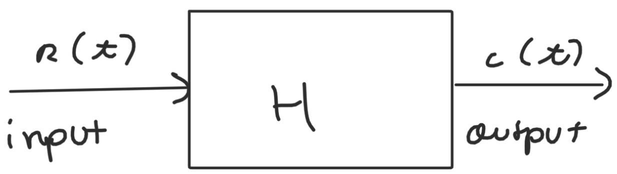
- Passive / active:

  - Passive: have no explicit source of energy, energy required comes from the measurement process itself (ex: Temperature probes).
  - Active: have internal power source, necessary for the measurement process, uses that energy to interact with environment (ex. laser range finder).

→ Control systems

Objective is to impose a given value of some physicall quantity in a system by acting on some other physicall quantity.

Basic concepts: Systems approach input signal, output signal and process transforming input to output. The objective is to impose a given value at a system's output by acting in its input.

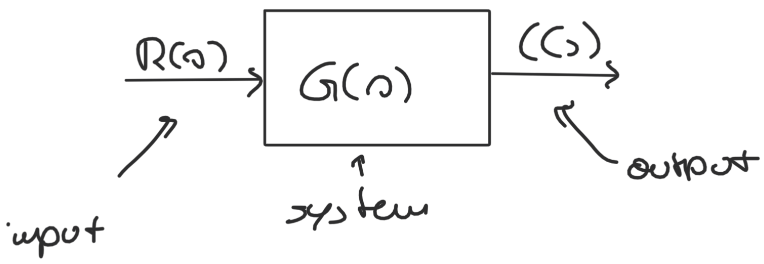


$r(t)$ and $c(t)$ are related by differential equations.

Differential equations are simplified by the use of Laplace Transforms. ($u(t)$ is the unit step function).

→ Transfer function

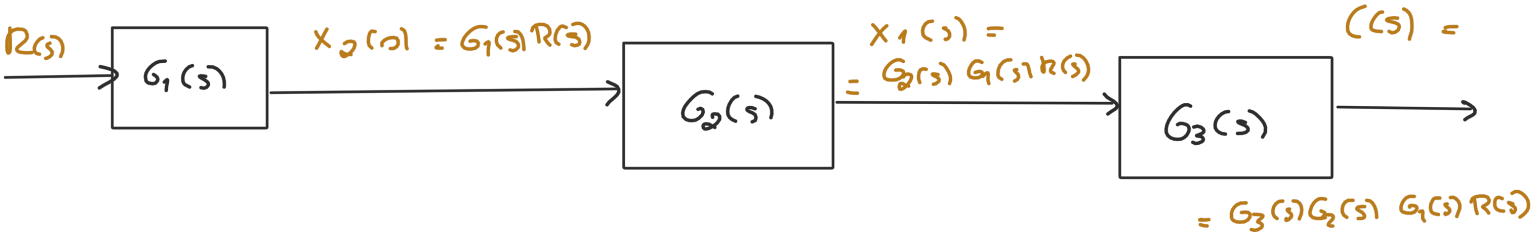
$$C(s) = G(s) \cdot R(s)$$



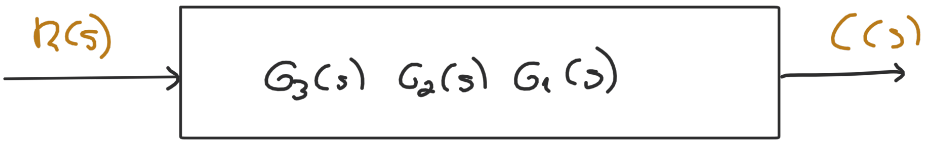
A relation expressed originally in terms of a differential equation is expressed as a product.

