Introduction to Wheeled Mobile Robotics

CONTRIVA

organized by

GCT IEEE Student Branch – STB81571, Coimbatore

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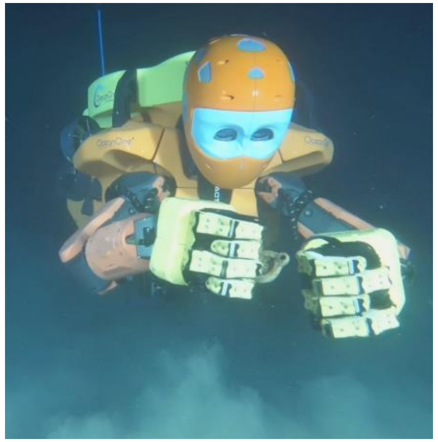
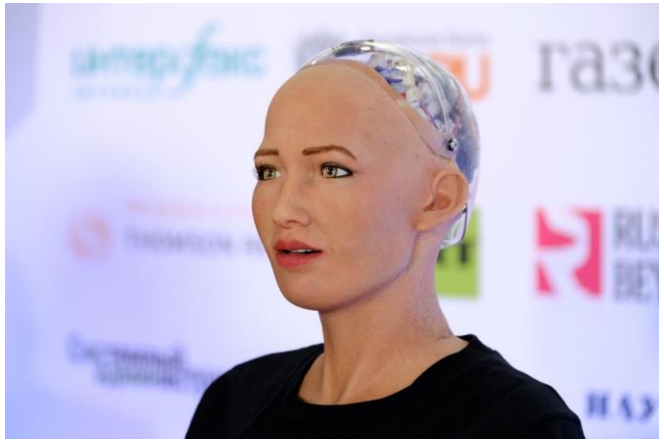
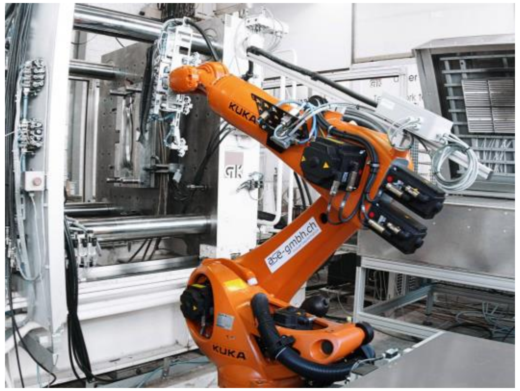
What are these?





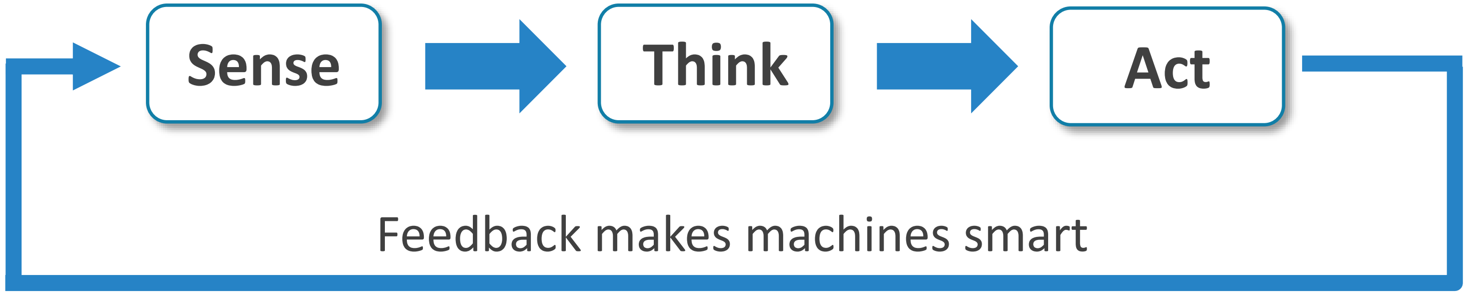

Credits: Universal Robots, Stanford Robotics Lab, Ohmni Labs, Hanson Robotics, Boston Dynamics, KUKA, DJI Agriculture, da Vinci

What is a robot?

What is a Robot?

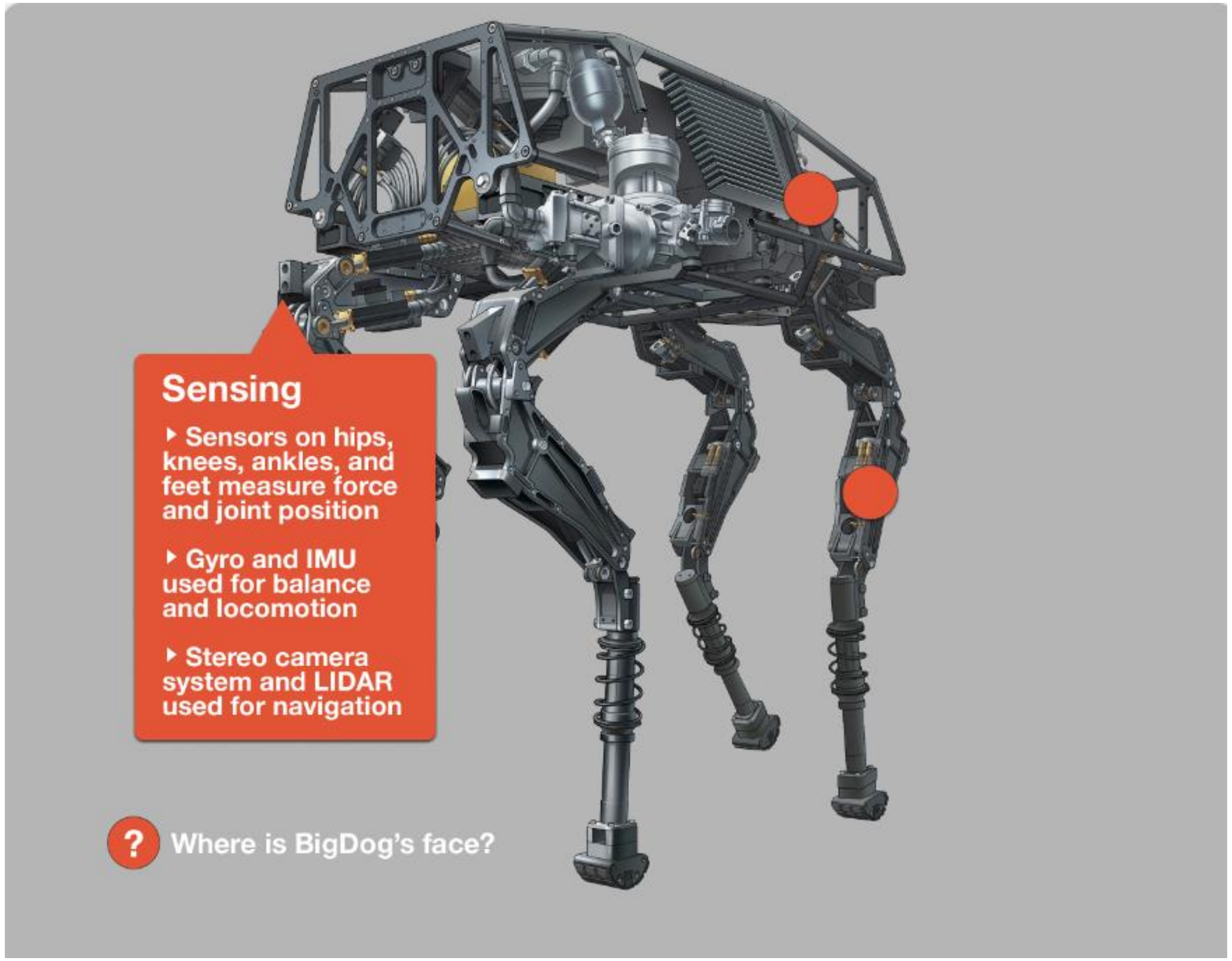
"A robot is an autonomous machine capable of sensing its environments, carrying out computations to make decisions and performing actions in the real world" [1]

- Rodney Brooks, Roomba creator



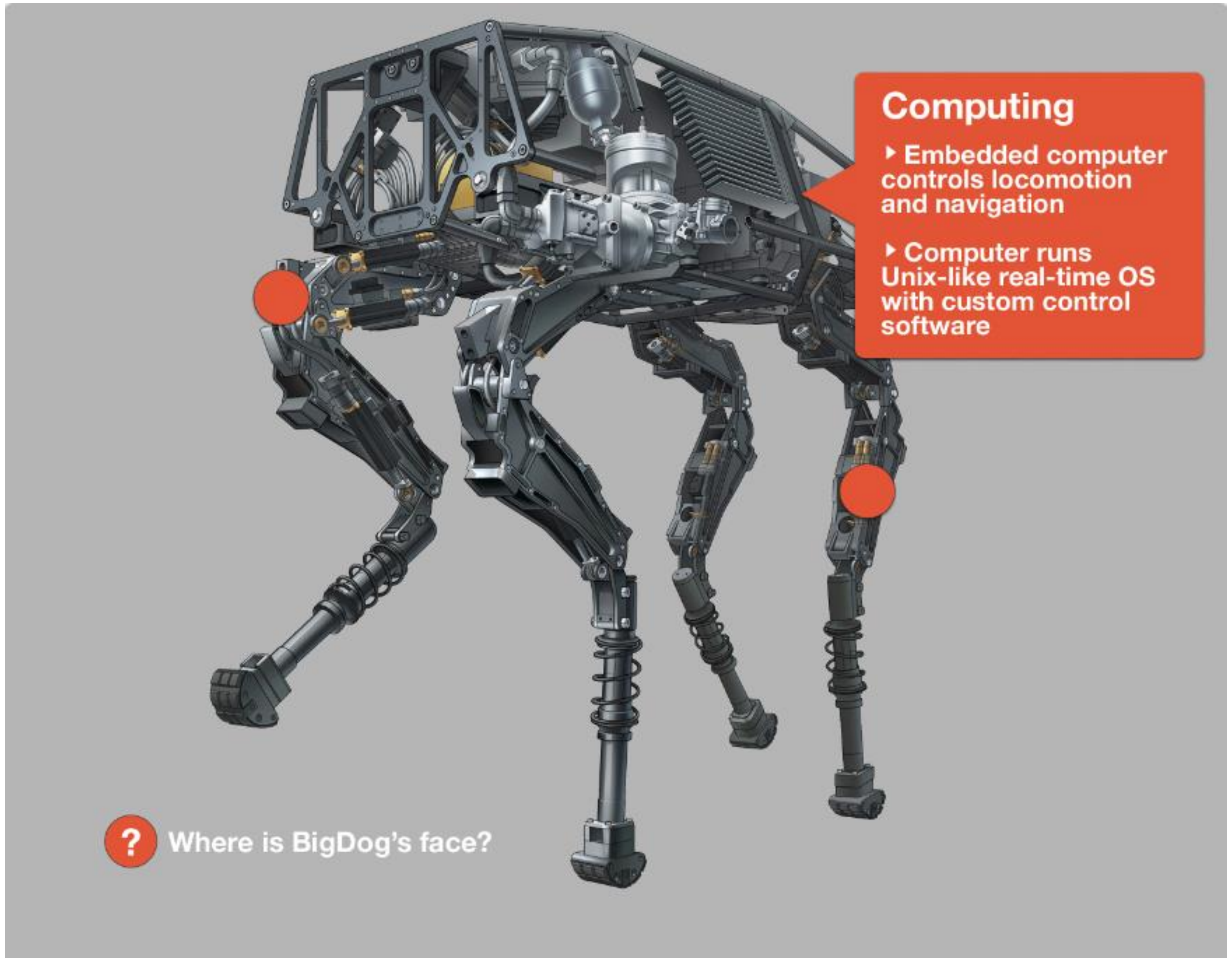
[1] What Is a Robot? - ROBOTS: Your Guide to the World of Robotics (ieee.org)

