9 – Robot‘s Sensory Equipment

Robotics and Computer Vision (BPC-PRP)

Course supervisor: Ing. Adam Ligocki, Ph.D.

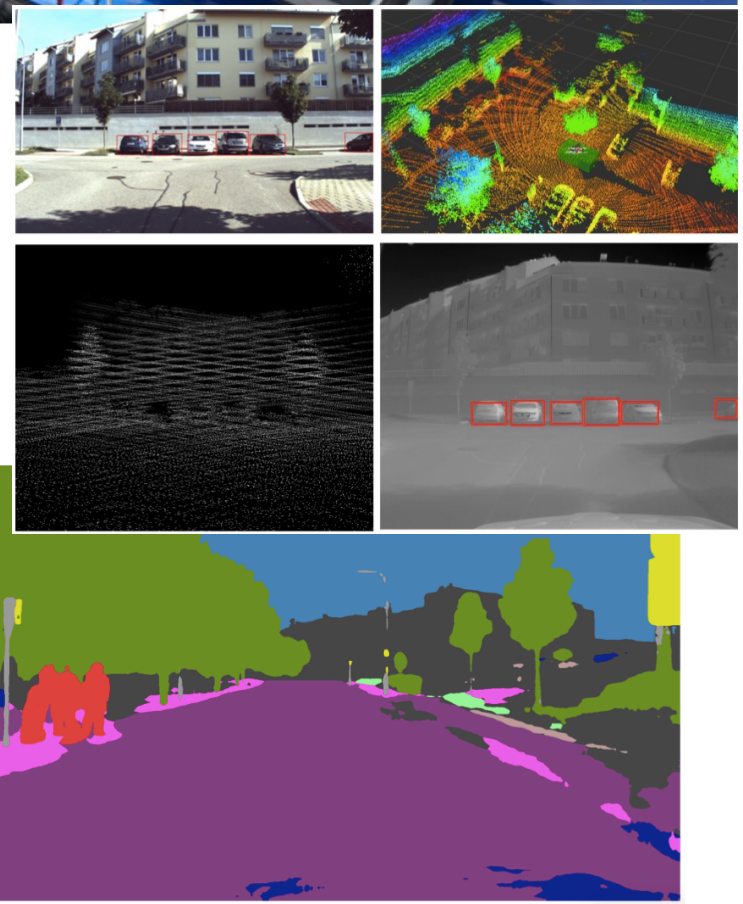
Ing. Adam Ligocki, Ph.D.

Brno University of Technology
2025

Robotics and AI

Profile

Robotics and AI



Ing. Adam Ligocki, Ph.D.

Position: Assistant Professor

Research: Data Fusion

Room: SE1.102

Web: https://www.vut.cz/lide/adam-ligocki-154791

Background:

- Artificial Intelligence
- Neural Networks
- Software Development

Robot Big Picture

„Fenrir“ Project

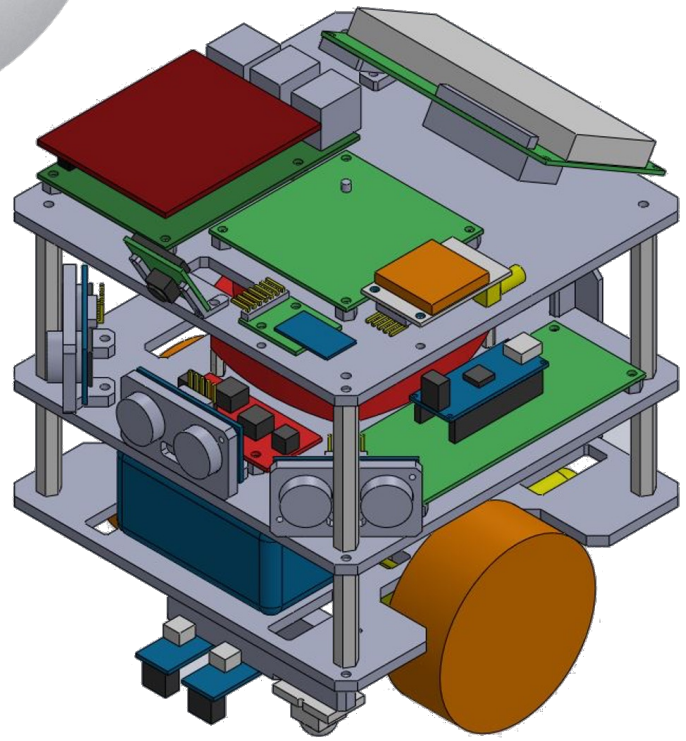
All hardware and software are fully documented

Open-source GitHub repository:
github.com/Robotics-BUT/fenrir-project

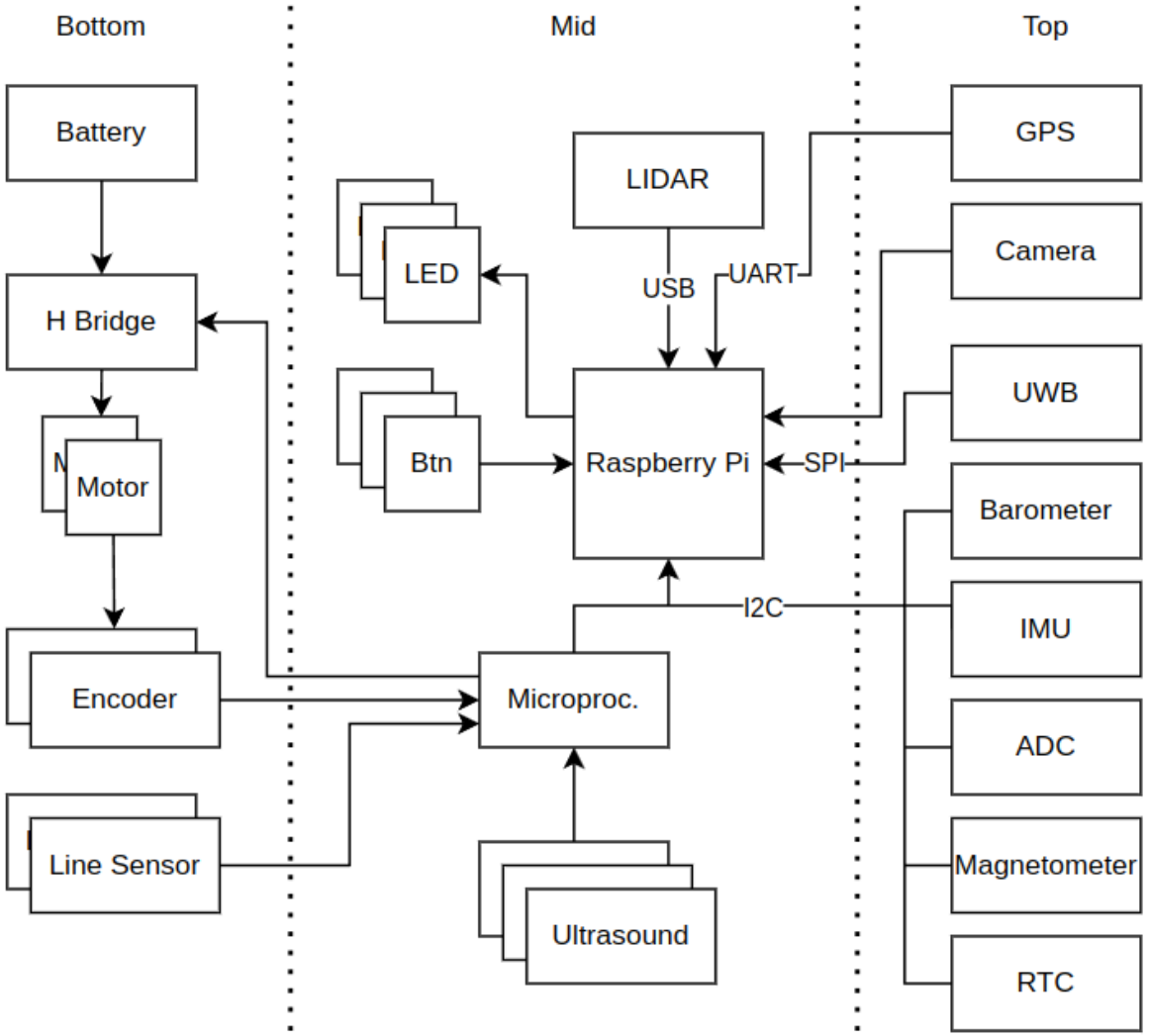
Includes:

- Full hardware design
- 3D printed parts
- Robot software and setup scripts
- Tutorials for building and running the robot

Everything you need to assemble and bring the robot to life!