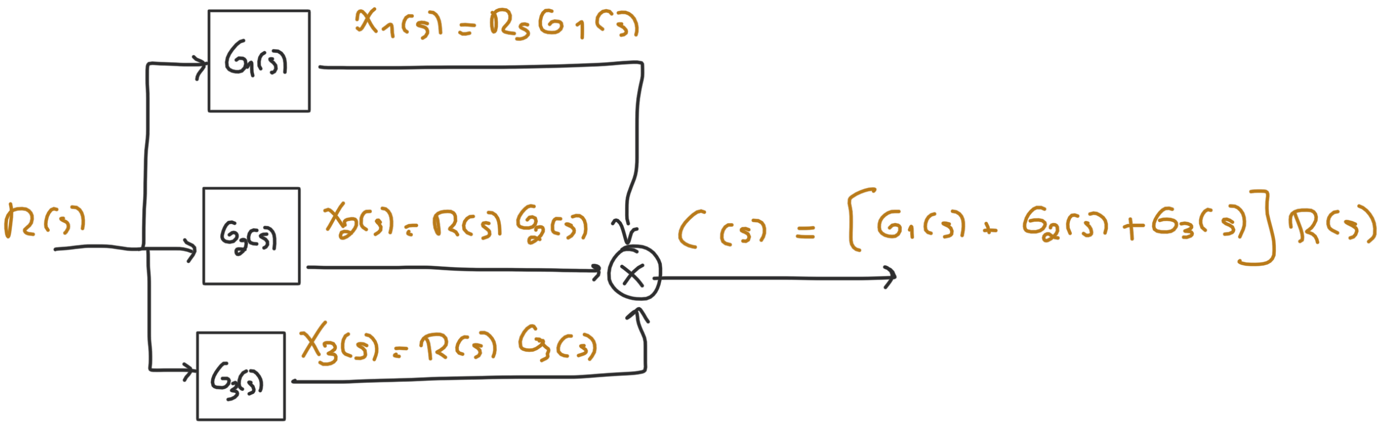
The physical nature of input/output relationship is irrelevant, only mathematical relationship matters - abstraction

→ Block diagram algebra



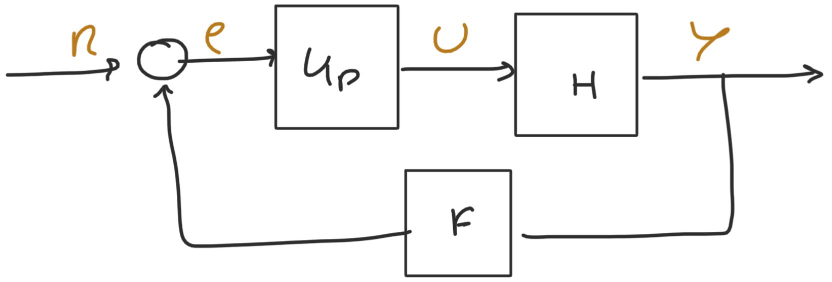
↳ multiplication





↳ Controller:

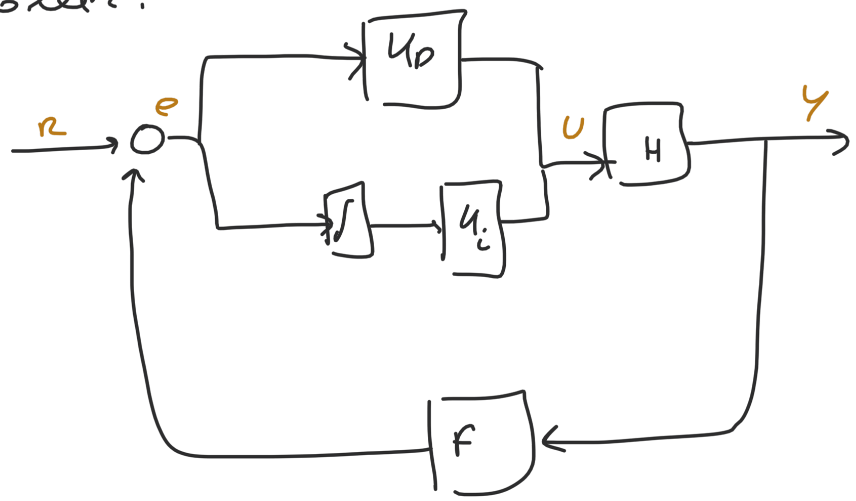
- P: simplest form of linear controller, uses a control feedback mechanism to control the process variable by adjusting output. (proportional)