Sense – Think – Act



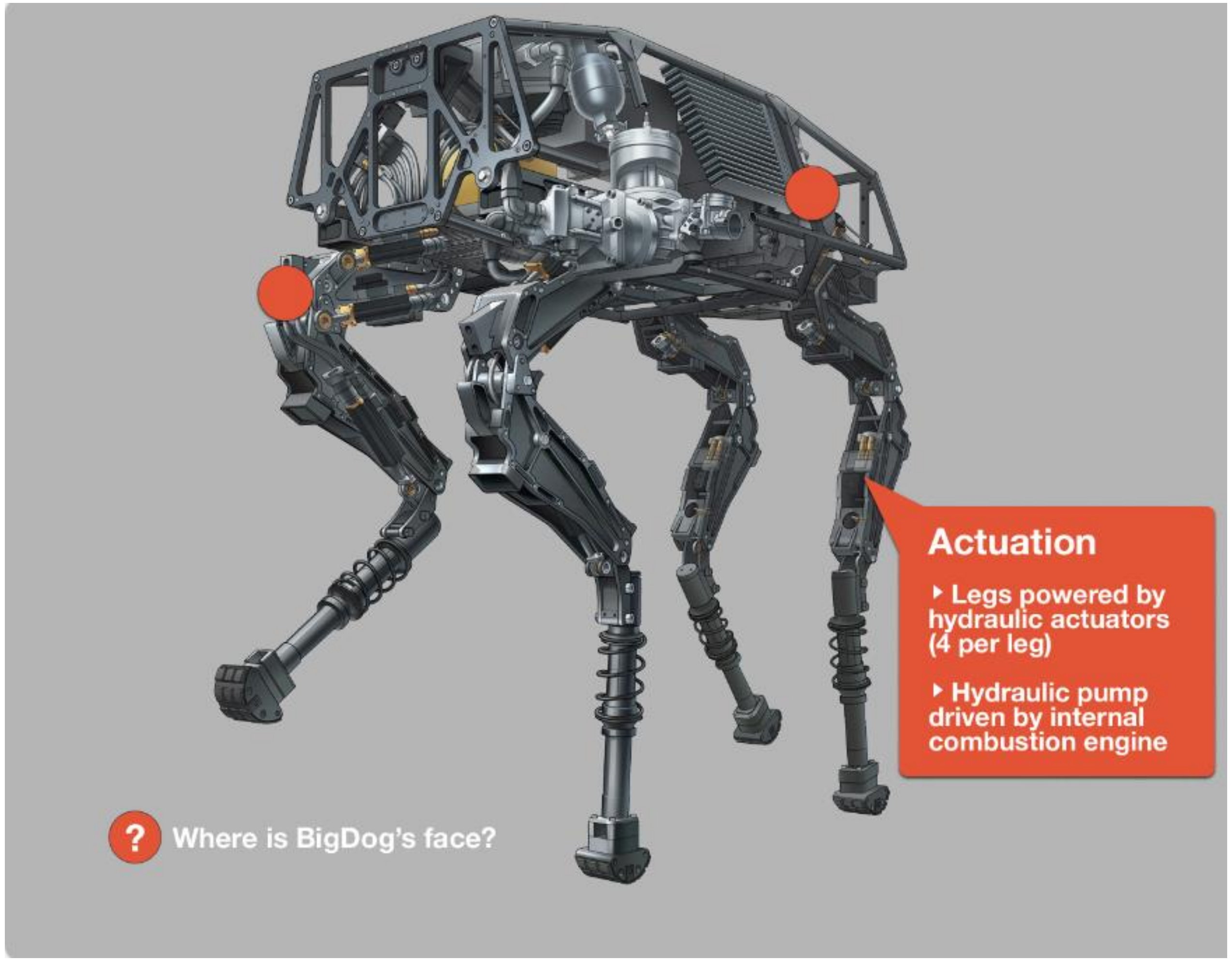
Credits: Big Dog - Boston Dynamics

Sense – Think – Act



Credits: Big Dog - Boston Dynamics

Sense – Think – Act



Credits: [Big Dog - Boston Dynamics]

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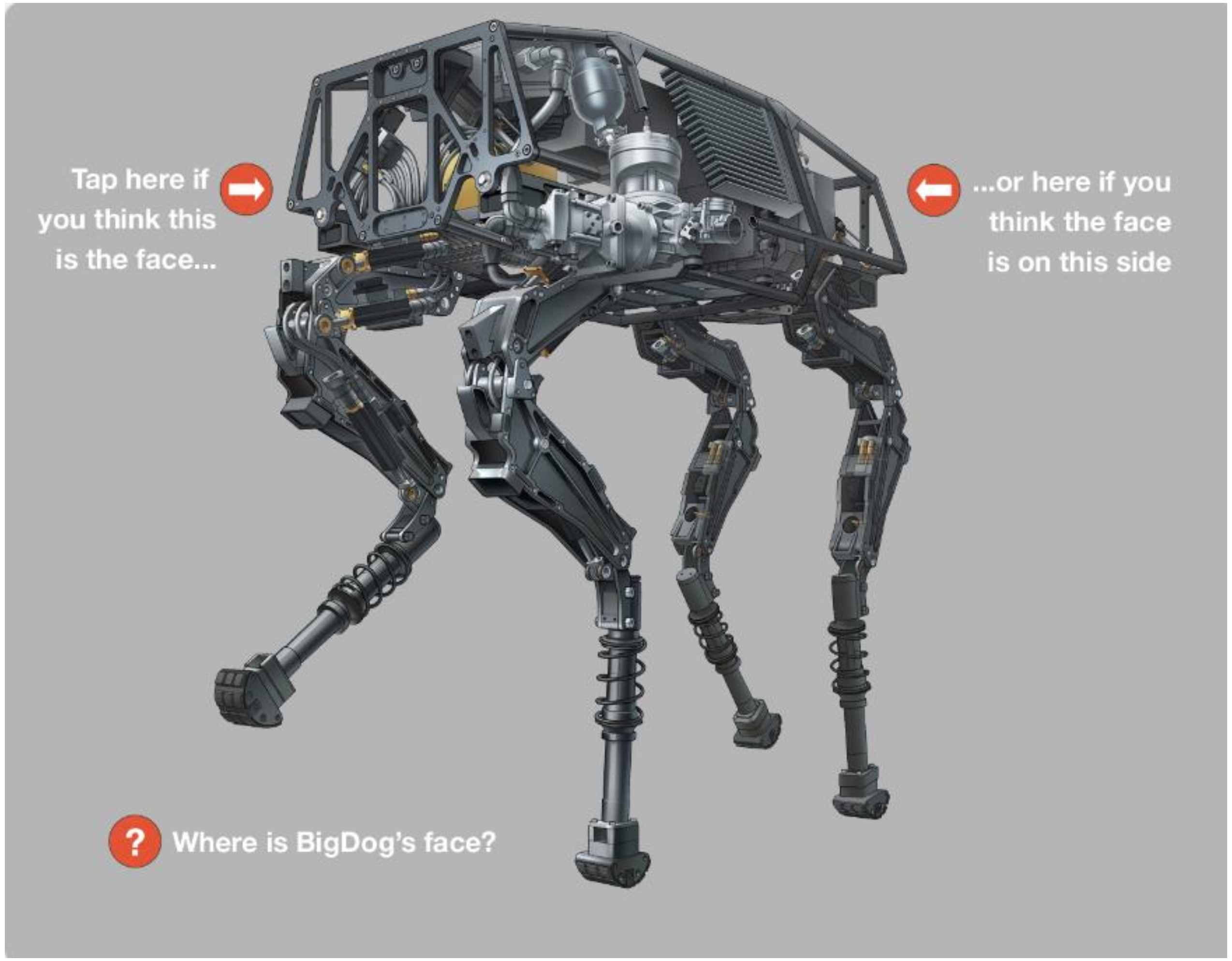
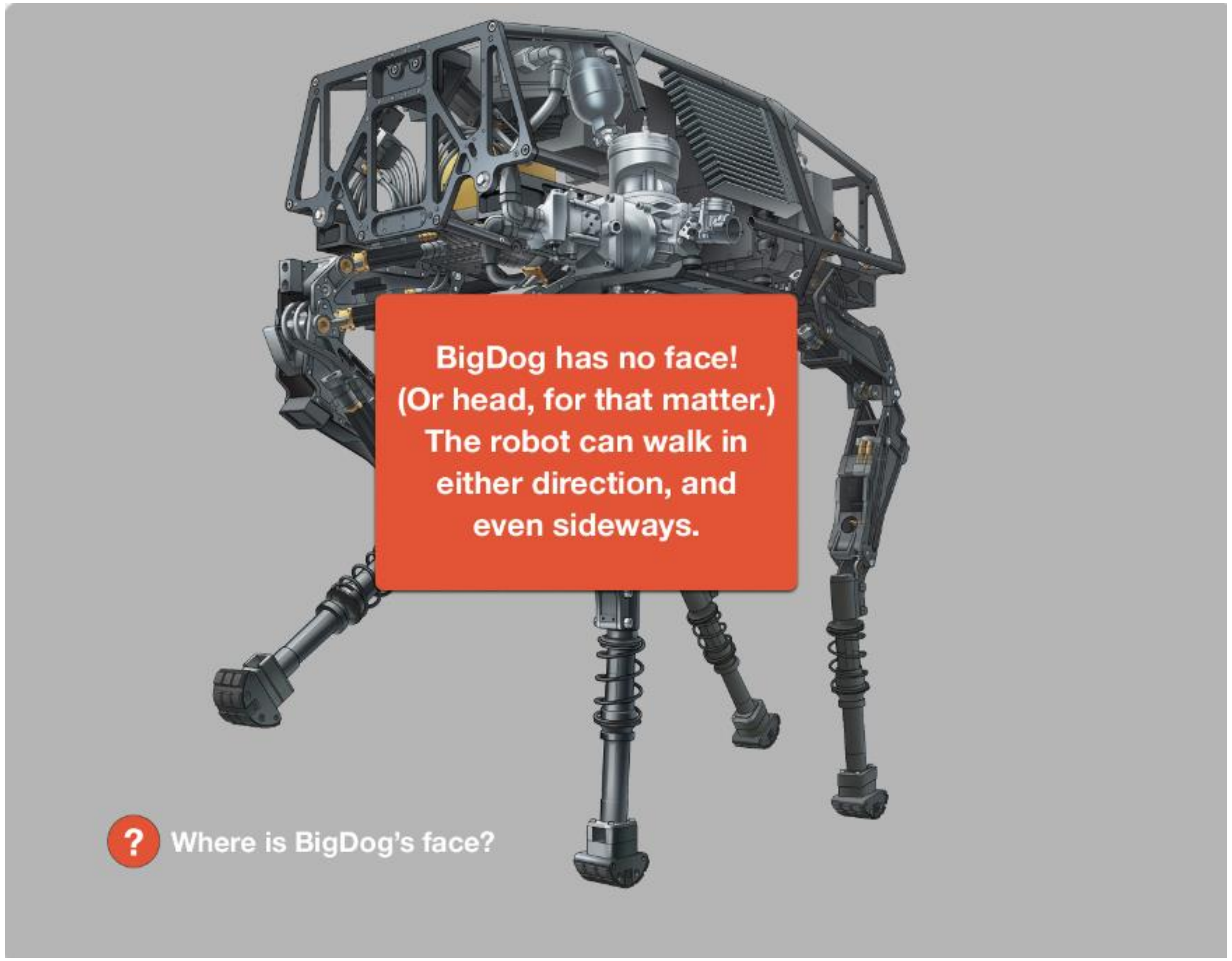
Sense – Think – Act