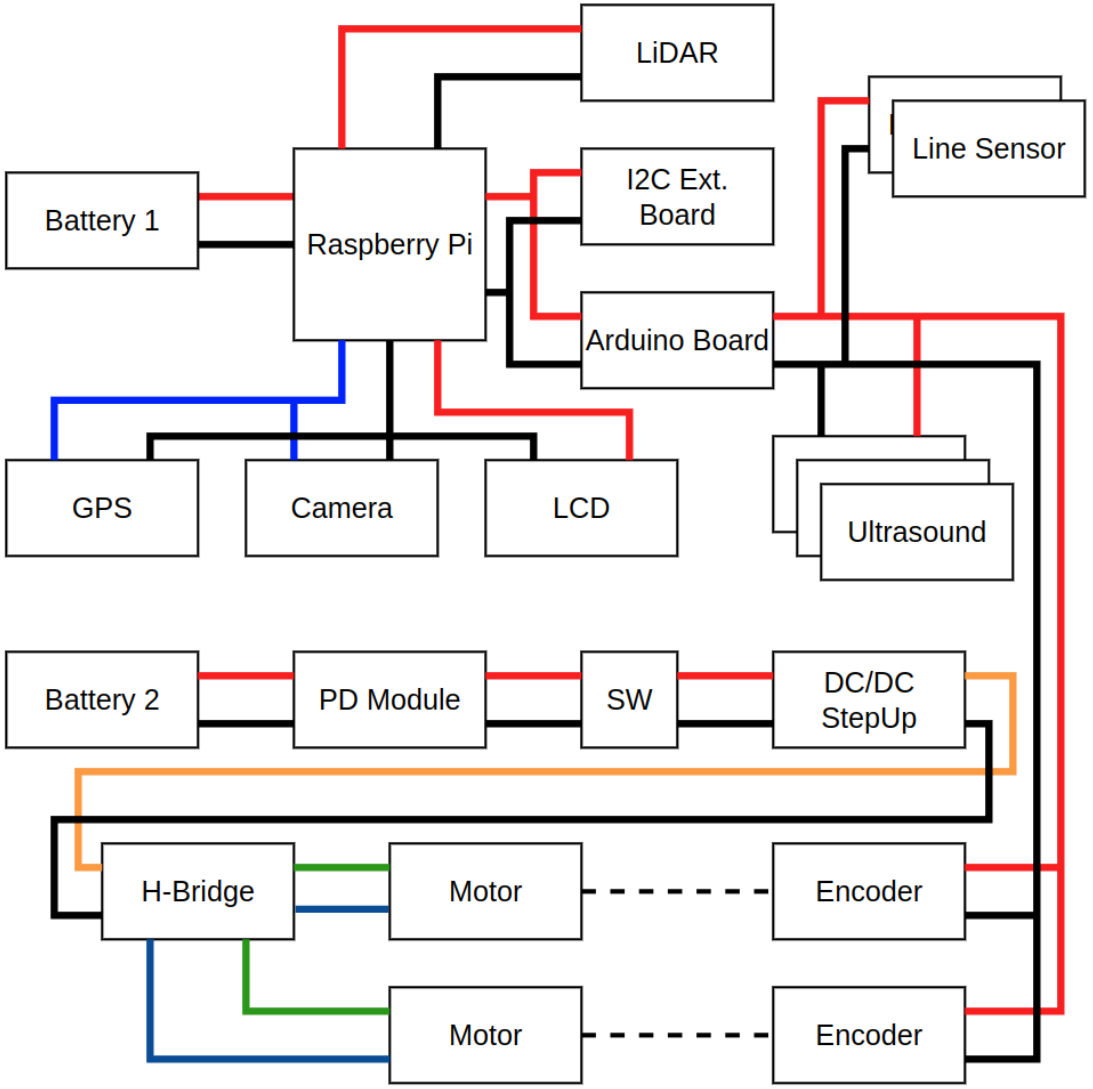


Robot – Component Scheme



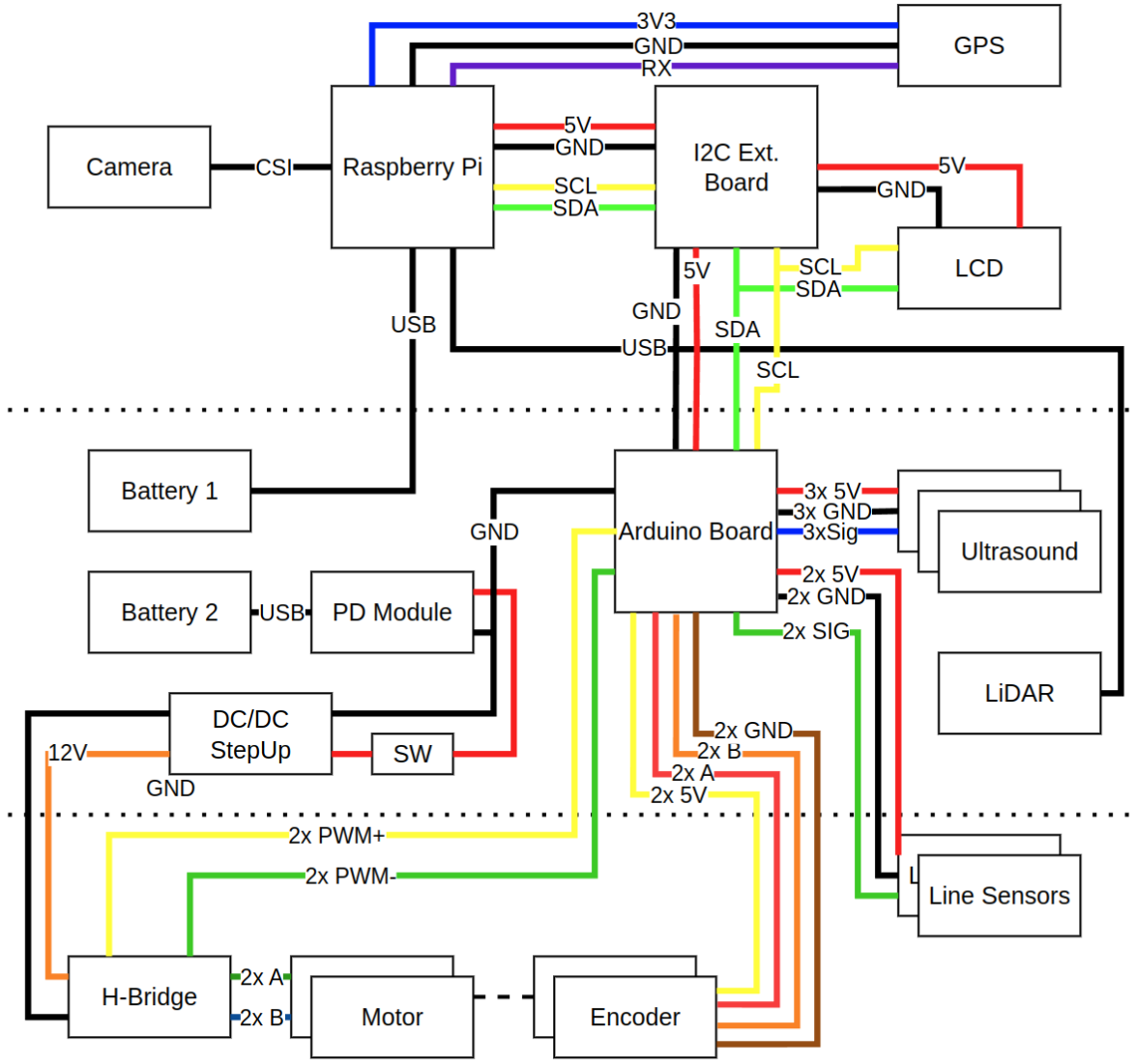
Details: https://github.com/Robotics-BUT/fenrir-project

Robot – Electrical Schema



Details: https://github.com/Robotics-BUT/fenrir-project

Robot – Wiring



Details: https://github.com/Robotics-BUT/fenrir-project

UART Bus

UART is a hardware communication protocol used for **asynchronous, full-duplex serial communication** between two devices. It is commonly found in embedded systems for interfacing with peripherals or debugging.

Each UART transmission is framed to enable synchronization:

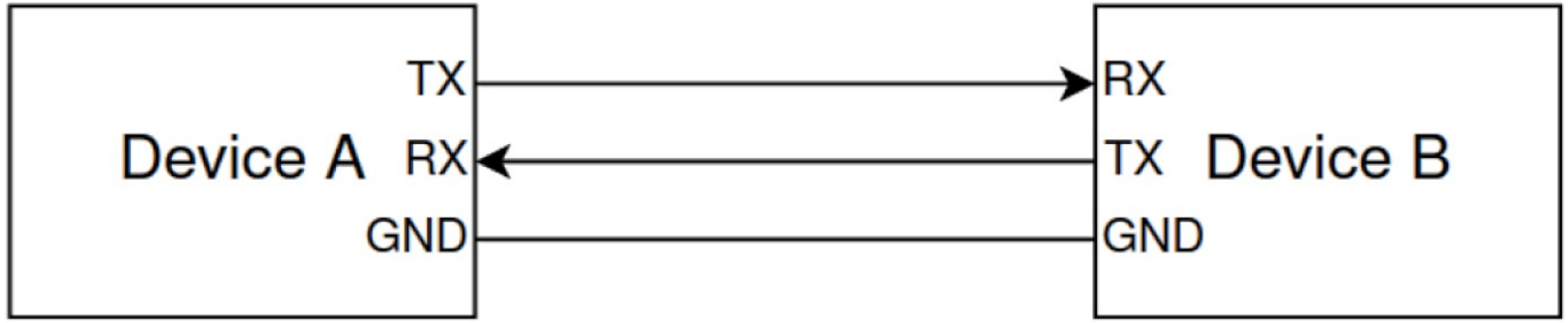
- **Start Bit (1 bit)** – pulls the line low to signal the start of transmission
- **Data Bits (5 to 9 bits)** – actual payload
- **Optional Parity Bit (1 bit)** – basic error detection (even/odd)
- **Stop Bit(s) (1 or 2 bits)** – idle high, indicates end of frame

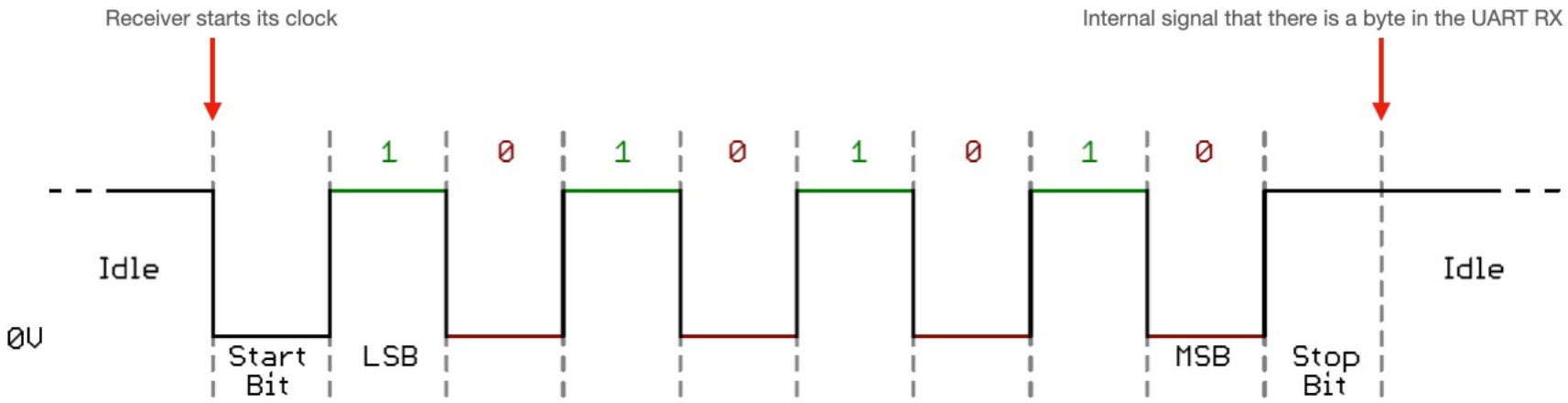
All bits are transmitted **LSB first**. Line is idle (logic high) between frames.

Use Cases

- Embedded debugging (serial console)
- Communication with modules (GPS, Bluetooth, Wi-Fi)
- Firmware flashing (bootloader interface)
- Inter-MCU communication (point-to-point)

UART Bus





https://vanhunteradams.com/Protocols/UART/UART.html

I2C Bus

I²C is a **synchronous, master-slave serial communication protocol**, commonly used to connect low-speed peripherals to microcontrollers in embedded systems.