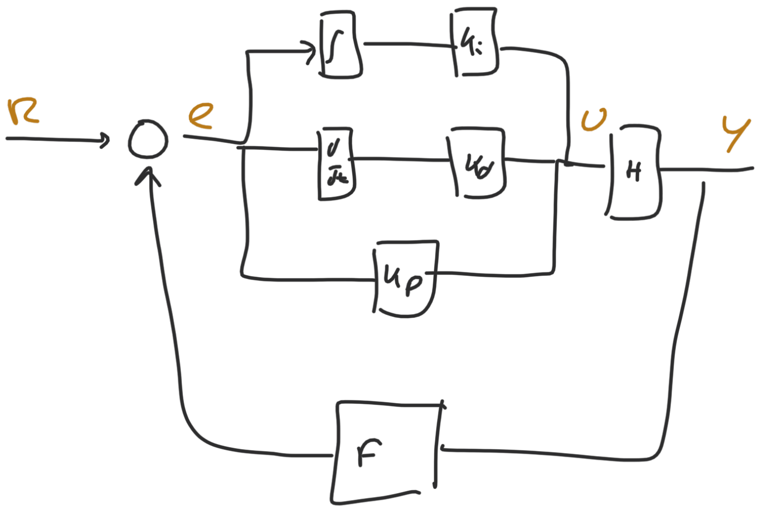
To reduce error, high value of K_p is required.

High K_p may cause unstability.

- PI : combinational of proportional controller and integer controller. Eliminates steady state error of P controller.



- PID : previous controllers plus derivative which helps to anticipate future error



→ Sensor Fusion

Act of combining sensory data from separate sources. The resulting info is 'better' than individually. (more accurate, complete). It's considered a subset of Information Fusion.

Usually based on modeling the sensors and the system being measured. Most common methodologies are probability based. (others are interval calculus, fuzzy logic, theory of evidence).

↳ Bayes Rule

Determine prob. of event given the result of related events.

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}$$

→ conditional probability

P(A) and P(B) are marginal probabilities

↳ Bayesian Filter

Application of the Baye's Rule when:

- x_t is state vector at time t
- u_t is the control vector used to drive from x_{t-1} to x_t
- z_t is the observation of the state at time t.

↳ Monte Carlo localization

Based on random (educated) guesses drawn into the pose space (particles), belief is given by a set of particles.

Measurement is used to determine the importance weight of particles.

Weights are used to influence a random selection of particles (heavier particles are more likely to be selected). Number of particles is key.

Can be used to solve global position, not bound to unimodal distributions.

→ Actuators in mobile robotics.

Actuator 'is' an active device that converts a primary energy source into physical movement.

Two classifications:

- The type of primary energy (used to generate motion in the actuator)
- Type of generated movement.

↳ Type of primary energy

- Eletrical: Transform primary eletrical energy (from battery) into the intended movement. Main class of actuators in robotics. Diverse and adaptable.

- Pneumatic: Powered by energy stored as compressed air. Used in situations where accurate and easy to control movements is required but the force is not a critical criteria. Very high pressure, robust. Less efficient in converting energy than eletric.

- Hydraulic: Flow and pressure of fluid to convert the primary energy into linear and/or rotational motion or torque. Used when force required is extremely high. Heavy and bulky machines. Not relevant for this field of robots covered.

↳ Type of generated movement

- **Rotary actuator:** primary energy is converted to rotating motion which can be continuous, positional or a source of application of force (torque).

- **Linear actuator:** converted into linear motion. Can include the direct application of a force, positioning of a mechanical element or execution of a repetitive continuous motion.

→ Rotary Actuators

Most common, use electricity as primary source of energy. (commonly named as 'drivers' or 'motors')

Three types:

- Brushed DC motors
- Brushless DC motors
- Stepper motors

↳ Brushed DC Motors

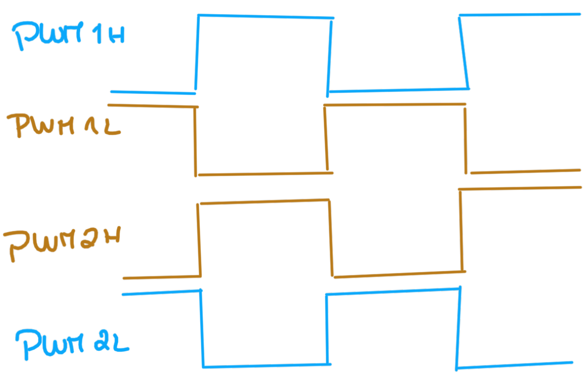
Use DC power to generate rotational motion. Consist of rotor (rotating part, attached to shaft equiped with magnets) and stator (contains set of coils powered by direct current).