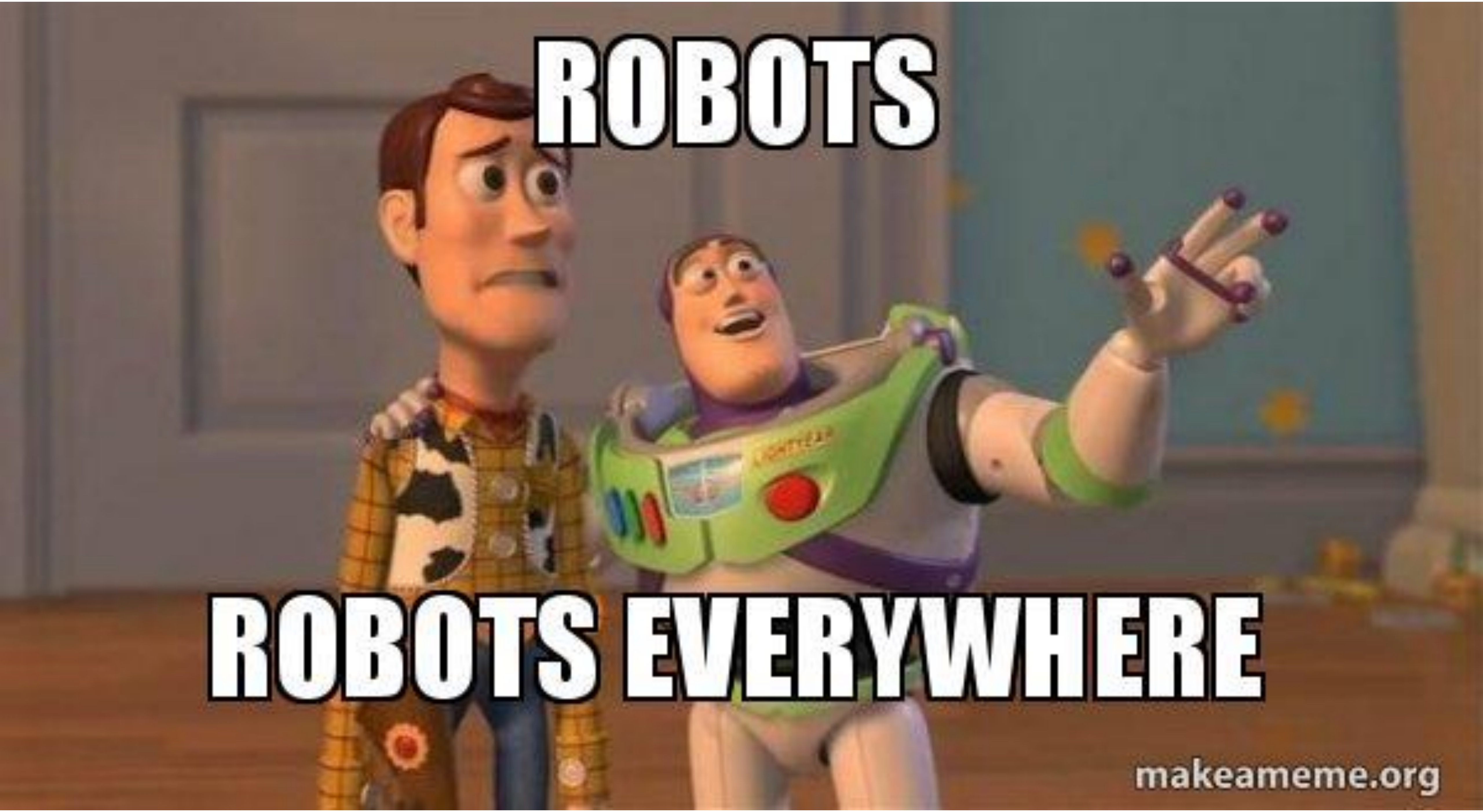


Credits: Big Dog - Boston Dynamics

Sense – Think – Act



Credits: Big Dog - Boston Dynamics


ROBOTS
ROBOTS EVERYWHERE
makeameme.org

Motivation

- Acquaint with interdisciplinary aspects of robotics
- Blend your skillset towards the automated world
- Develop and build a real-time working robot

Agenda

- **Introduction to Robotics**
- **Board Classification**
- **Wheeled Mobile Robots**

Introduction

- **Co-ordinate Frames & Transformations**
- **Differential Drive Kinematics**

Mechanical Aspects

- Perception – Sensors
- Cognition – Processors
- Actuation – Actuators

Electronics Aspects

- ESP8266 Programming Basics
- Code Walk-through
- PID Control

Programming Aspects

- Advanced Concepts & Current Research

Advanced Methods

History

1921

The term 'Robot' is coined

1959

First Robotic Arm - Unimate

2002

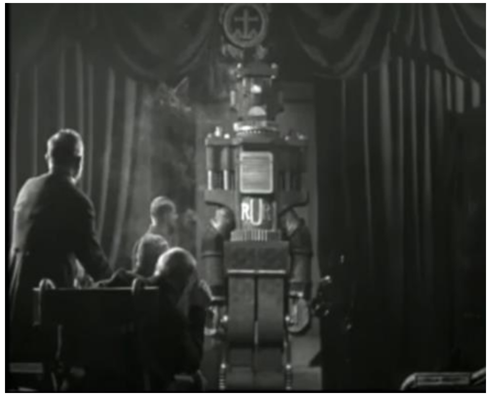
First Household Robot – Roomba

2005

First Self Driving Car - Stanley

2016

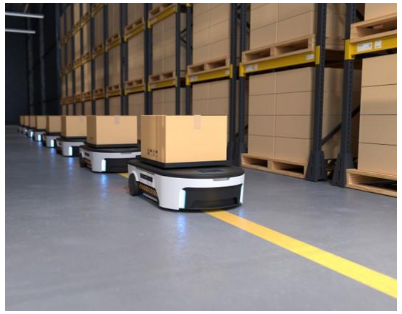
First Robot Citizen - Sophia



Credits: Rossum's Universal Robots, Unimate Robot, iRobot, Sanford Racing Team, Hanson Robotics

Broad Classification

- Robots
  - Autonomous Mobile Robots (AMRs)
  - Autonomous Guided Vehicles (AGVs)
  - Manipulators
  - Humanoids
  - Hybrid



Credits: Types of Robots (intel.com), ClearPath Robotics, Warehouse Robots, ABB Robotics, Boston Dynamics, PRODRONE

Which category a self driving car falls in?

Wheeled Mobile Robots

Robots that navigate around the ground using motorized wheels to propel themselves [2]

References: [2] Wikibooks, [3] ScienceDirect, Amazon

Wheeled Mobile Robots

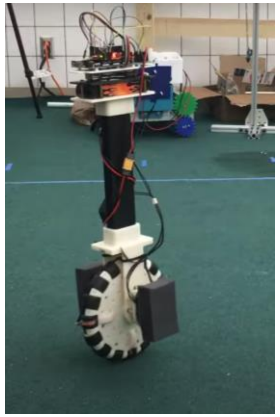
More rigorous definition,

Dynamic systems where an appropriate torque needs to be applied to the wheels to obtain desired motion of the platform [3]

References: [2] Wikibooks, [3] ScienceDirect, Amazon

Types of Wheeled Mobile Robots

- WMR
  - Number of wheels
    - One
    - Two
    - Three
  - Type of Wheel
    - Standard
    - Omni-directional
    - Macanum
  - Type of Configuration
    - Differential Drive
    - Ackermann





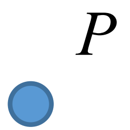



Credits: OmBURo, nBot, Turtlebot3, SuperDroid Robots, IPC, Turtlebot4, JEAS

We are not robots
Let’s have a break now

Co-ordinate Frames

Representing a point in 2 dimensional space,



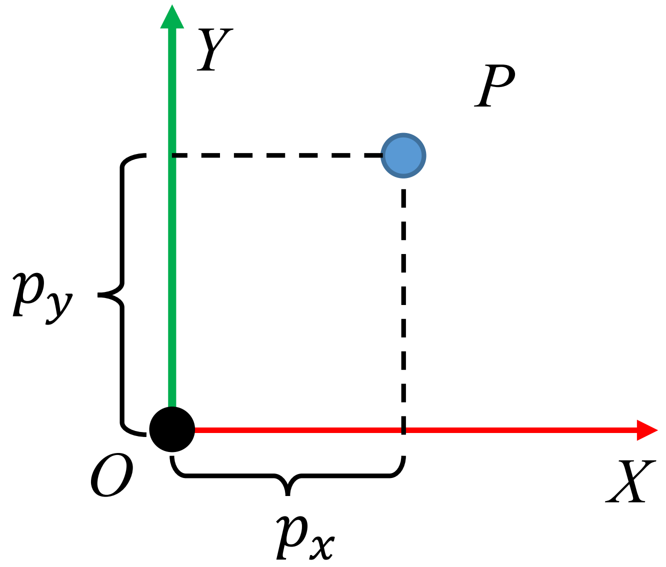
Without a reference co-ordinate frame, the definition of point is meaningless

Robot Motion = Translation and Rotation

Credits: CoordinateTransformations (illinois.edu)

Co-ordinate Frames

Representing a point in 2 dimensional space,



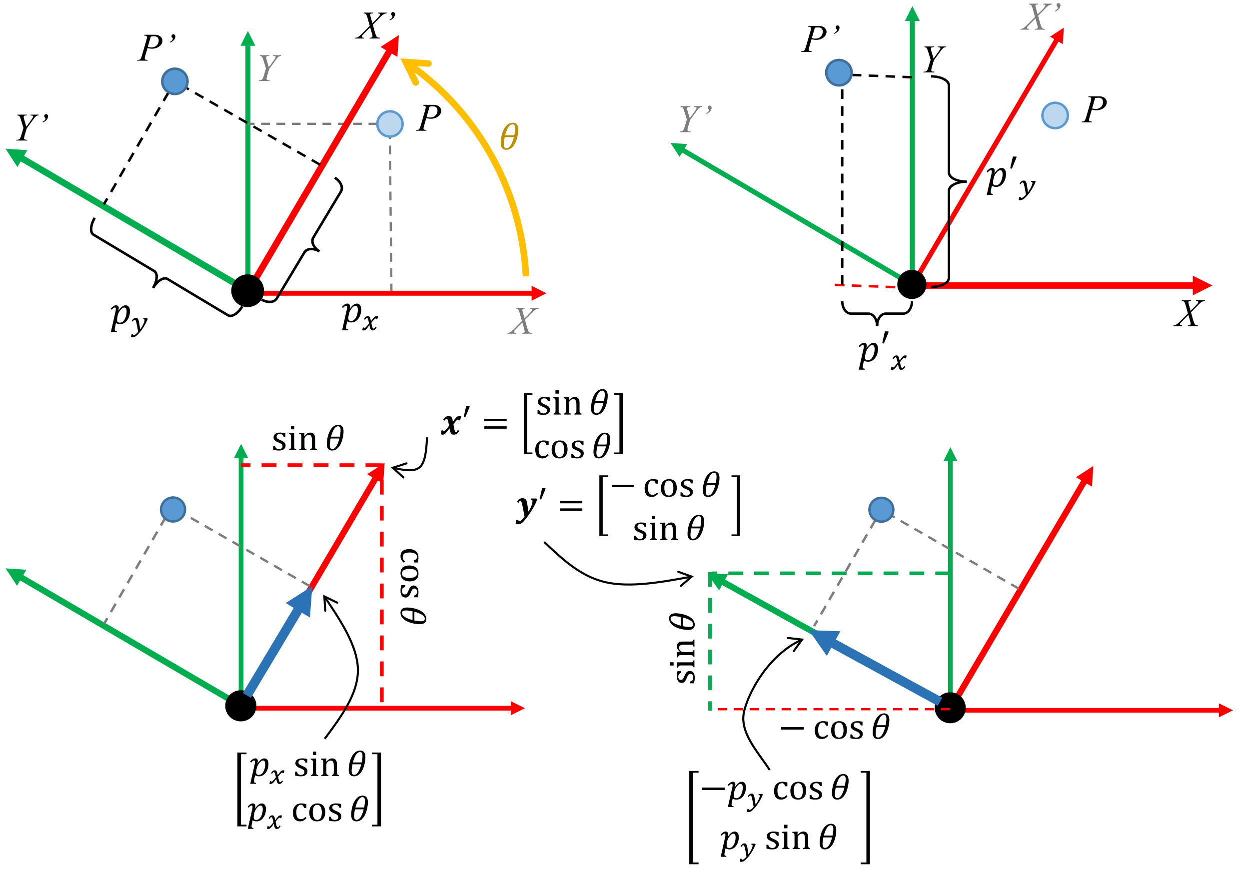
$$\mathbf{p} = \begin{bmatrix} p_x \\ p_y \end{bmatrix}$$

Robot Motion = Translation and Rotation

Credits: CoordinateTransformations (illinois.edu)