It operates over **two bidirectional lines**:

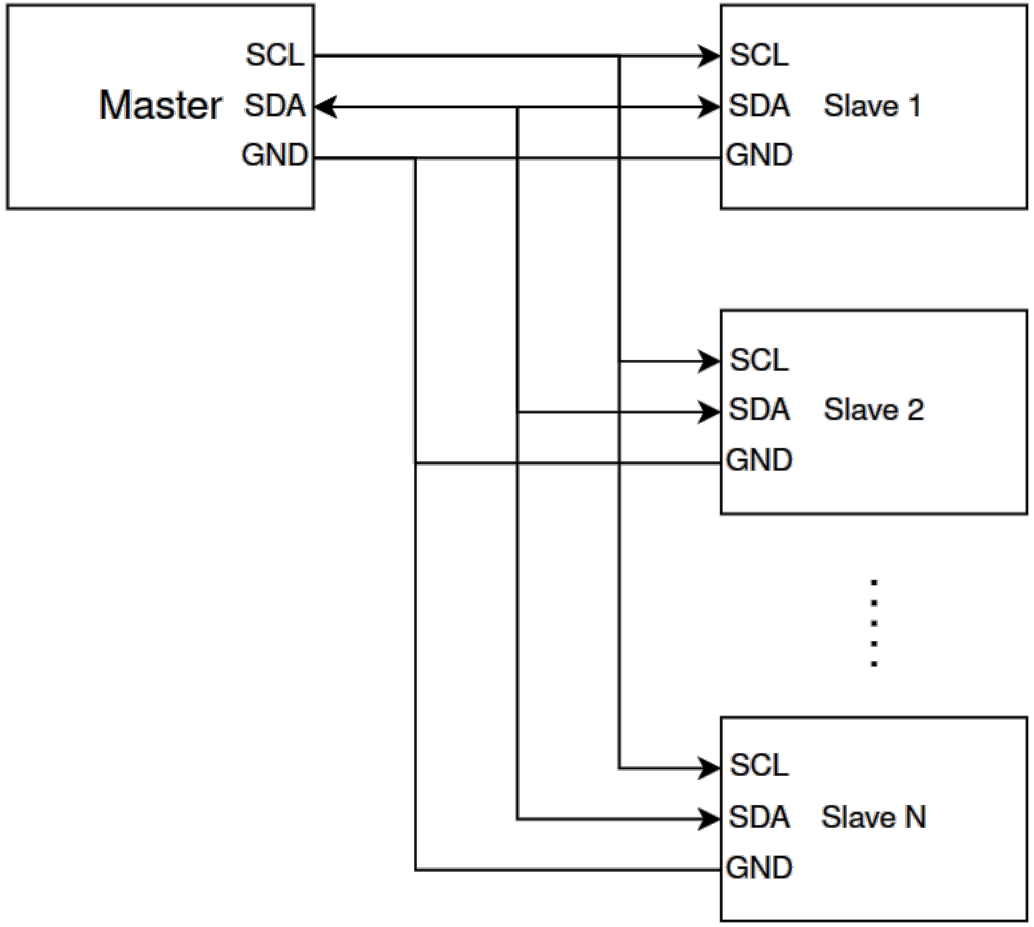
- SCL – Serial Clock Line (driven by master)
- SDA – Serial Data Line (shared by all devices)

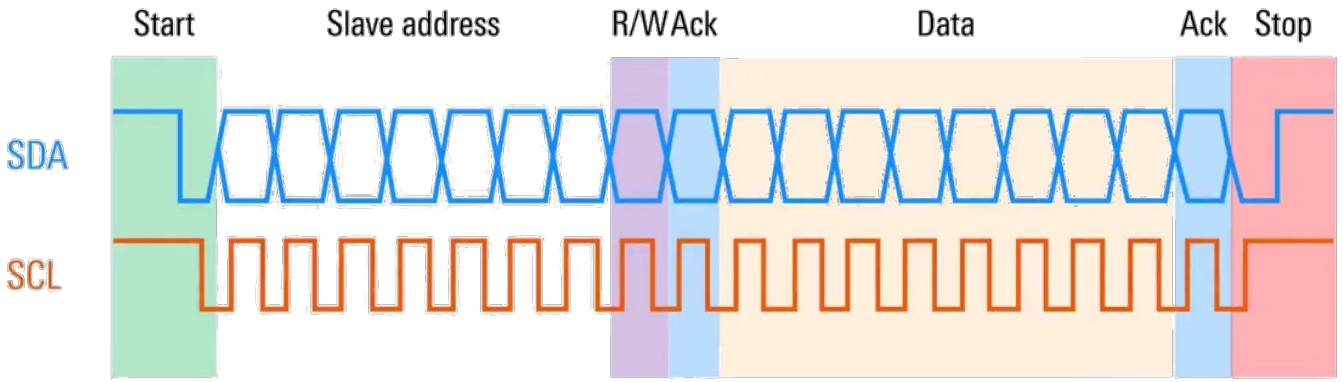
Both lines are **open-drain** and require **pull-up resistors**.
Speeds: 100kHz, 400kHz, 1MHz, 3.4MHz
Bus length and speed are limited by **capacitance** and **line resistance**

Use Cases

- Connecting EEPROMs, RTCs, sensors, displays, ADCs/DACs
- Short-range communication on PCB or between closely located boards
- Preferred when multiple peripherals share a common bus

I2C Bus





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

SPI Bus

SPI is a **synchronous, full-duplex serial communication protocol** used primarily for high-speed communication between a single master and one or more slave devices. It is widely used in embedded systems for sensors, memory, and display interfaces.

SPI operates using **4 primary lines**:

- **MOSI** – Master Out, Slave In
- **MISO** – Master In, Slave Out
- **SCLK** – Serial Clock (generated by master)
- **SS/CS** – Slave Select / Chip Select (one per slave device)

Communication Model

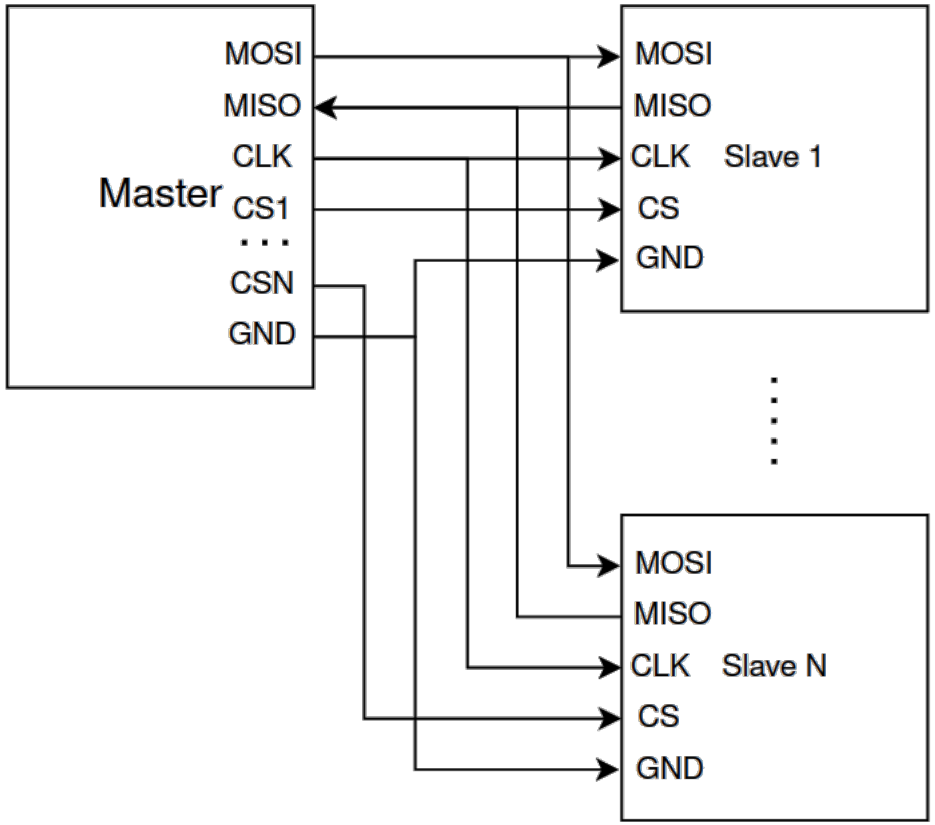
- Master generates the clock and selects the target slave
- Communication is **full-duplex** – both parties transmit and receive simultaneously

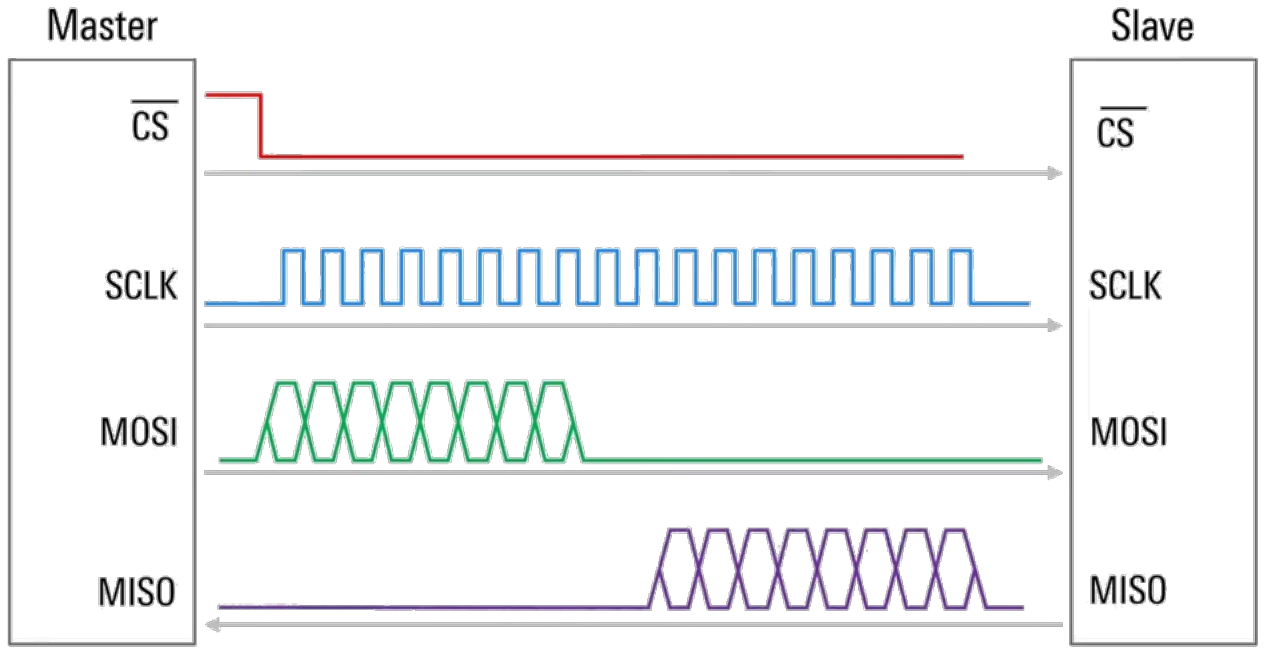
Each transfer is synchronized by **SCLK**, with data shifted on clock edges