Current makes the coils create a magnet field, and the interaction of these magnet fields makes the rotor rotate.

Switching the direction of current flow to ensure torque remains in same direction is performed mechanically by the brushes.

Speed control of DC motors can be done by varying the voltage applied to the terminals. (by a PWM controller).

To change the direction of rotation of a DC motor, the polarity of the applied voltage must be reversed.

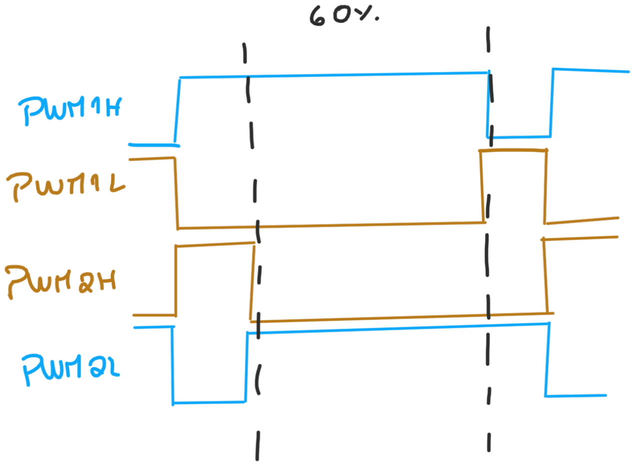


STOPED

O PWM1H e PWM2H estão ambos fechados e por isso não há diferença de voltagem e portanto não há corrente aplicada.

A mesma coisa com PWM1L e PWM2L (os dois switches de baixo).

60%



RPM ~ 60%

Neste caso, o duty cycle é de ~60% e portanto o motor está a 60% da energia máxima e a rotação é dada pela rotação atribuída ao PWM1H e PWM2L, pois são esses dois sinais que estão a 1 esse intervalo (azuis).

↳ Brushless DC Motors (BLDC)

Use permanent magnets mounted on the motor. The poles are excited by an externally applied voltage.

This configuration eliminates the need for a mechanical switching system (brushes), requiring an electronic control which ensures the correct sequential switching of the poles.

Have greater efficiency and almost no maintenance.

It requires a mechanism to provide information on the absolute position of the motor.

↳ Stepper motors

Magnets and coils. With current, generates a magnetic field which aligns teeth. The teeth of the other coils are slightly out of phase, so when the current switches to other coil, a new binary is generated to trigger a new alignment.

→ Comparison of these three types

Brushed DC	Brushless DC	Stepper Motors
+ cheap	- price	-- price
. efficiency	+ efficiency	-- efficiency
- power vs volume	+ power vs volume	+ very precise
+ simple startup	- complex startup	+- complex
	+ good for planar topologies	+ good for planar topologies
+ simple control	- complex control	+- control
- mechanical wear-out	+ maintenance	- mechanical vibration
+ power range	+ range of rot. speeds	+ positioning apps.

→ Solenoids

Converts eletrical energy into linear motion. Uses coils and magnetic fields (used in valves, actuators, locks, relays).

→ Servo motors

Combination of BLDC, reduction gearbox and eletronic control loop.

Good for angular positioning which require good accuracy.

→ Locomotion

Maps physical actions into movement, defining how a robot moves in the environment.

Three solutions:

- tracked locomotion
- legged locomotion
- wheeled locomotion

↳ Tracked locomotion

Great traction power, good for very tough terrain. Change of direction is done by sliding the tracks, which makes it difficult to use odometry. Large ammount of power to turn.

↳ legged locomotion

Locomotion with legs, complex, power consumption and lack stability.

↳ Wheeled locomotion

Most suitable for common apps.

Configuration and type of wheel depend on app.

Main constraint is flat terrain

Big wheels → + torque (better for large obstacles)

- wheel types:
  - standard
  - steered standard
  - off centered orientable wheel (castor)
  - swedish (omnidirectional)

Static stability:

- **two wheels:** minimum for stability, center of mass should be bellow the axle that links the wheels.