Rotation Matrix

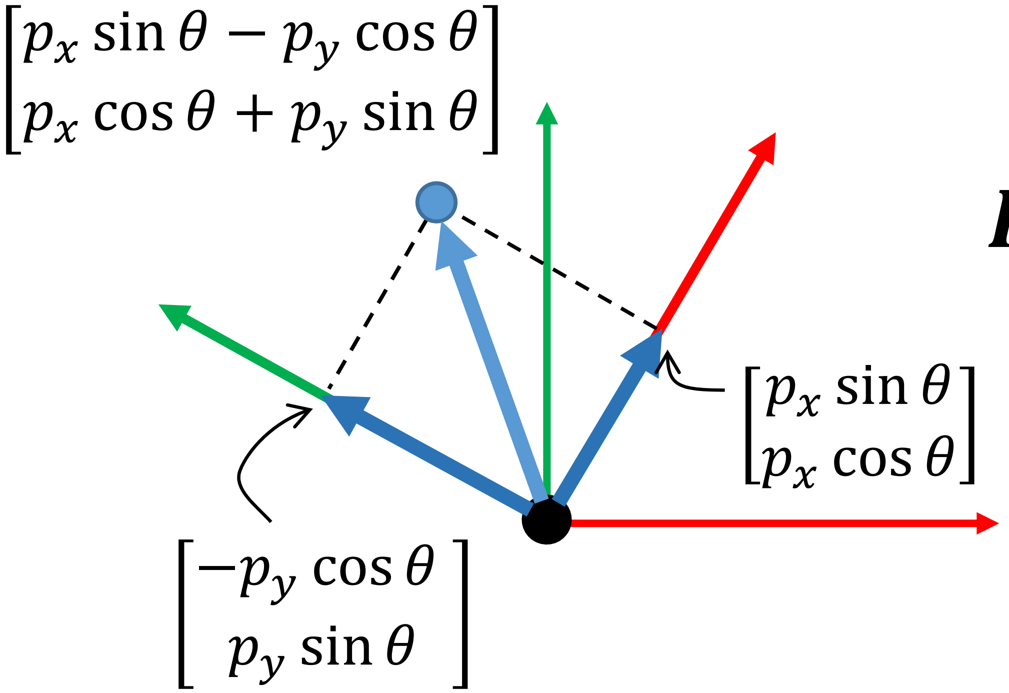
Representing rotation of the point in 2 dimensional space,



Credits: CoordinateTransformations (illinois.edu)

Rotation Matrix

Representing rotation of the point in 2 dimensional space,

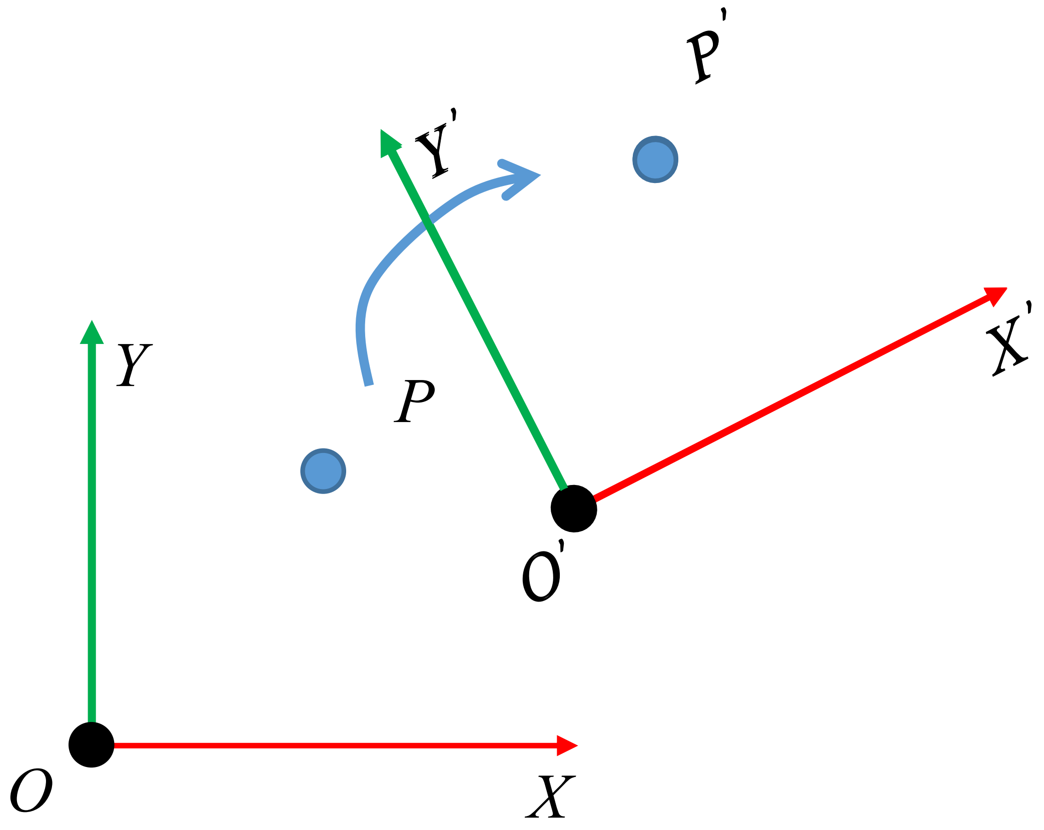


$$\boldsymbol{R}(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

$$\mathbf{p}' = \boldsymbol{R}(\theta) * \mathbf{p}$$

Credits: CoordinateTransformations (illinois.edu)

Homogeneous Transformation



$$\boldsymbol{T}(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & p_x \\ \sin\theta & \cos\theta & p_y \\ 0 & 0 & 1 \end{bmatrix}$$

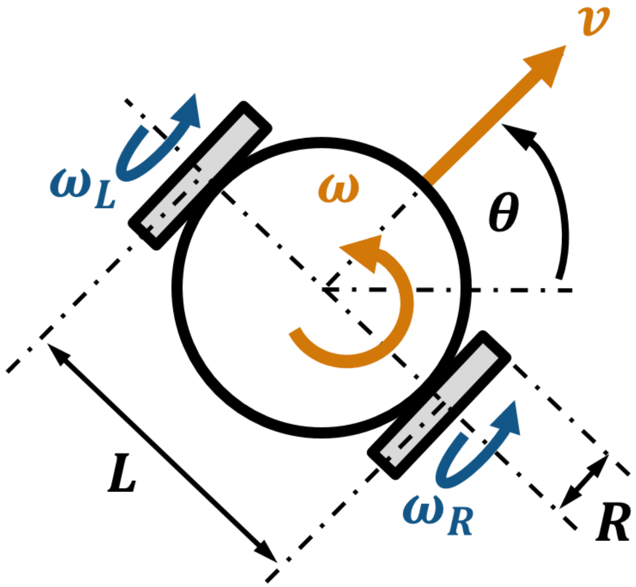
$$\boldsymbol{T}(\theta) = \begin{bmatrix} \boldsymbol{R}(\theta) & & \mathbf{p} \\ 0 & 0 & 1 \end{bmatrix}$$

Credits: CoordinateTransformations (illinois.edu)

Differential Drive Kinematics

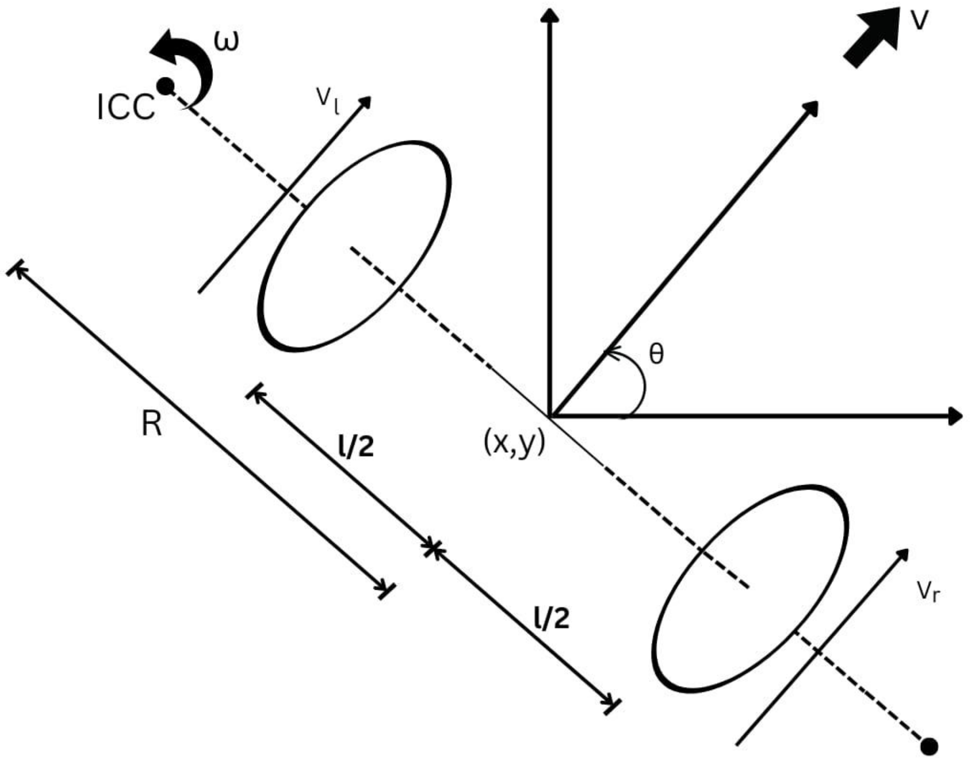
The differential drive is a two-wheeled drive system with independent actuators for each wheel [4]

Kinematics model governs how wheel speeds map to robot velocities [5]



Credits: [4] MIT CSAIL (mit.edu), [5] Modern Robotics – Book by Kevin Lynch

Differential Drive Kinematics



$$V_r = \omega * \left(R + \frac{l}{2}\right)$$

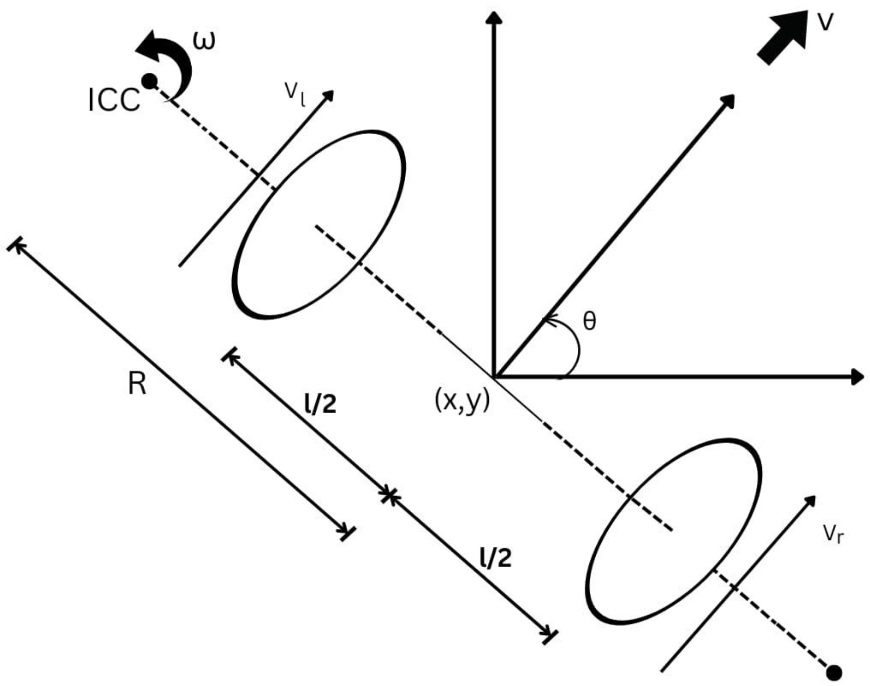
$$V_l = \omega * \left(R - \frac{l}{2}\right)$$

$$\omega = \frac{V_r - V_l}{l}$$

$$R = \frac{(V_r + V_l)}{(V_r - V_l)} * \frac{l}{2}$$

Credits: [Computational Principles of Mobile - Book by Dudek and Jenkin]