Use Cases

- High-speed peripherals: flash memory, LCDs, ADCs/DACs, SD cards
- Short-distance communication on PCBs
- Often used in sensor modules, embedded storage, or streaming data

SPI Bus





https://www.youtube.com/watch?v=0nVNwozXsIc

Sensory Equipment

Analog Digital Converter (ADC)

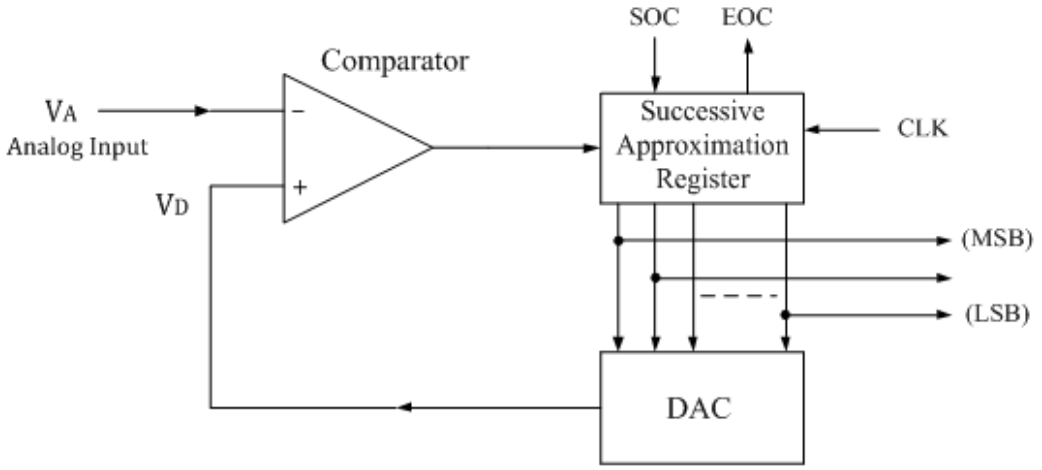
An **ADC** converts a **continuous analog voltage** signal into a **discrete digital value.**

Key Parameters

- **Resolution**: Number of bits in output (e.g., 8-bit, 12-bit, 16-bit)
  - Determines number of quantization levels: e.g., 8-bit = 256 levels, 12-bit = 4096 levels
- **Sampling Rate**: How often the analog signal is sampled (samples per second)
- **Input Voltage Range**: Minimum and maximum voltage that can be measured

Conversion Process

1. **Sampling**: ADC periodically captures the analog input voltage
2. **Quantization**: Maps the voltage to the nearest digital level
3. **Encoding**: Produces a binary representation of the level

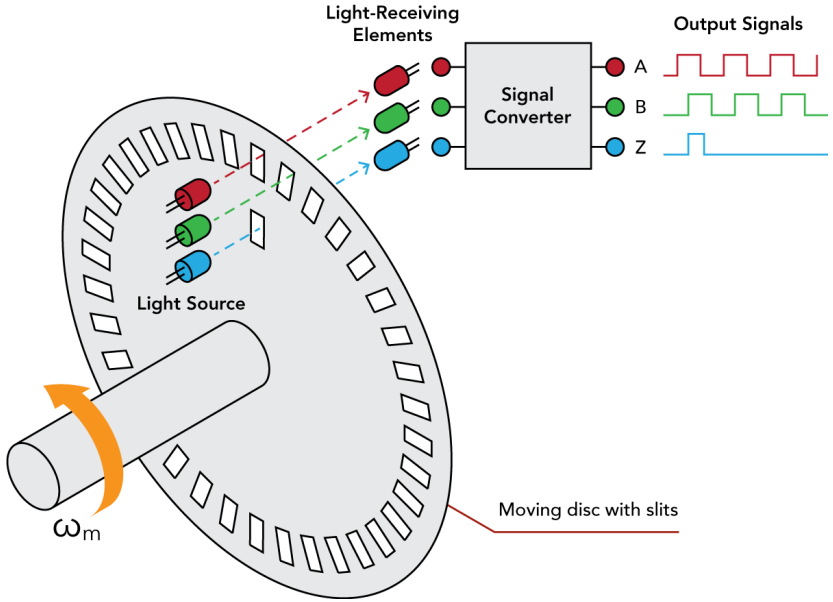


Types of ADCs

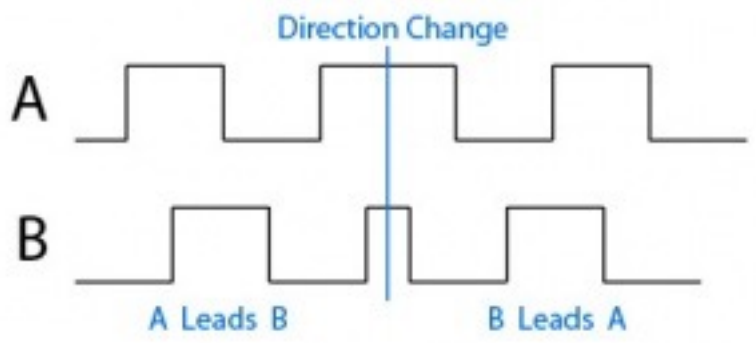
- **Successive Approximation (SAR)** – common in microcontrollers
- **Delta-Sigma** – high resolution, slower, used in audio and precision sensors
- **Flash ADC** – ultra-fast, low resolution, used in high-speed applications

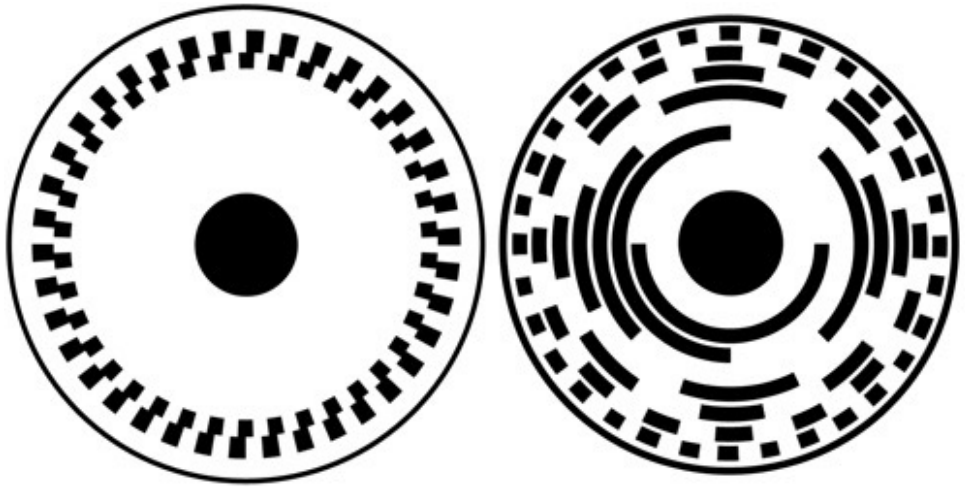
https://www.electronics-tutorial.net/analog-integrated-circuits/data-converters/successive-approximation-type-adc/