  2 configs: - one steering wheel in the front and traction wheel in the back.

  - two differential drive with center of mass bellow axle.

- **three wheels:** stable, center must be inside the triangle formed by ground contact of wheels.

  various configs, from differential, independent traction wheels, free wheels, motorized swedish, ...

- **four wheels:** stable, requires suspension system to compensate for irregularities in the environment.

  multiple different configurations.

→ **Kinematics:** modeling the motion without considering the forces that cause the object to move.

→ Differential drive

Common configs: 2 active independent wheels or 1 / 2 passive castor wheels.

Robot follows trajectory defined by speed of each wheel. Trajectory is sensitive to differences in the relative velocity of the wheels.

For small displacements:

$$x' = x + d_{center} \times \cos\theta$$

$$y' = y + d_{center} \times \cos\theta$$

$$\theta' = \theta + \phi$$

distance travelled

$$d_{center} = \frac{d_{right} + d_{left}}{2}$$

$$\phi = \frac{d_{right} - d_{left}}{L} = \frac{dist}{R}$$

→ Tricycle drive

Two rear wheels and one (steering) front wheel, which can be passive or the driving wheel).

Main problems: traction.

Kinematic model:

$$v_x(t) = v_s(t) \cdot \cos\alpha(t)$$

↳ steering angle

linear velocity of steering wheel

$$v_y(t) = 0$$

$$\omega(t) = \frac{v_s(t)}{l} \times \sin\alpha(t)$$

angular velocity

↘ distance between back and front wheels

→ Ackerman steering

Method of choice for outdoor vehicles.

Inside turning wheel is turned more than the outside turning wheel.

A differential gear must be used in the traction axel.

→ Synchro Drive

3+ wheels.

The robot can move in any direction and can always reorient its wheels to move along a new trajectory without changing its foot print.

Orientation of the chassis is not controllable

→ Omnidirectional drive

Uses swedish wheels, each having independent motor.

Allows to move in any direction and complex movements.

Excellent maneuverability

→ Computer vision

Techniques for image accuisition, extraction, characterization and interpretation of the 3D world.

↳ Luminance

Measurement of the ammount of light that goes through or is emitted from a particular area and falls within a given solid angle (cd/m²)
↓
candela

↳ Chrominance

How light is distributed along the visible spectrum.

Chrominance has no info about luminance but is used with it to describe a coloured image (ex: RGB).

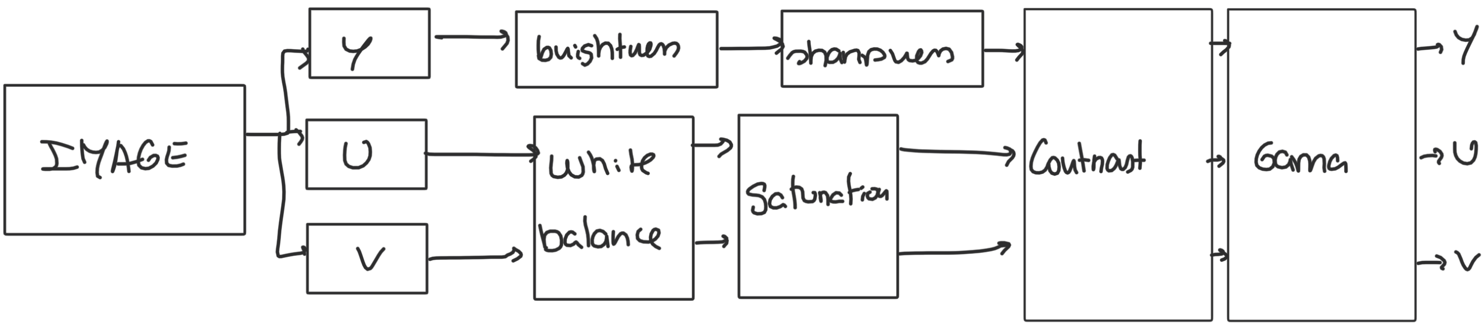
In RGB, if R=G=B then there is no info about chrominance.