Let’s visualize



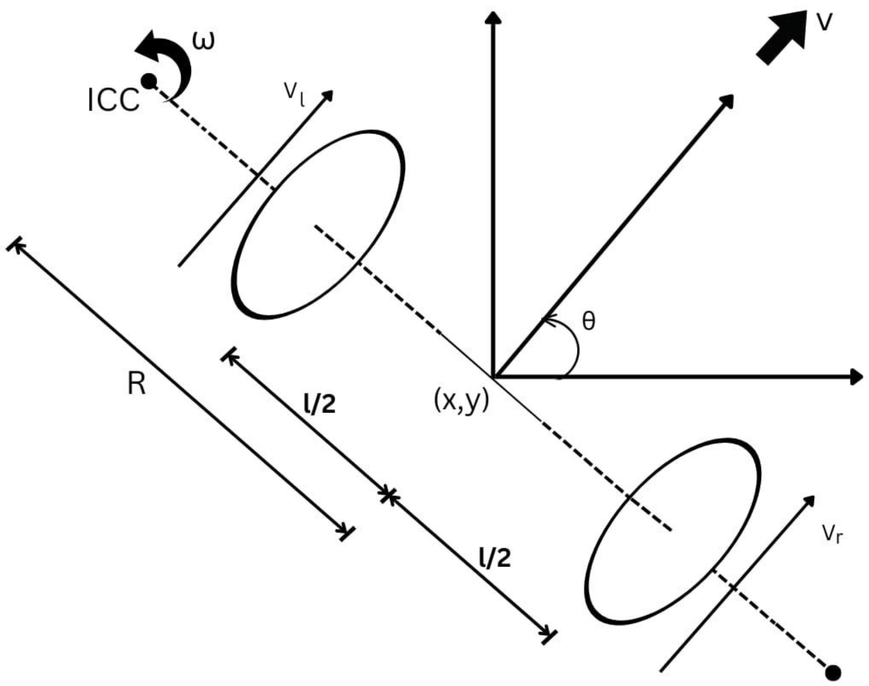
How to move it forward?

When $V_r = V_l$,

$$\omega = 0$$
$$R \rightarrow \infty$$

Credits: [Computational Principles of Mobile - Book by Dudek and Jenkin]

Let’s visualize



Ok, how to rotate about its center?

When $V_l = -V_r$,

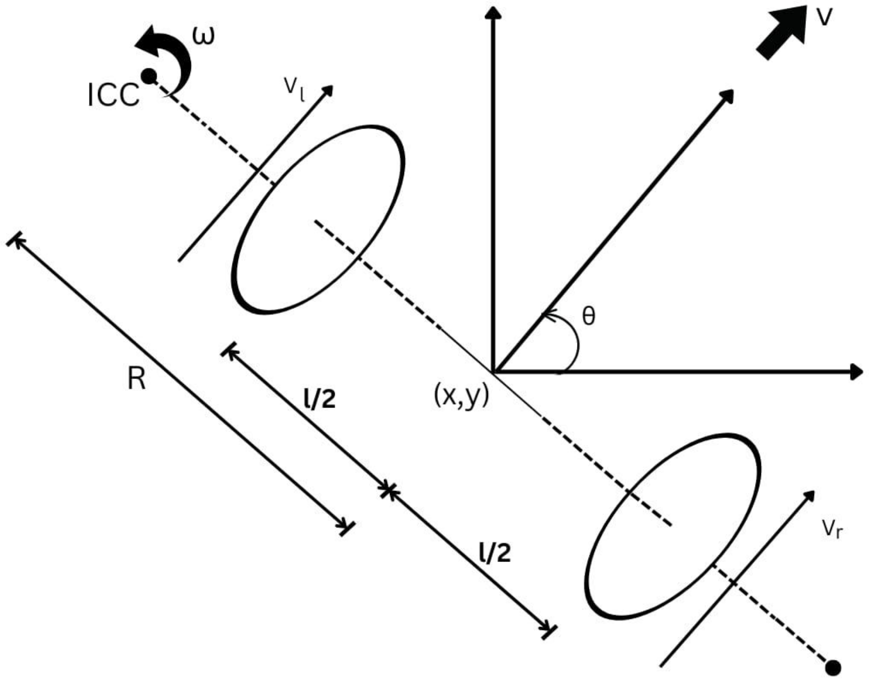
$$R = 0$$

$$\omega = \frac{2V_r}{l}$$

Credits: Computational Principles of Mobile - Book by Dudek and Jenkin

Alright, what does happen when one of the wheels stopped rotating? (prove me mathematically)

Let’s visualize



Alright, what does happen when one of the wheels stopped rotating?

When $V_l = 0$,

$$\omega = \frac{V_r}{l}$$

$$R = \frac{l}{2}$$

Credits: Computational Principles of Mobile - Book by Dudek and Jenkin

Recap

- Definition of a robot
- ‘Sense – Think - Act’ feedback loop
- Milestones in robotics
- A high level classification of robots
- Introduction to WMRs and it’s types
- Representing a point in 2D space
- Mathematical modeling of motion
- Differential drive kinematic robot and it’s working

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- Wheeled Mobile Robots

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- Differential Drive Kinematics

Mechanical Aspects

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- **Cognition – Processors**
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Programming Aspects

- Advanced Concepts & Current Research

Advanced Methods

Let’s bring life to robots

Robot Perception

"Making sense of real-world"

Physical properties of an environment → **Sensor** → Data

Human

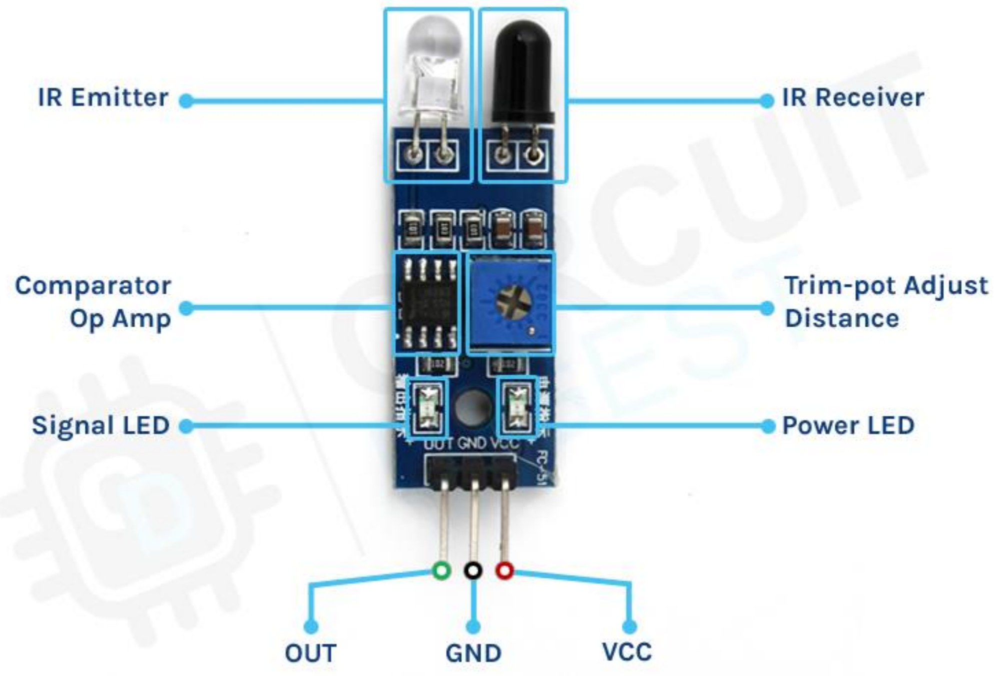
- See – Vision
- Listen – Auditory
- Touch – Tactile
- Heat – Thermoception
- Balance – Equilibrioception
- Body-Awareness – Proprioception

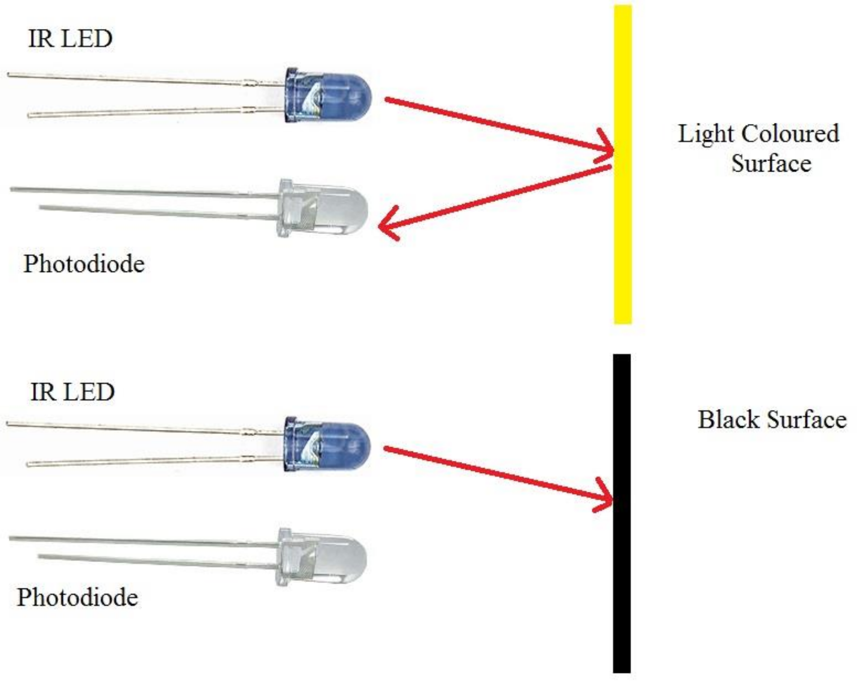
And Much more!