Encoder

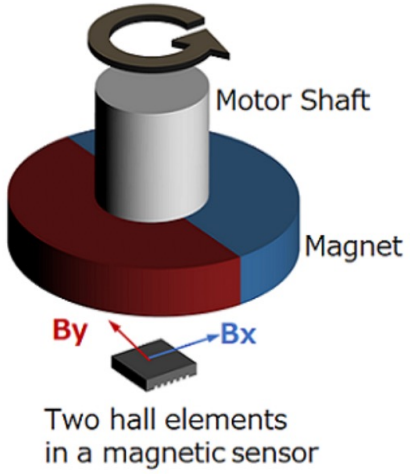


Quadrature Encoder

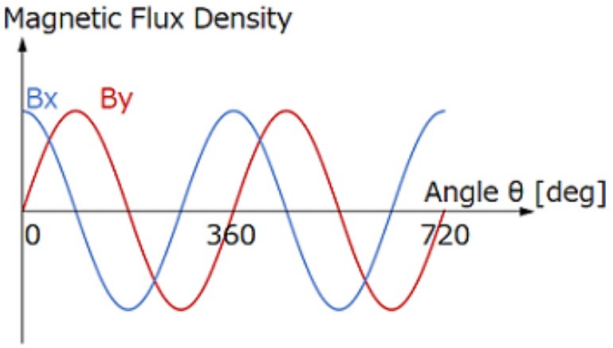




Relative vs Absolute



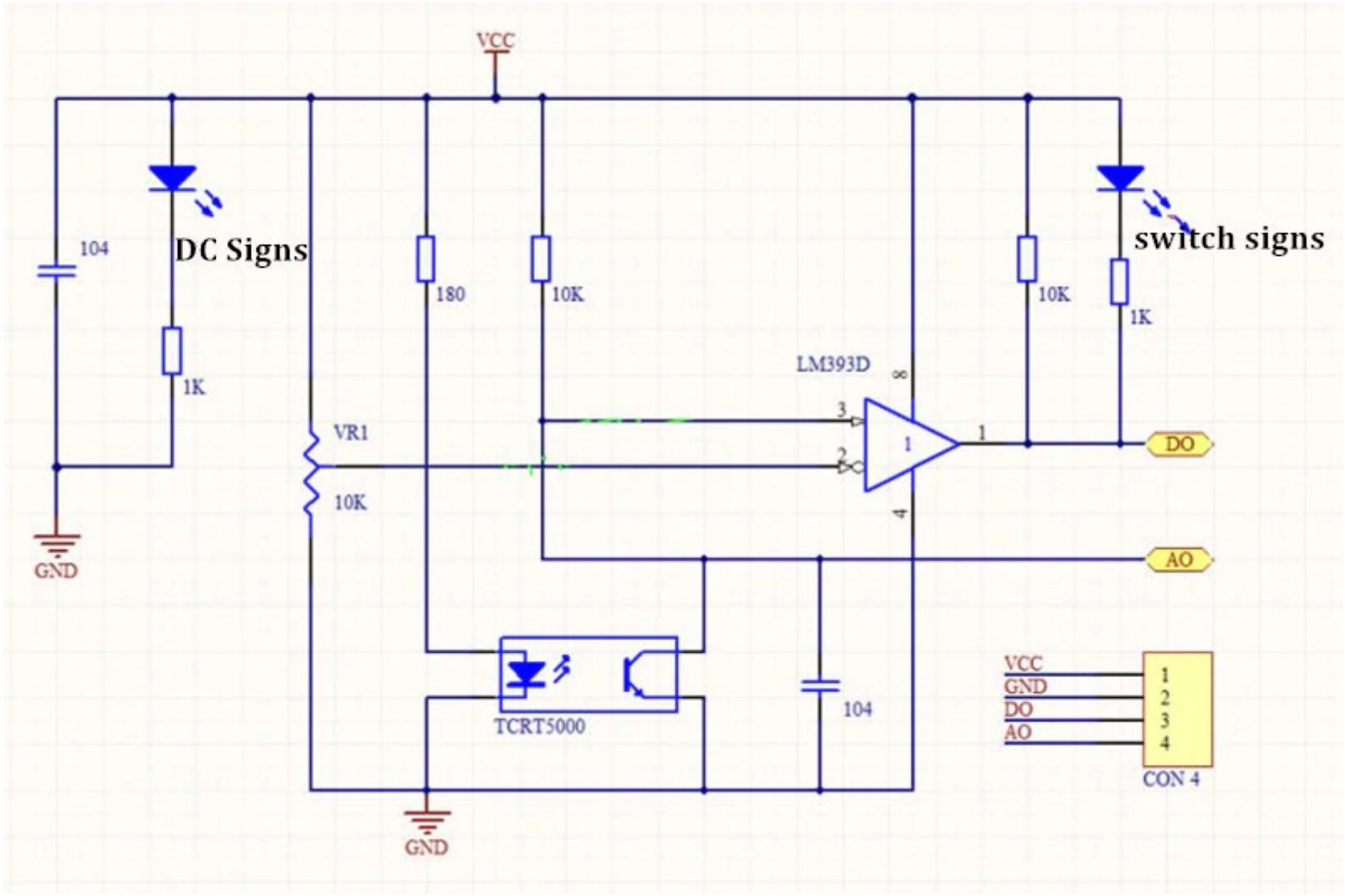
Two hall elements
in a magnetic sensor

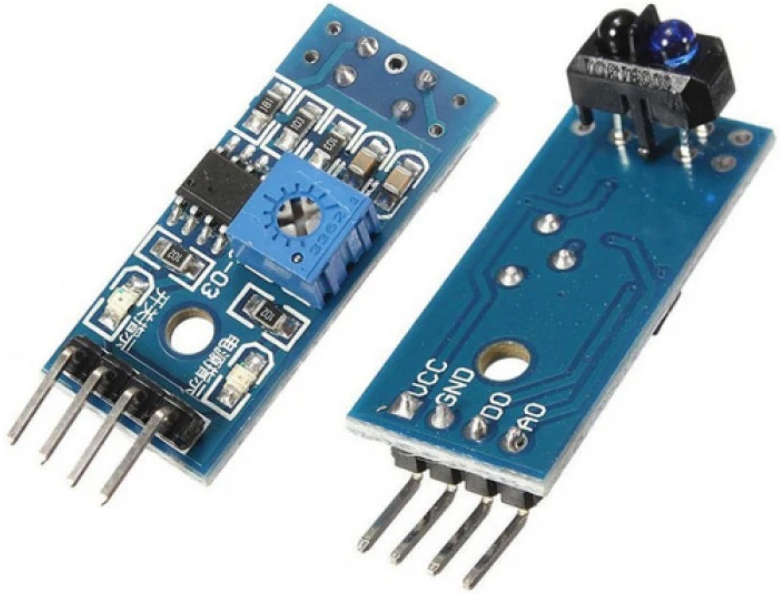


Magnetic Encoder

https://www.futek.com/Incremental-Encoder-Signal-Converter
https://www.phidgets.com/docs/Encoder_Guide
https://www.akm.com/global/en/products/rotation-angle-sensor/tutorial/magnetic-encoder/

Line Sensor

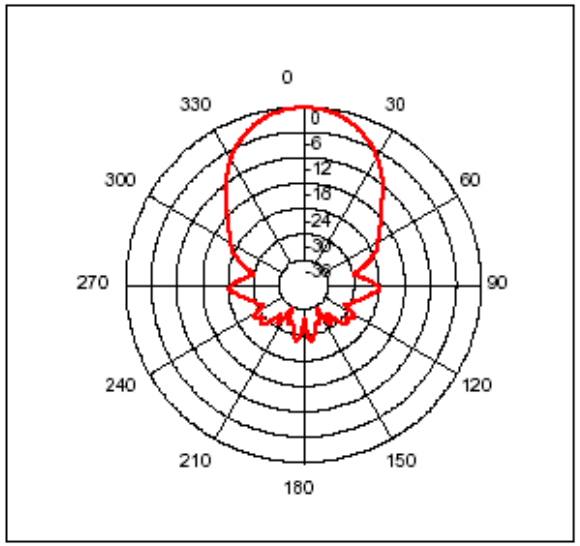


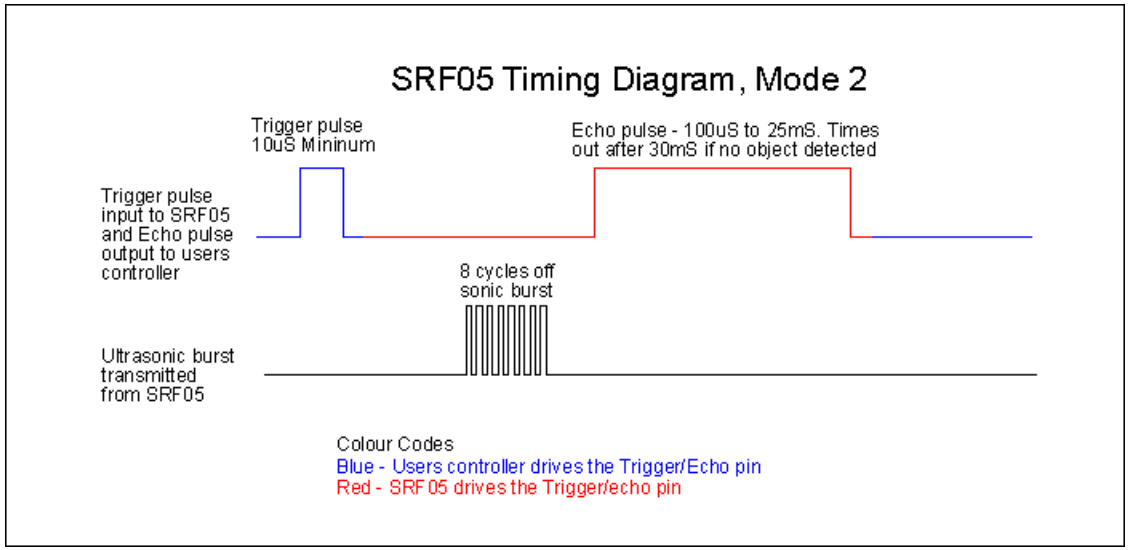


https://osoyoo.com/2017/08/15/tcrt5000-infrared-line-tracking-sensor/

Ultrasound Proximity Sensor

- Trigger: 10 uS digital pulse
- Frequency: 40 kHz
- Measurement Resolution: 0.3cm
- Measurement Angle: up to 15 deg
- Detection distance: 2cm-450cm



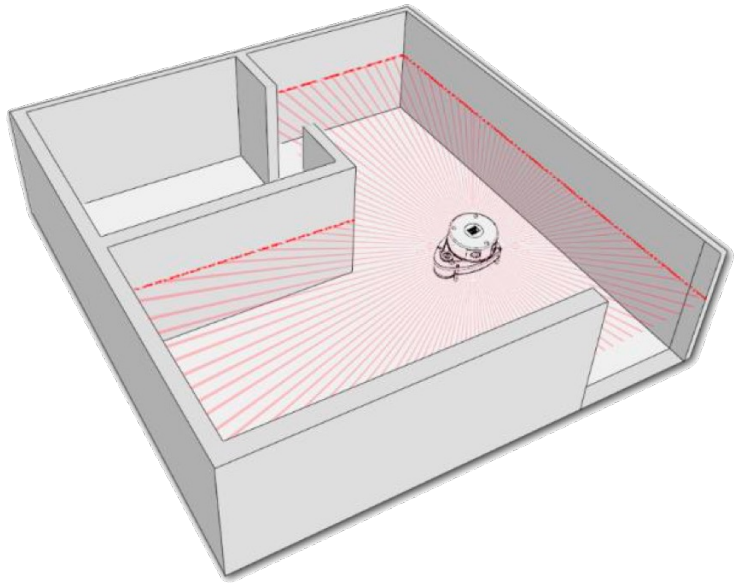


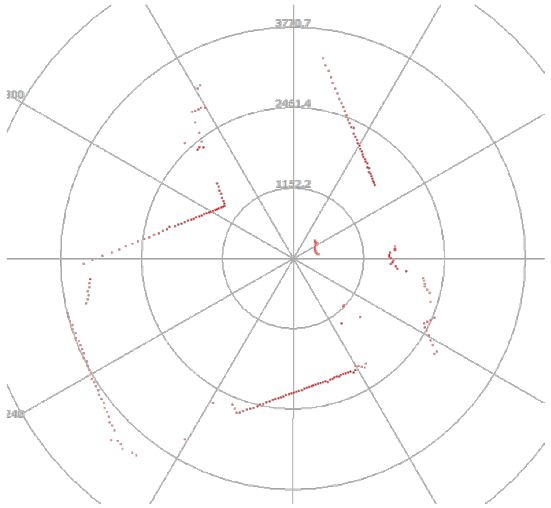
https://www.robot-electronics.co.uk/htm/srf05tech.htm