↳ Image formation

Most image sensors use either CCD (charged coupled device - better dynamic range, lower dark noise) or CMOS (lower voltage, quick, lower complexity) to 'grab' light energy and convert to photons to electrons. Only luminance is captured this way.

To obtain color, a set of filters must be used (most common Bayer configuration).

↳ Image processing pipeline



Brightness: measure of the average amount of light that is integrated over the image during the exposure time.
As a parameter, its a value (constant) that can be added or subtracted from the luminance component.

Contrast: difference in luminance (or difference in color and brightness of the object and other objects in same FOV).
Maximum contrast is contrast ratio.

$$\frac{\text{luminance difference}}{\text{average luminance}}$$

As a parameter, is the variation of the gain control function of the luminance component of the image.

White balance: global adjustement of intensities of the colours (rgb). Important to render specific colors.

Saturation: saturation of a color is determined by a combination of light intensity of a pixel and how this light is distributed across the spectrum.
To reduce saturation, we can add white to the original colours (same as changing the gain of U and V

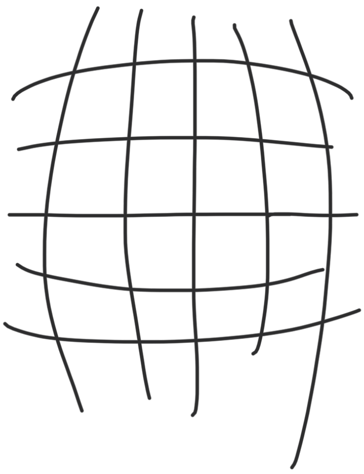
Gama: nonlinear operation used to code and decode luminance on RGB tristimulus values.

Sharpness: measure of energy frequency spatial distribution over the image. Allows the control of the cut-off frequency of a low pass spatial filter.

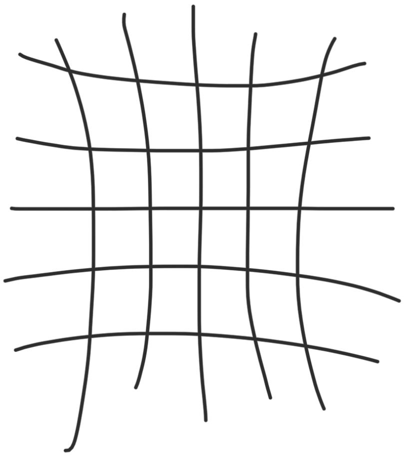
→ Lenses

Spherical aberration:

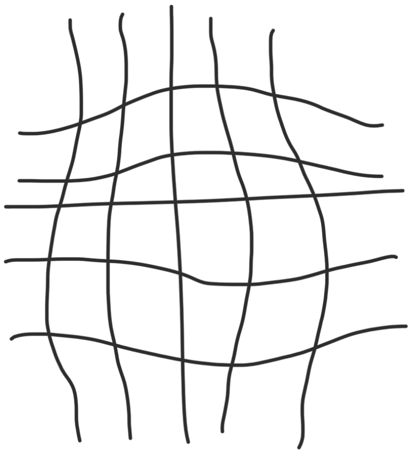
barrel



pincushion



mustache distortion



→ Camera parameters

Extrinsic: parameters that define location and orientation of the camera reference frame.

Intrinsic: parameters to link the pixel coordinate to the corresponding coordinates in the camera reference frame.

→ Machine Learning in Robotics

Key concepts: experience (data), task, performance measure and improvement.

↳ Supervised learning

Method where model is trained on labeled dataset (from examples) with the goal of making predictions of unseen data. Model can be trained on examples of input-output, input can be sensors and the output are actions for robot to take

↳ Unsupervised learning

Model is trained on unlabeled dataset with the goal of discovering patterns or structure in the data. There is no specific output or target variable the model is trying to predict

↳ Evolutionary learning

Inspired by the process of natural evolution
A population of potential solutions (agents) is created and evolved over time.
Generations can evolve and better agents 'reproduce' on their genetic information. Objective is to get better fitness values.

↳ Reinforcement learning

How agents learn by interacting with the environment to maximize the notion of cumulative reward.

The agents learn by interacting with environment and receiving feedback in the form of rewards and penalties, which are used to update its policy and improve performance over time.