- Bird – Magnetoception
- Bat – Echolocation

Robot Perception

Infra-Red (IR) sensor



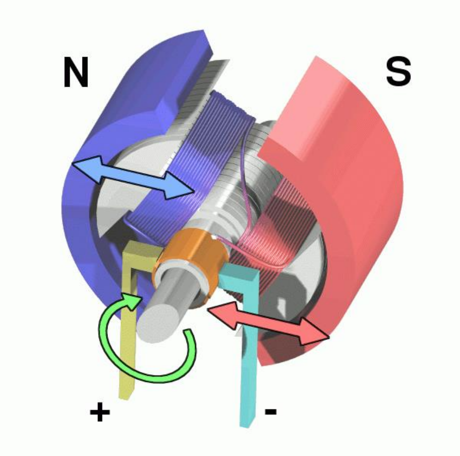


Credits: Circuit Digest, Electronics Hub

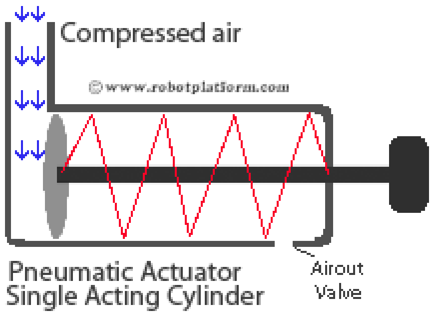
Robot Actuation

Physical properties of an environment ← **Actuator** ← Data

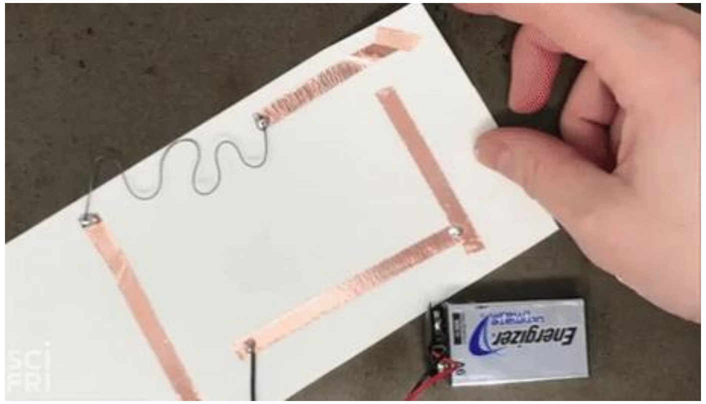
Electrical actuator



Pneumatic actuator



Shape Memory Alloy



Credits: Wiki Media, Robot Platform ,Science Friday

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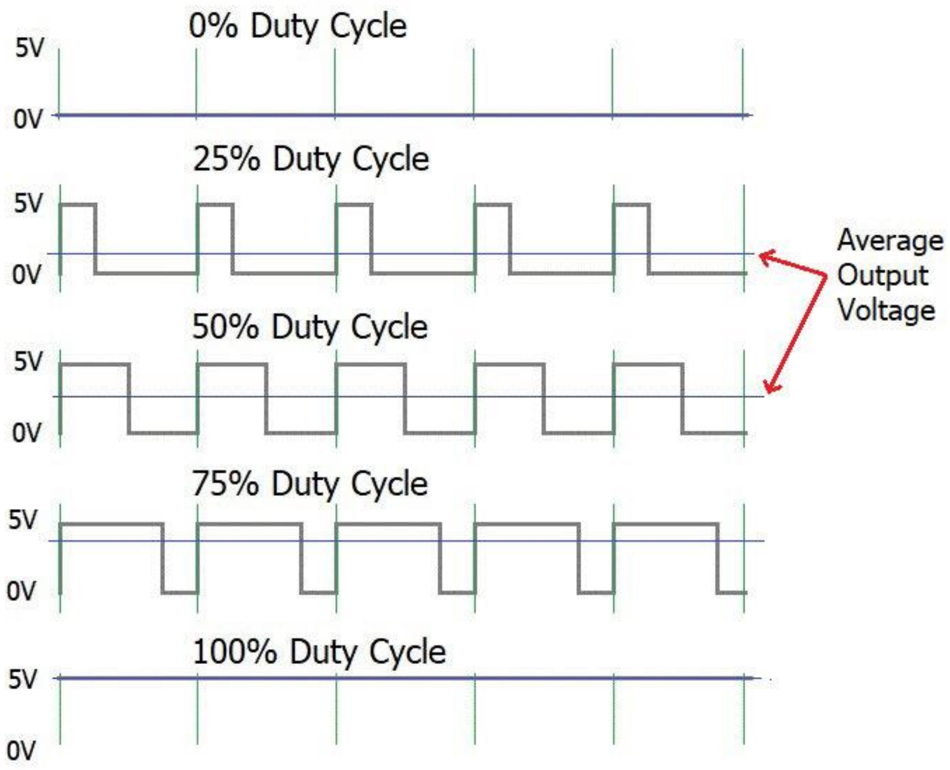
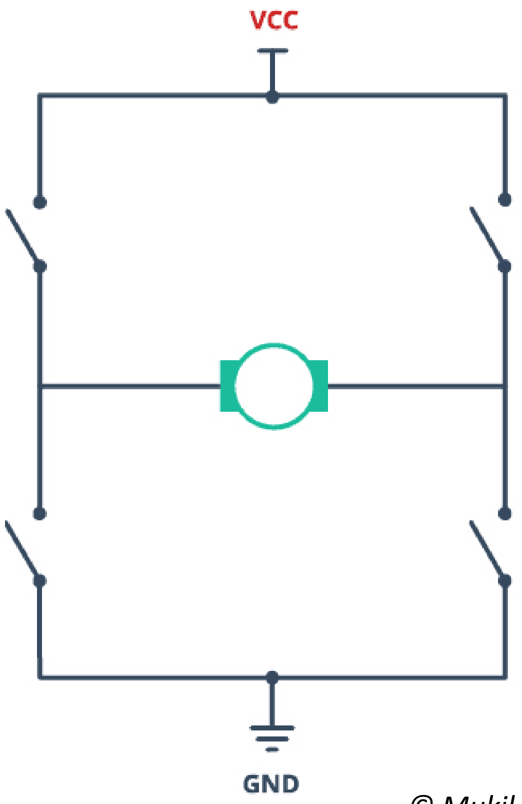
Robot Actuation

DC Motor

Speed - Pulse Width Modulation (PWM)



Direction - H bridge



Credits: Circuit Digest, lastminuteengineers.com

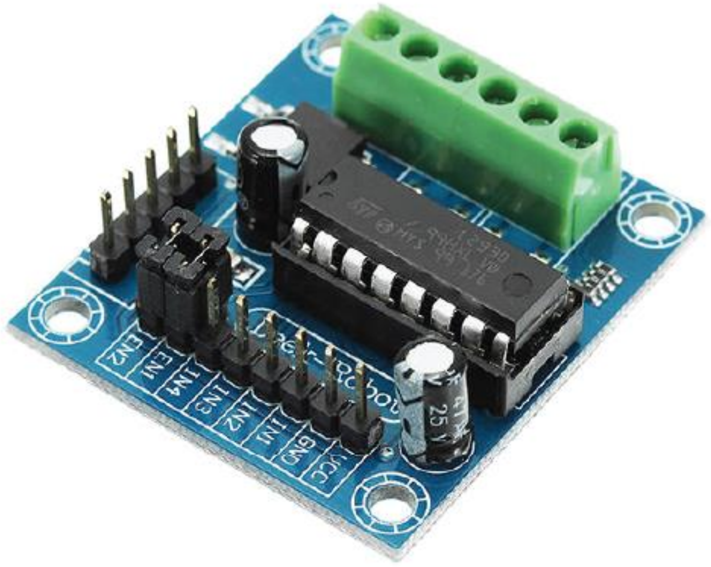
Robot Actuation

L293D Motor Driver

- **H Bridge:** L293D
- **No of channels:** 2 DC Motors
- **Output Current Capacity (per channel):** 600 mA
- **Supply Voltage Range:** 4.5 V to 36 V

PINS	Functionality
ENx	Speed Control
INy	Direction Control

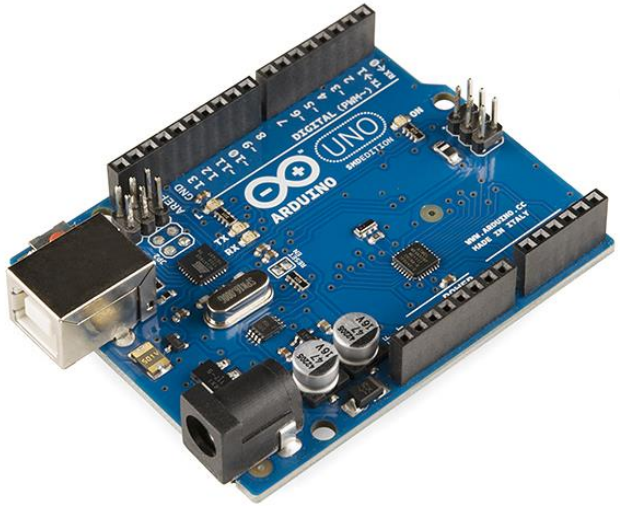
where $x \in \{1,2\}, y \in \{1,2,3,4\}$



Credits: Motor Driver L293D

Robot Cognition

Sensor → Cognition → Actuator

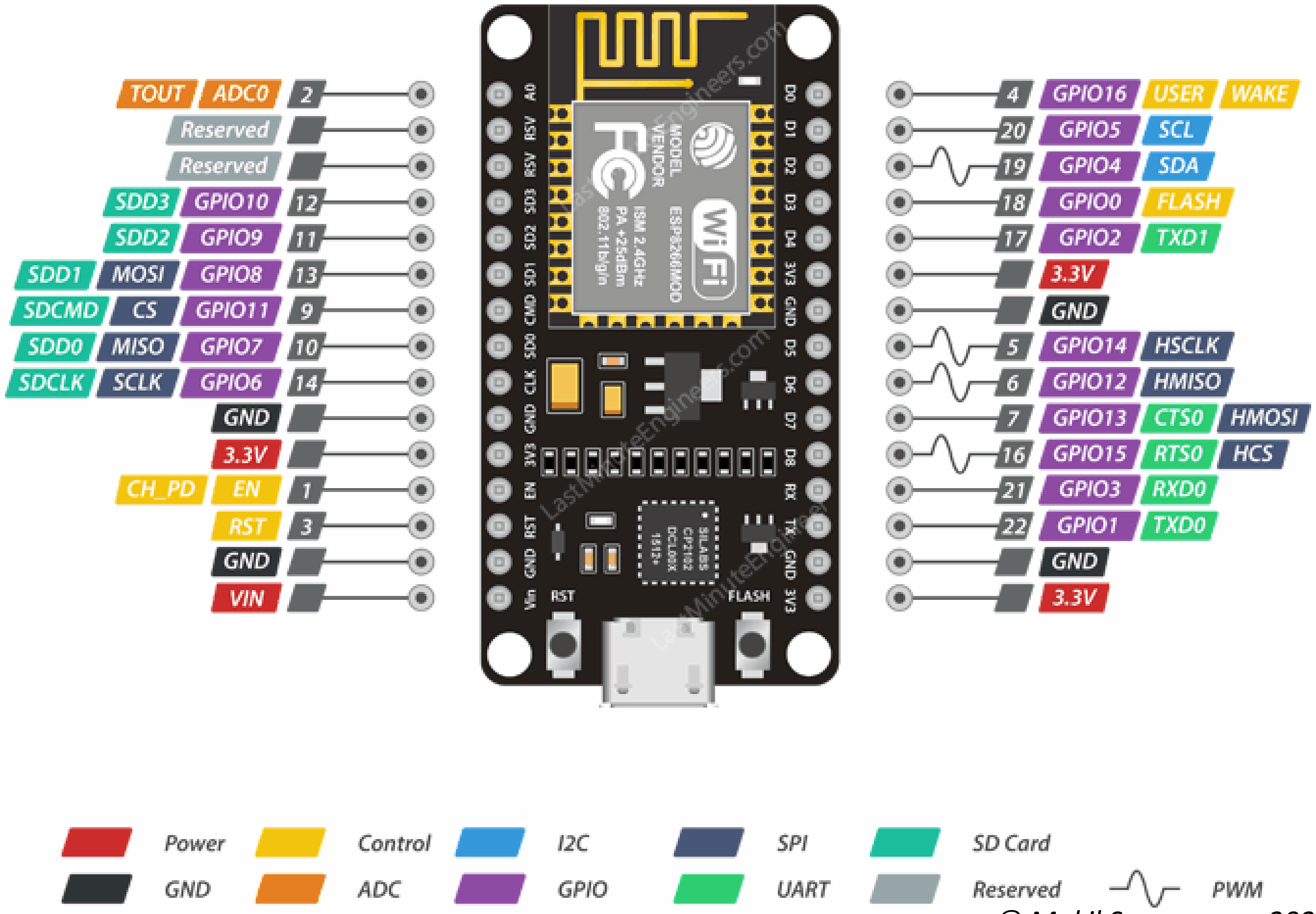


Credits: Arduino UNO, Raspberry Pi 4, Jetson Nano

Robot Cognition

ESP8266 NodeMCU

- **Microcontroller:** ESP8266 32-bit
- **Clock Speed:** 80 MHz
- **Operating Voltage:** 3.3 VDC
- **Input Voltage:** 4.5 V – 10 V
- **Digital IO Pins:** 11
- **Analog Input Pin:** 1
- **PWM Outputs:** 4
- **Serial Protocols:** I2C, SPI, UART



Credits: lastminuteengineers.com

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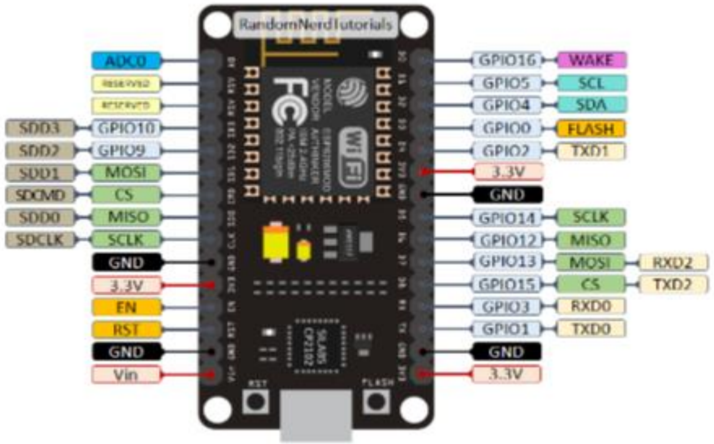
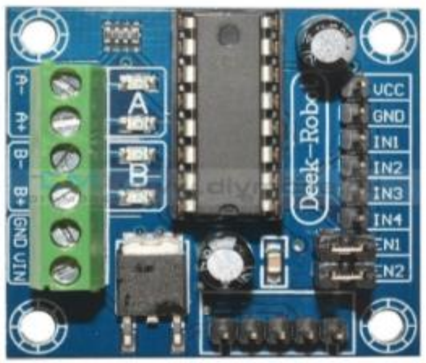