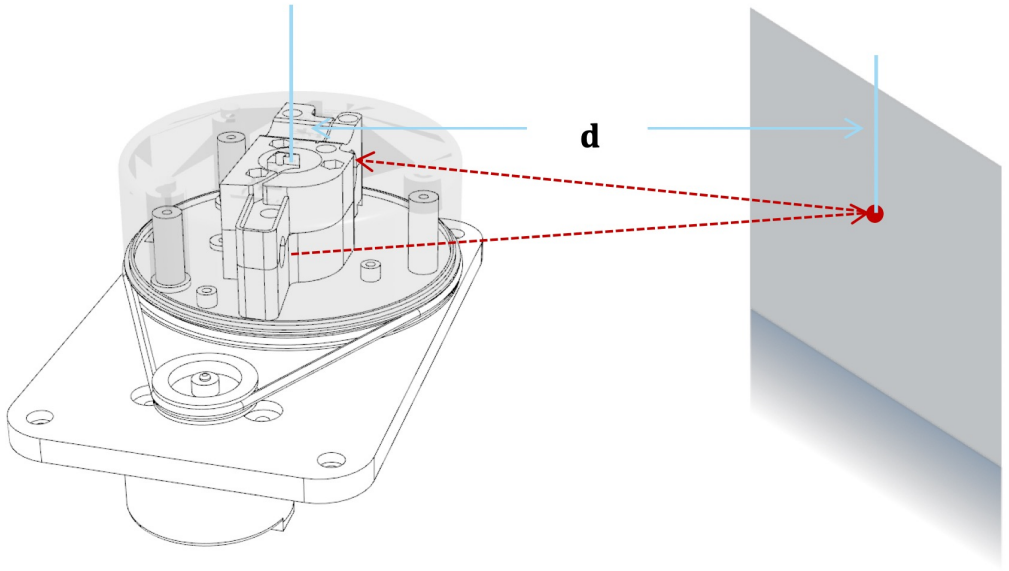
Light Detection And Ranging (LiDAR)

Triangulation based laser distance scanner
- Distance range: 0.15-12m
- Angular range: 360 deg
- Scan rate: ~6Hz (up to 10)

ROS 2 message definition:
- https://docs.ros2.org/foxy/api/sensor_msgs/msg/LaserScan.html





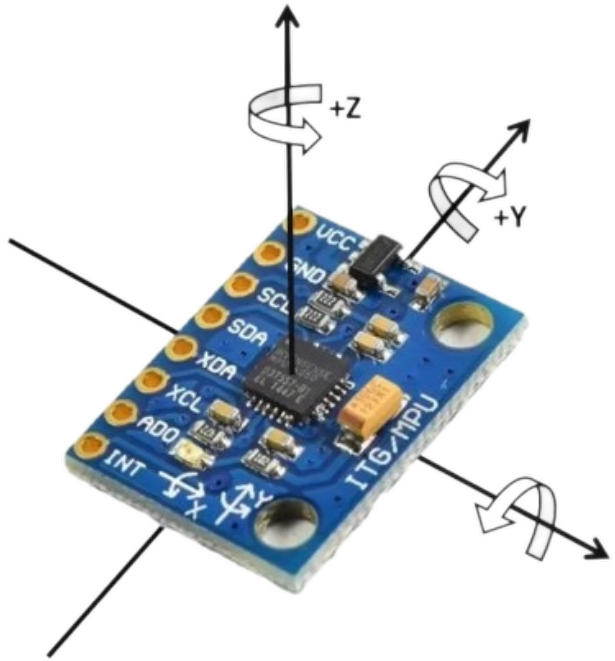


http://bucket.download.slamtec.com/b90ae0a89feba3756bc5aaa0654c296dc76ba3ff/LD108_SLAMTEC_rplidar_datasheet_A1M8_v2.2_en.pdf

Inertial Measurement Unit (IMU)

MPU6050 is a 6-axis motion tracking device.
Combines a **3-axis gyroscope** and **3-axis accelerometer** on a single chip.

Chip price ~1USD



3-Axis Accelerometer

- Selectable range: **±2g, ±4g, ±8g, ±16g**

3-Axis Gyroscope

- Selectable range: **±250, ±500, ±1000, ±2000 °/s**

Digital Motion Processor (DMP)

- Built-in processor that can compute orientation (pitch, roll, yaw) internally
- Reduces load on host microcontroller

I²C Communication

- Default address: **0x68**

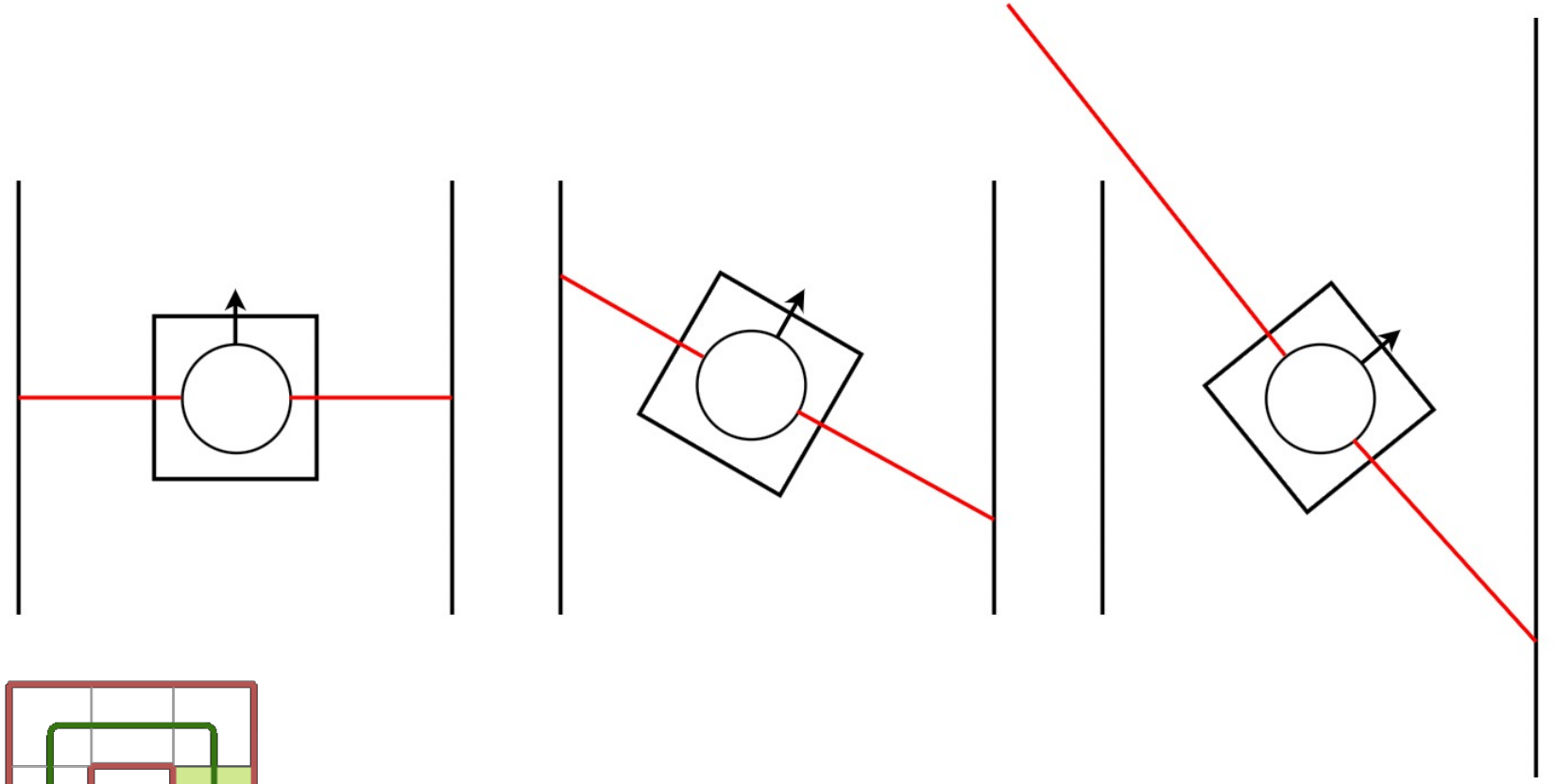
Interrupt Support

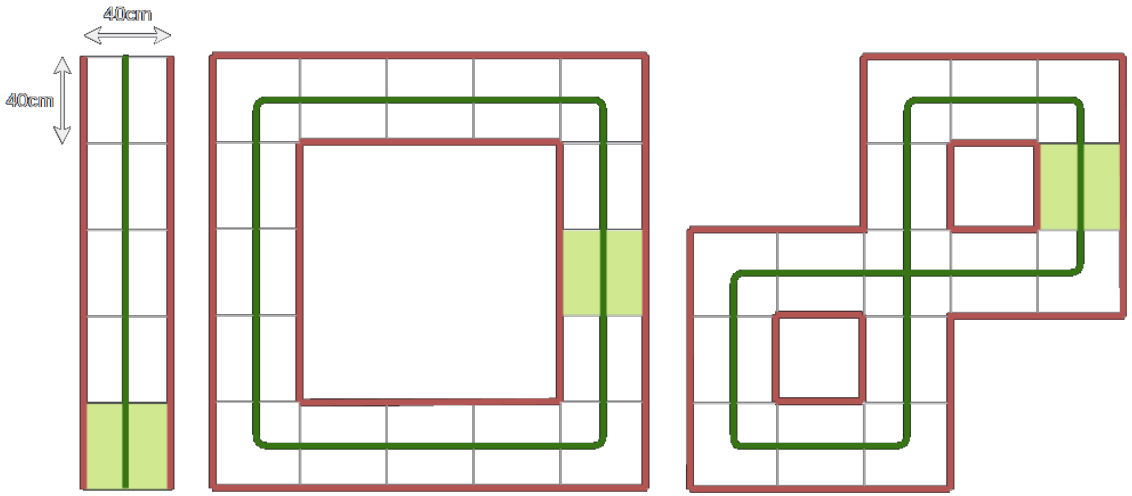
- Configurable interrupt pins for motion detection, data ready, FIFO overflow

https://github.com/ElectronicCats/mpu6050

Exam Step by Step

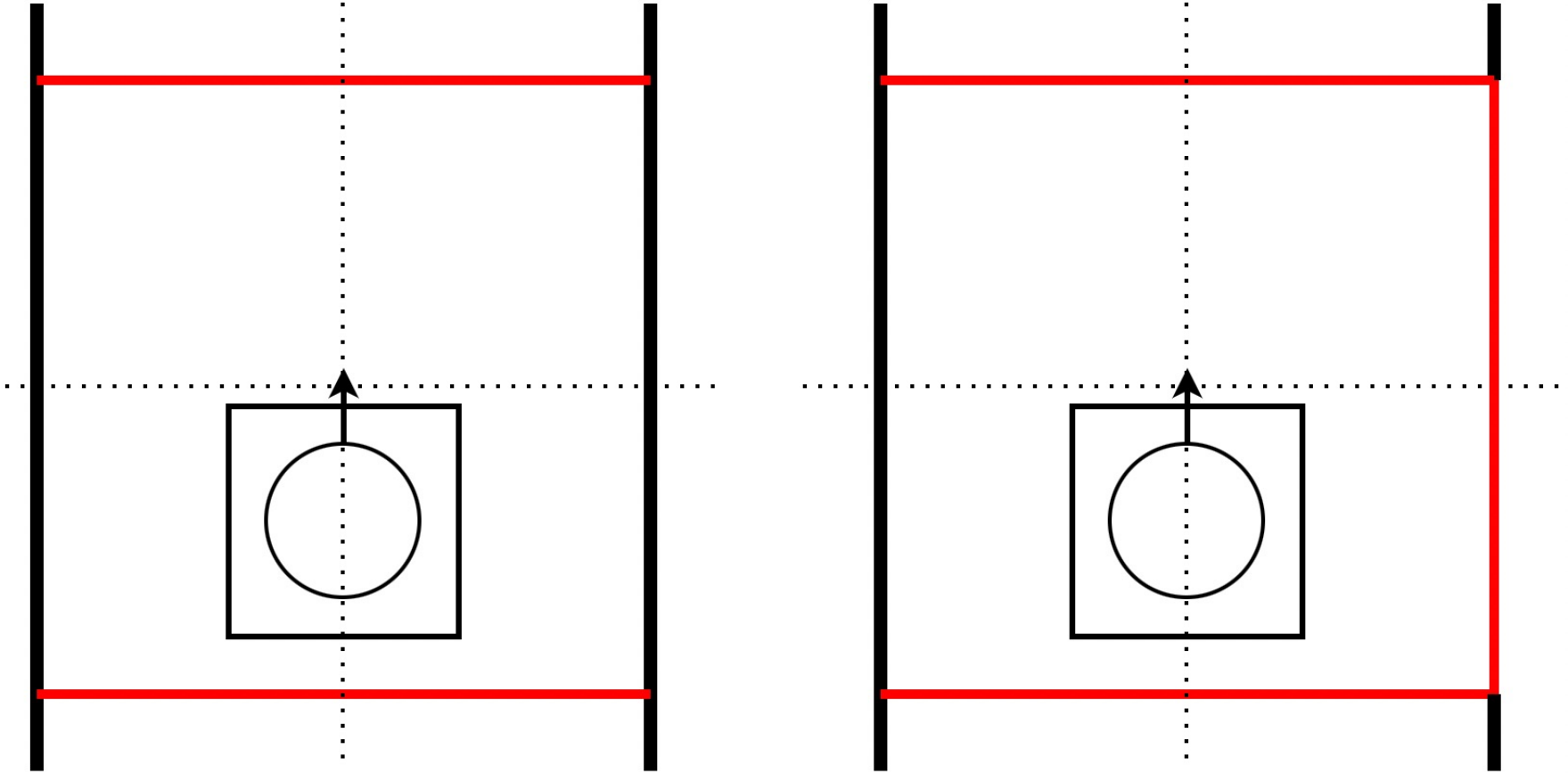
Corridor Following



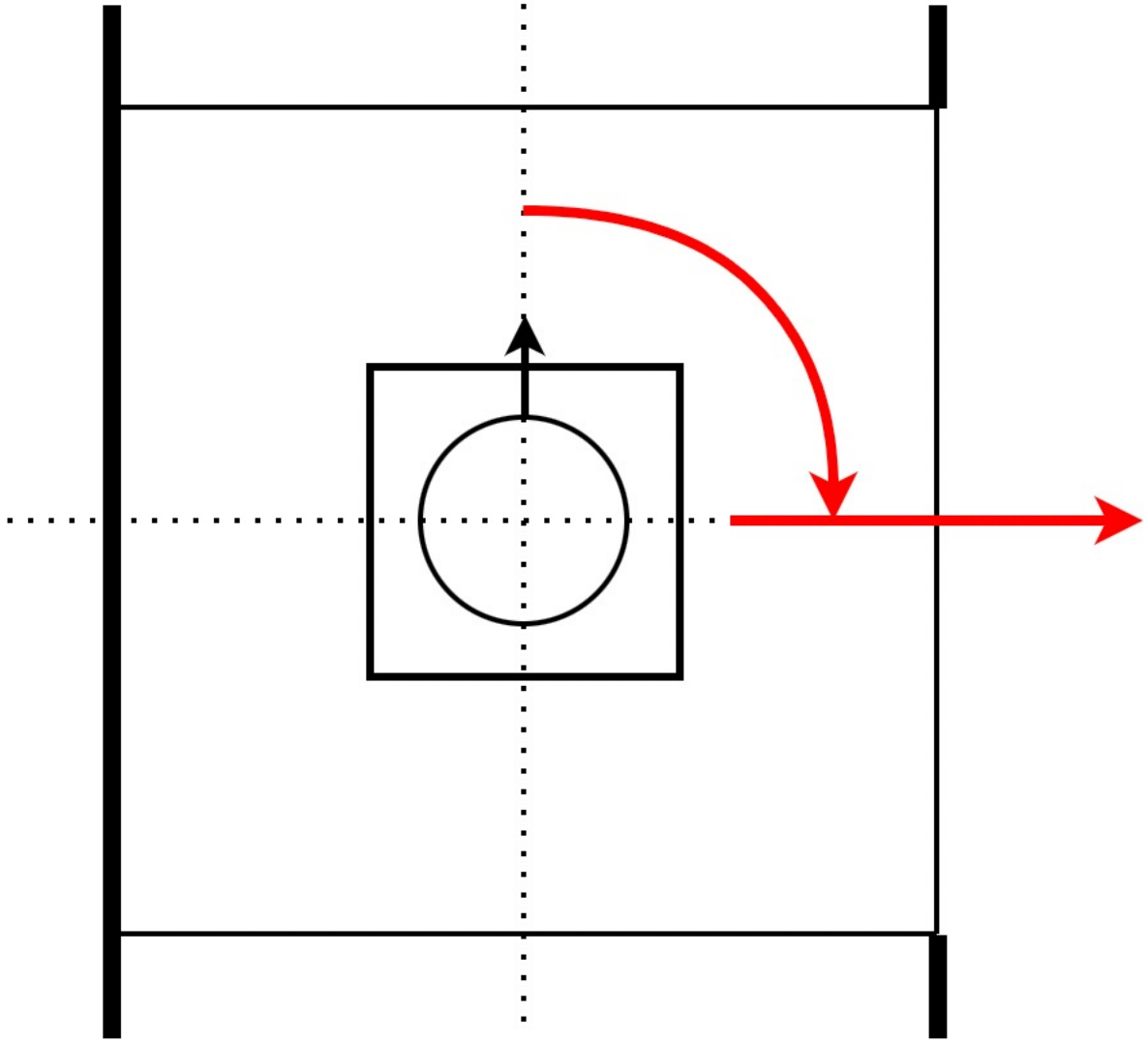


https://robotics-but.github.io/BPC-PRP/2_labs/text/12_lab.html

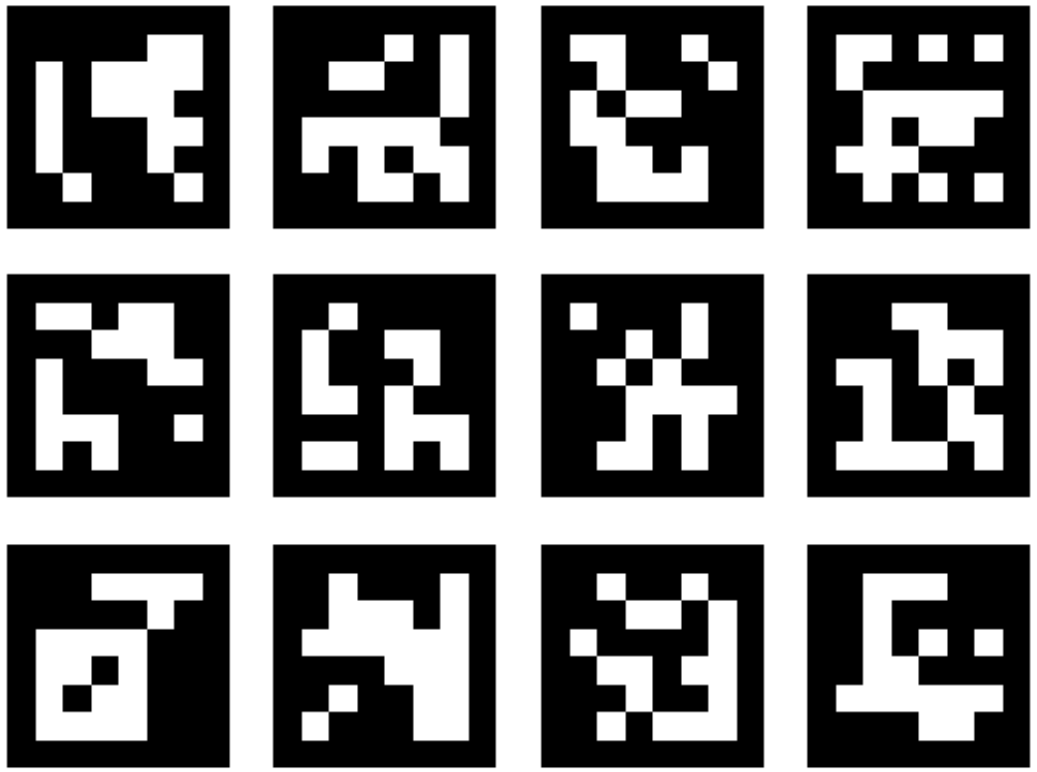
Cell Crossing Detection

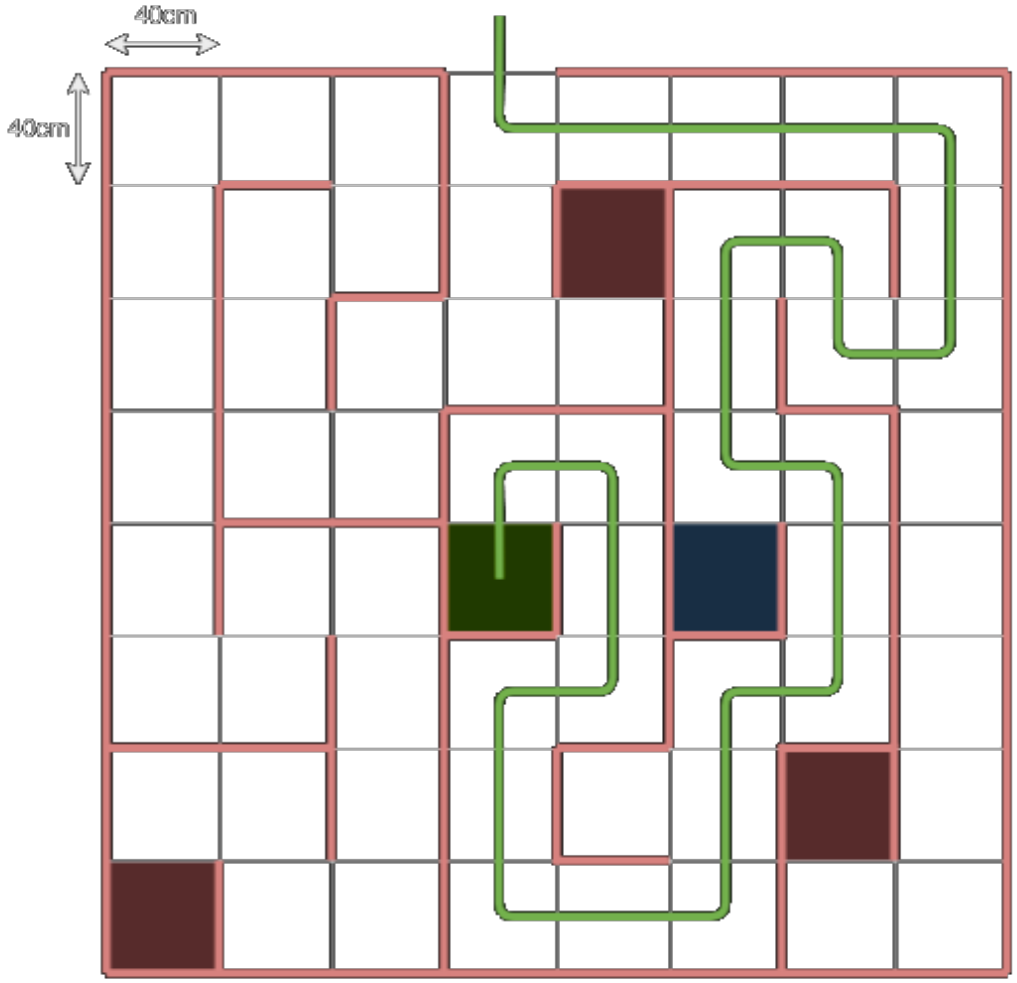


Robot On Place Rotation



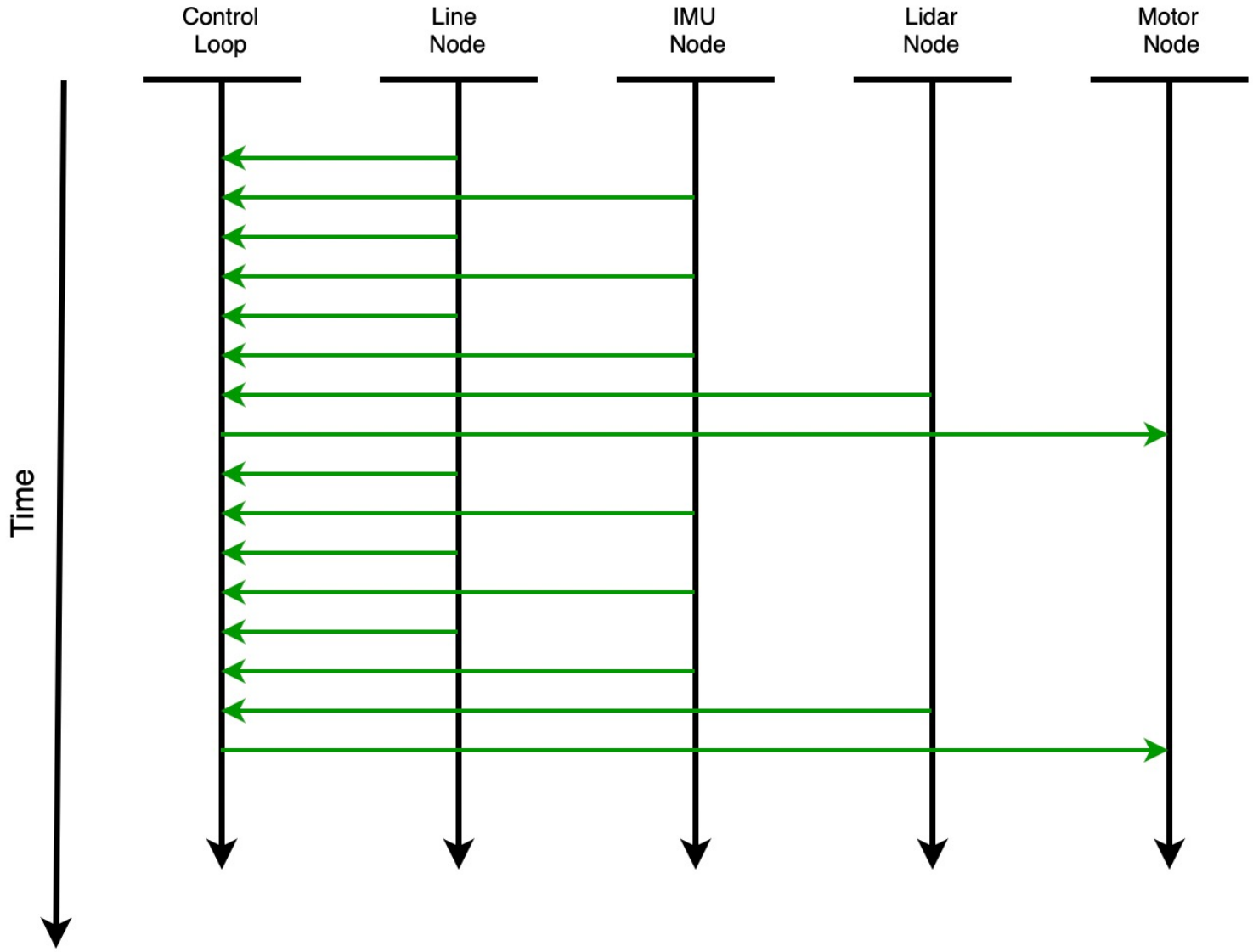
Following Optimal Way (Aruco Markers)