ESP8266 - Motor Driver

D0---->IN4
D1---->IN2
D2---->EN1
D5----->IN1
D6----->EN2
D7----->IN3

Motor A+ and A+ ------>
Motor 1

Motor B+ and b- -------->
Motor 2

ESP8266 - IR sensor

D3----->IR out 1
D4----->IR out 2

powering connection

3v3 to -Vcc
GND to GND

Connect your batteries
and point it to Motor
Driver Vin and GND
(power your board with
that port only

Recap

- How robot perceives the environment?
- Adding “super human” capabilities
- Making physical changes to the environment
- Controlling a DC motor
- Intelligence to robot
- ESP8266 NodeMCU pinouts

Agenda

- Introduction to Robotics - Board Classification - Wheeled Mobile Robots	Introduction
- Co-ordinate Frames & Transformations - Differential Drive Kinematics	Mechanical Aspects
- Perception – Sensors - Cognition – Processors - Actuation – Actuators	Electronics Aspects
- **ESP8266 Programming Basics** - **Code Walk-through** - **PID Control**	**Programming Aspects**
- **Advanced Concepts & Current Research**	**Advanced Methods**

ESP8266 Programming Basics

Basic skeleton

```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

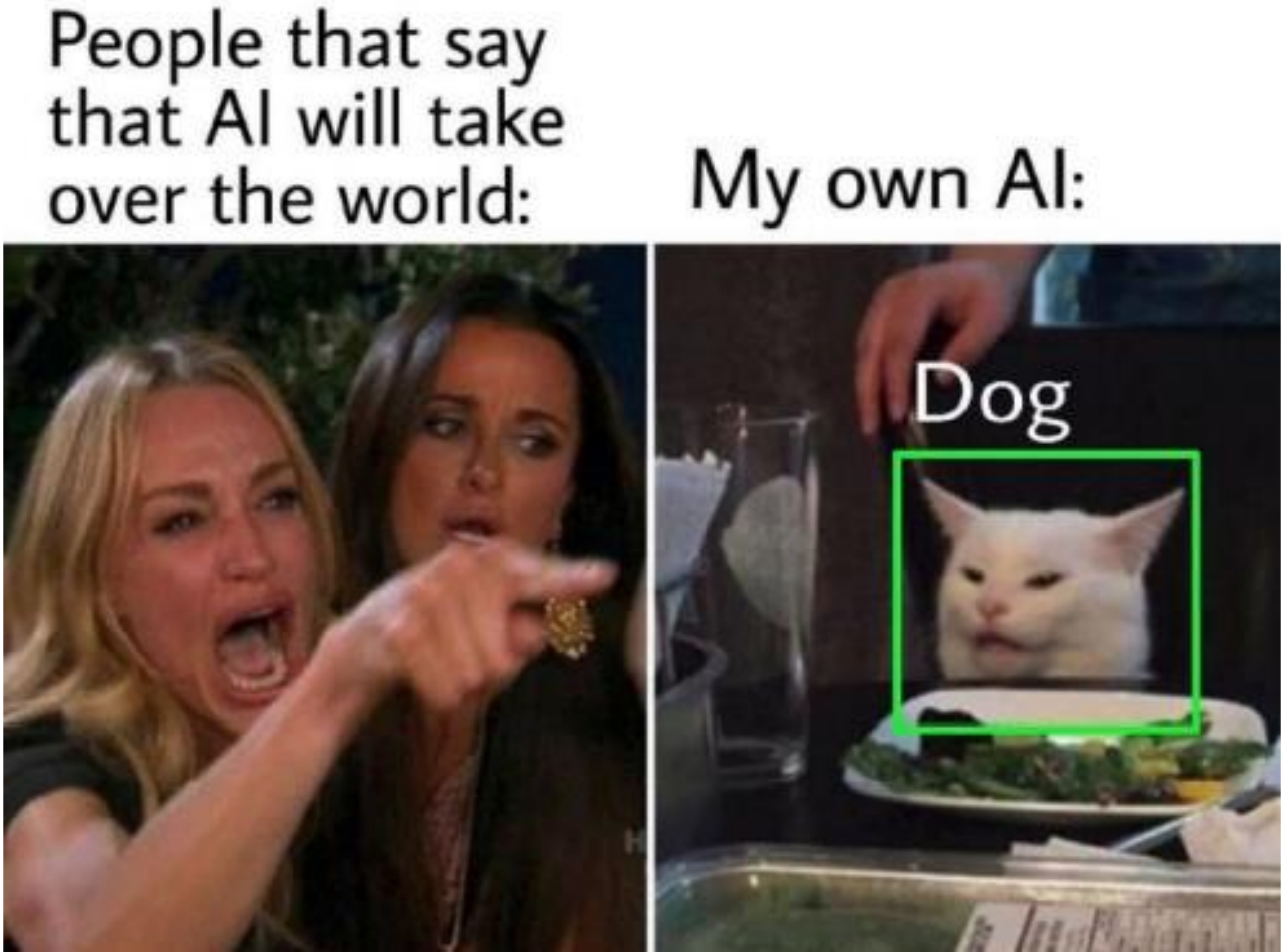
Credits: Arduino Reference

ESP8266 Programming Basics

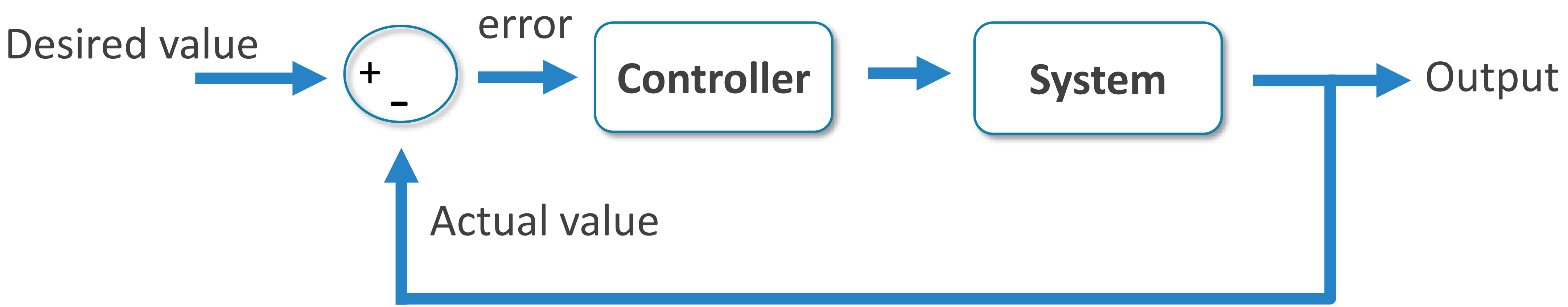
Basic GPIO Operations

Syntax	Description
pinMode(pin,mode)	Configures the specified pin to behave either as an input or an output
digitalWrite(pin,value)	Write a HIGH or a LOW value to a digital pin
digitalRead(pin)	Reads the value from a specified digital pin, either HIGH or LOW
analogRead(pin)	Reads the value from the specified analog pin
analogWrite(pin, value)	Writes a PWM value to a pin
delay(ms)	Pauses the program for the amount of time (in milliseconds)

Credits: Arduino Reference


People that say that AI will take over the world:
My own AI:
Dog

PID Control



Error = Desired value – Actual value

PID = Proportional + Integral + Differential
(present) (past) (future)