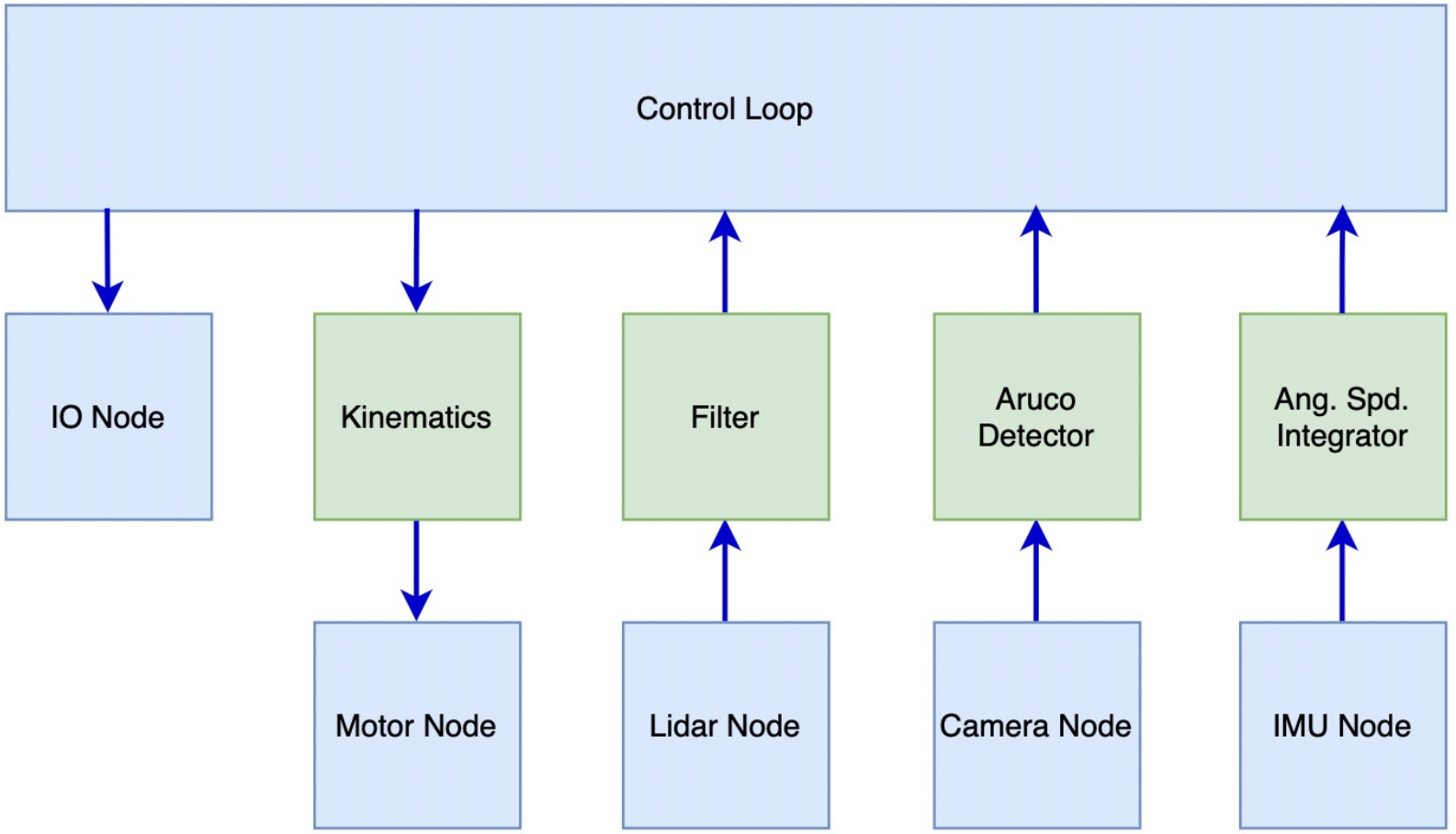


https://robotics-but.github.io/BPC-PRP/2_labs/text/13_exam.html

Threading



Software Encapsulation



Adam Ligocki

ligocki@vutbr.cz

https://www.linkedin.com/in/adamligocki/

https://github.com/adamek727

Robotics and AI Research Group

https://github.com/Robotics-BUT

Brno University of Technology
Faculty of Electrical Engineering and Communication
Department of Control and Instrumentation