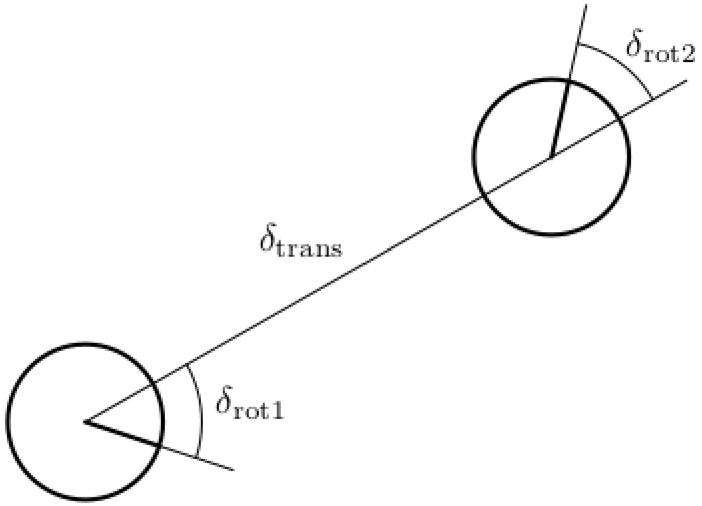
PID Control

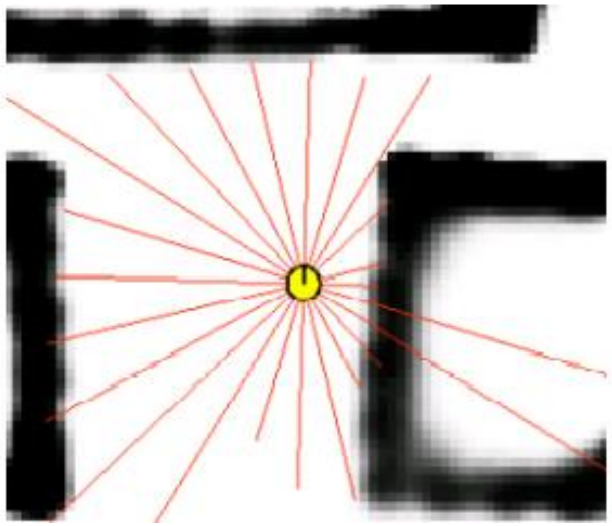
PID Tuning

Parameters	Rise Time	Overshoot	Steady-State Error
Kp	Decrease	Increase	Decrease
Ki	Decrease	Increase	Decrease Significantly
Kd	Minor Decrease	Minor Decrease	No Effect

Credits: thorlabs.com

Advanced Concepts





Odometry Motion Model

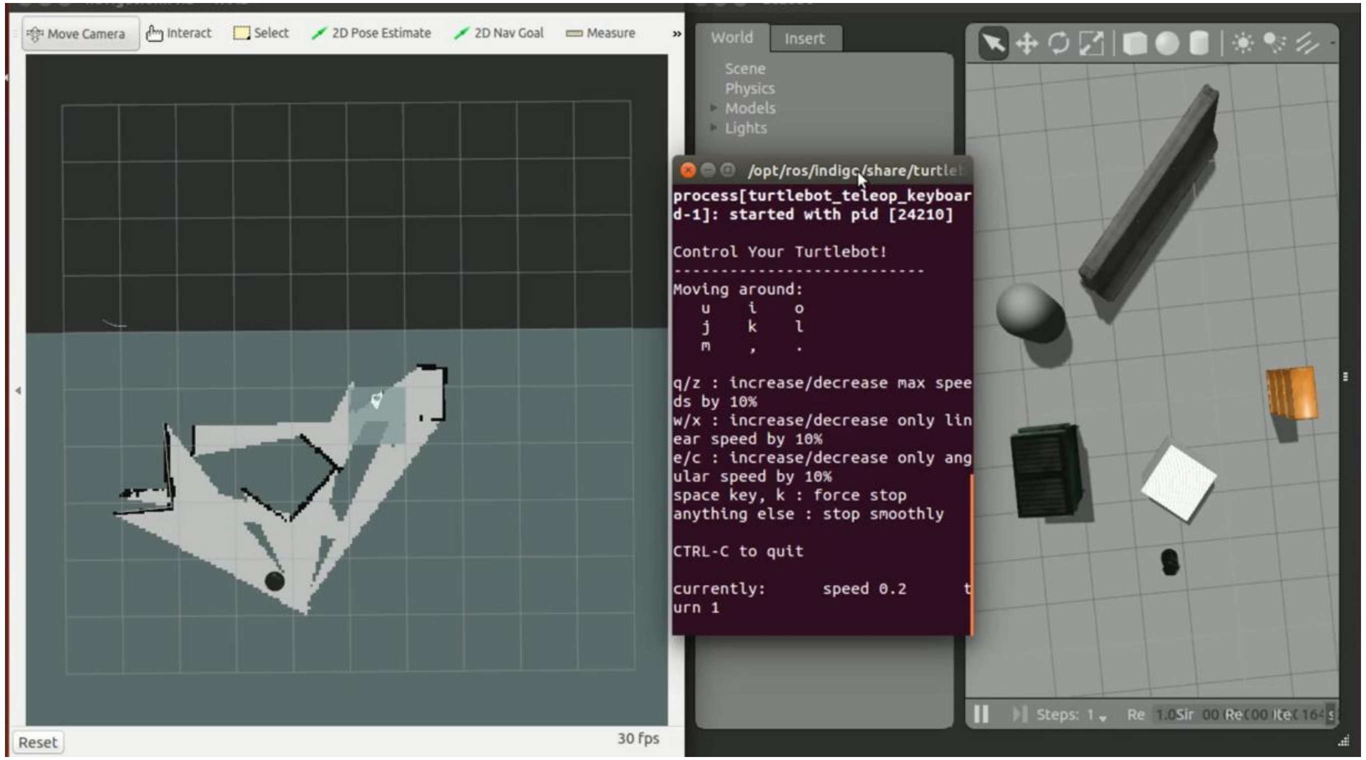
$$p(x_t|x_{t-1}, u_t)$$

LiDAR Observation Model

$$p(z_k|x, m)$$

Credits: [Probabilistic Robotics - Book by Dieter Fox, Sebastian Thrun, and Wolfram Burgard]()

Advanced Concepts

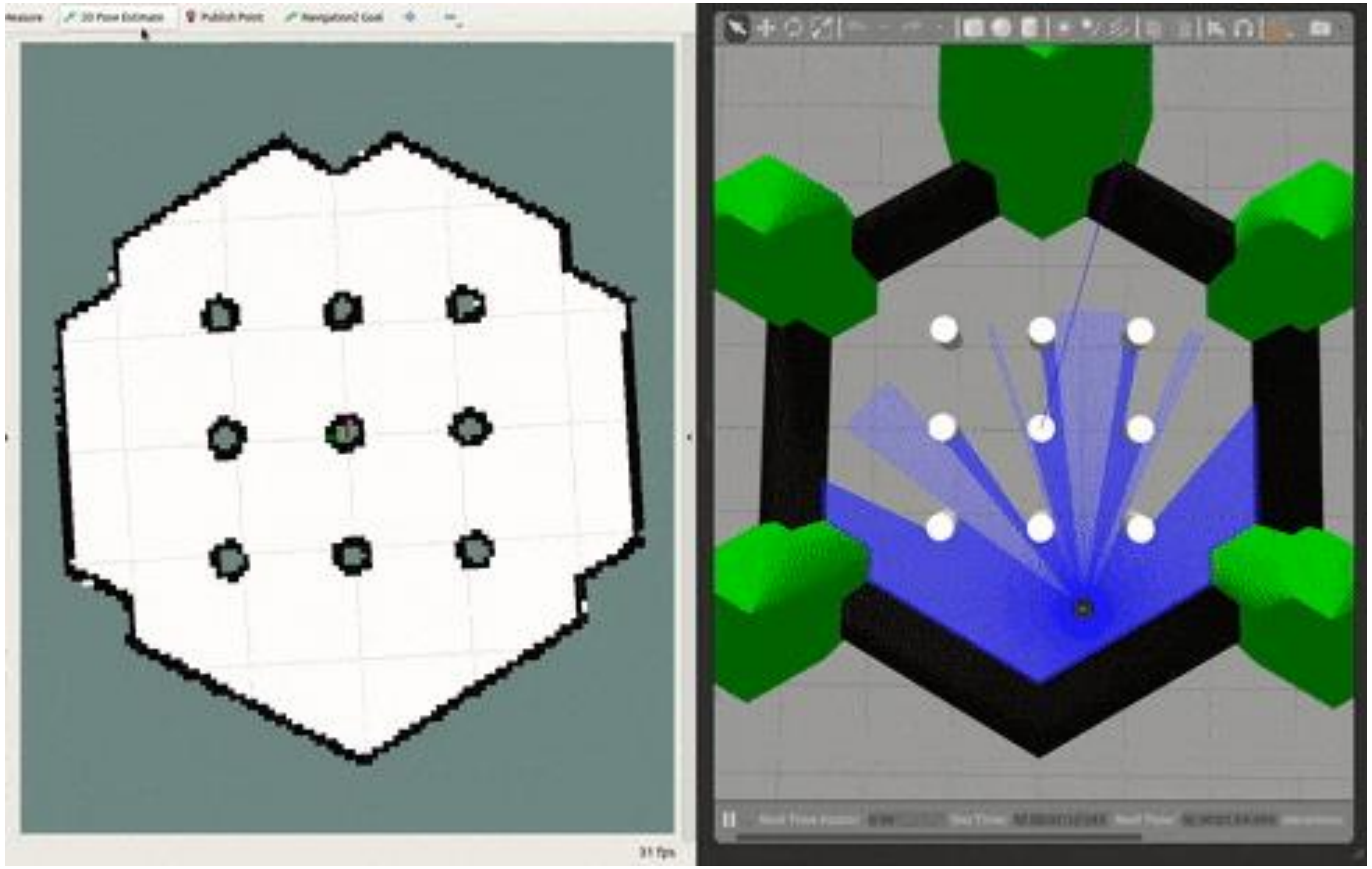


Simultaneous Localization and Mapping (SLAM)

$$p(x_{t+1}, m \mid z_{1:t+1}, u_{1:t+1})$$

Credits: Probabilistic Robotics - Book by Dieter Fox, Sebastian Thrun, and Wolfram Burgard

Advanced Concepts



Trajectory Planning

Credits: [Probabilistic Robotics - Book by Dieter Fox, Sebastian Thrun, and Wolfram Burgard](), [Nav2]()

Current Research

Credits: Deep Reinforcement learning for real autonomous mobile robot navigation

Current Research

Experimental Setup

Fig. 5

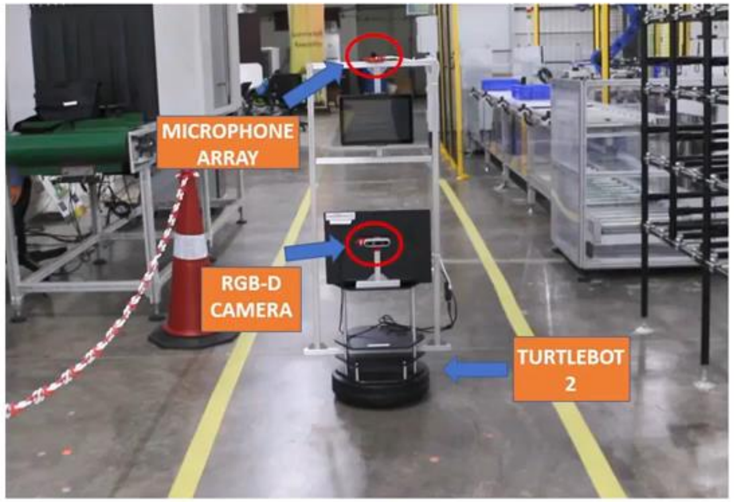


Fig. 6

The testbed was subjected
to minor structural changes.

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Credits: [Deep Learning based Audio-Aware Robot Navigation in Industry 4.0]

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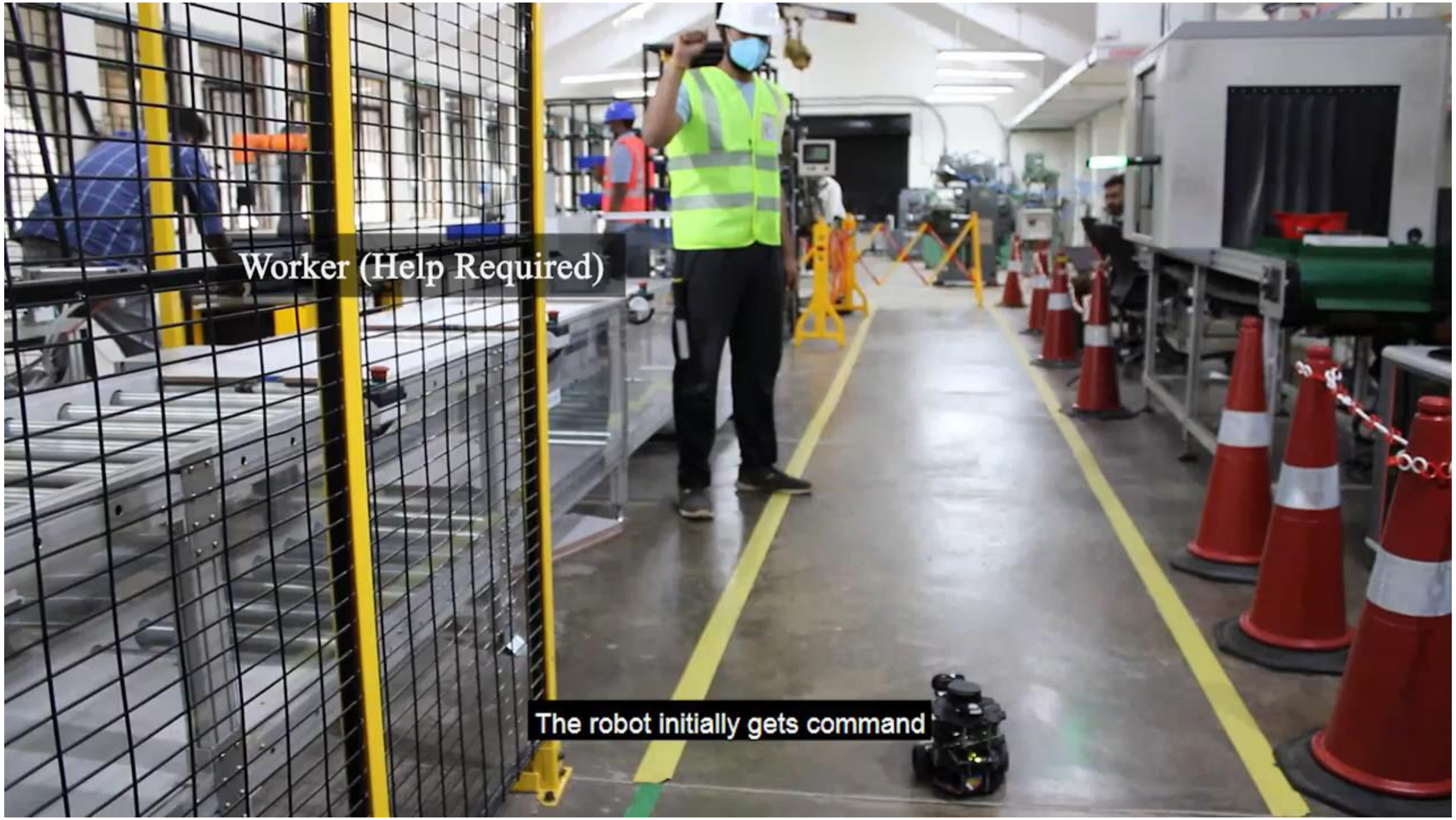
Current Research



Credits: Nature inspired Human-Robot Cooperative Package Delivery


This is beyond science

Recap

- ESP8266 Programming 101
- Code walkthrough
- Enhancing intelligence with PID Control
- Tuning PID constants
- Probabilistic models – motion model, observation model
- SLAM
- Current Research

GitHub Repository

https://github.com/MukilSaravanan/Wheeled_Mobile_Robotics_101_Workshop.git

Thank You

Let’s get connected!

Reach out to me

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LinkedIn: Mukil Saravanan